SEAMLESS SHARED URBAN MOBILITY

KPI review

Project deliverable D1.2

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CIVITAS 2030
Sustainable and smart mobility for all

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List of abbreviations and acronyms

Acronym	Meaning
BSS	Bike Sharing System
CEV	Civitas Evaluation Framework
DRST	Demand Responsive Shared Transport
GHG	Greenhouse Gases
GIS	Geographic Information System
KPI	Key performance indicator
LL	Living Lab
MCA	Multi-Criteria Assessment
MICMAC	Matrix Multiplication Applied to Classification
MRA	Multiple Regression Analysis
NSM	New and Shared Mobility
PCA	Principal Component Analysis
PT	Public Transport
PTSIL	Public Transport Sustainability Indicator List
RUM	Random Utility Maximization
SIEF	Standardized Impact Evaluation Framework
SLR	Systematic Literature Review
SMART	Specific, Measurable Attainable, Realistic and Timely
STPI	Sustainable Transport Planning Index
SUMI	Sustainable Urban Mobility Indicators
T-WSI	Walking Suitability Index of the Territory
ULI	Urban Liveability Index
UMPSI	Urban Mobility Project Sustainability Index

UQoL	Urban Quality of Life

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Project Executive Summary

The objective of the SUM project is to transform current mobility networks towards innovative and novel shared mobility systems (NSM) integrated with public transport (PT) in more than 15 European Cities by 2026, reaching 30 by 2030. Intra-modality, interconnectivity, sustainability, safety, and resilience are at the core of this innovation. The outcomes of the project offer affordable and reliable solutions considering the needs of all stakeholders such as end users, private companies, and public urban authorities.

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Deliverable executive summary

This deliverable presents a Standardized Impact Evaluation Framework (SIEF) and comprehensive methodology to assist cities in assessing the impacts of the SUM innovative solutions. The deliverable is associated with Task 1.3, aiming to collect and define all the Key Performance Indicators (KPIs) needed to assess the current situation and the status of each project objective. This task is directly connected to Task 1.2 regarding the needs of each LL. The SIEF builds on existing knowledge and expertise in the field. This knowledge and expertise are obtained through literature review, documentation from other relevant EU projects and by leveraging the Consortium's expertise. The aim of this knowledge acquisition is to review existing KPIs for shared mobility and assessment of the Living Labs and to investigate which indicators have been previously used to assess the effects of urban logistics policies. Overall, the proposed framework is expected to be used as an important tool beyond the current project to assess sustainable mobility practices.

1. Introduction

The Seamless Shared Urban Mobility (SUM) project is a Horizon Europe project running from June 1st, 2023 to May 31st, 2026, and deployed by a Consortium of 30 partners. The objective of the SUM project is to transform current mobility networks towards innovative and novel shared mobility systems (NSM) integrated with public transport (PT) in more than 15 European Cities by 2026, reaching 30 by 2030. Intermodality, interconnectivity, sustainability, safety, and resilience are at the core of this innovation. The outcomes of the project will offer affordable and reliable solutions considering the needs of all stakeholders such as end users, private companies, and public urban authorities. The project addresses key barriers to the adoption of NSM solutions, including personal vehicle preference, integration issues with public transport, cost concerns, uncertainty of availability and limited parking.

1.1. Purpose of the deliverable

This deliverable presents a Standardized Impact Evaluation Framework (SIEF) and comprehensive methodology to assist cities in assessing the impacts of the SUM innovative solutions. The deliverable is associated with Task 1.3, aiming to collect and define all the Key Performance Indicators (KPIs) needed to assess the current situation and the status of each project objective.

Although the interest in shared mobility projects and initiatives has been continuously growing, there has been less progress regarding the evaluation and measurement of their outcomes. Effective assessment is essential to demonstrate the value and benefits of shared mobility projects and initiatives to city authorities and all city stakeholders. To support the monitoring of relevant projects and initiatives, KPIs are considered a universal instrument to evaluate the progress of shared mobility strategies.

A thorough literature review was initially conducted on indicators and metrics regarding the evaluation of LLs and their implemented policies as well as the assessment of sustainable mobility plans. Metrics and indices used for public transport infrastructure design, mobility on demand and mobility management were also reviewed. Following the literature review, all performance indicators were assessed to select a specific set which aligns with the project's objectives. In particular, LL-specific KPIs (in relation to the needs defined at an earlier stage) and common KPIs for all LLs, have been considered for the overall project assessment.

The impact assessment framework in SUM, builds on existing knowledge and expertise in the field. This knowledge and expertise are obtained through literature review, documentation from other relevant EU projects and by leveraging the Consortium's expertise. The aim of this knowledge acquisition is to review existing KPIs for shared mobility and assessment of LLs and to investigate which indicators have previously been used to assess the effects of urban logistics trials. Overall, the proposed framework is expected to be used as an important tool beyond the current project to assess sustainable mobility policies.

The target audience for this result is primarily the members of the consortium. It is important that all partners get an overview of the current mobility situation in the LLs, which will constitute a basis for measuring improvements throughout the duration of the project.

1.2. Structure of the deliverable and links with other work packages/deliverables

Section 2 presents the Research Methodology. A Systematic Literature Review has been performed, revealing the commonly used KPIs for assessing urban mobility. Section 3 presents the literature review on mobility indicators. Three main areas of focus have been identified. The first evaluates public transport, shared mobility, and network performance. The second focuses on social factors and equity. The last one, concerns the sustainable urban mobility indicators. Section 4 reports the outcomes of Task T1.2 on the ‘’Specification of living lab needs’’. The proposed Standardized Impact Evaluation Framework is presented in Section 5 while section 6 discusses conclusions and next steps.

This deliverable is directly connected to Task 1.2 related to the needs of each LL and to WP5 examining the Impact Assessment, Knowledge Utilization and Policy Recommendations.

2. Research Methology

A Systematic Literature Review (SLR) has been conducted to identify the most commonly used key performance indicators in existing research regarding Sustainable Urban Mobility. A systematic literature review involves a rigorous and structured approach to gathering, evaluating, and synthesizing existing research findings (Davis et al., 2014). The goal is to provide a comprehensive overview of the current state of knowledge in the field (Tsigdinos et al., 2022). This review will support the final decision for the KPIs that will be used in the SUM project. The collected KPIs of the systematic literature review, along with the objectives of the project and the expected outcomes are validated, discussed, and circulated with the LLs.

A SLR complies with a set of quality enhancing principles, including strict output inclusion rules, intending to limit possible biases in the sample of studies (Booth et al., 2016). A 3-step approach was followed in the current research, in line with the method used by Bask et al., (2017) and Yigitcanlar and Cugurullo (2020). The first step, Definition Step (Identification stage), where the research question is set, setting the basis of a review protocol, the sources examined, and procedures for literature searching. The identification step consists of the framework used to define and filter relevant literature, the sources, and processes for the research. The second step is the review of the filtered papers, respecting the relevant inclusion/exclusion criteria (Yigitcanlar et al., 2019). Finally, the third part (Analyze and Report), where the synthesis of the gathered research is performed, grouping into different indicator categories. In this deliverable, a summary of the relevant indicators, a categorization, and final decision of KPIs is included. **Figure 1** summarizes the PRISMA diagram of this SLR study.

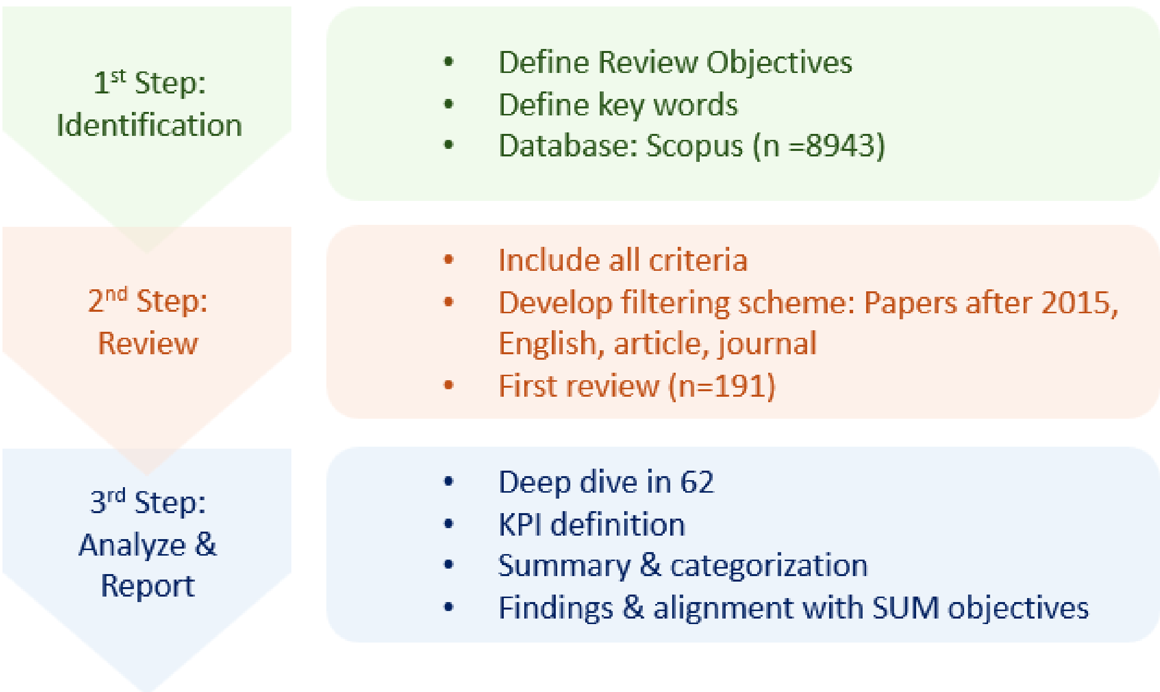


***Figure 1**. PRISMA workflow and number of identified documents per step.*

A plethora of key words was assessed to reach a satisfactory level of coverage. The keywords provided are related to the project's objectives. **Figure 2** highlights the keywords that represent best the SUM project, and is a direct outcome of SUM kick-off meeting held in June 2023. The keywords used for the initial screening of the title and abstract are mentioned below. Group 1: "indicators" and KPI, Group 2: "mobility", "transport", "intelligent transport", Group 3: "shared mobility", "seamless mobility", "future mobility", "up-to-date", "traffic congestion", "equity", "accessibility", "emissions", "energy consumption", "green transport", "multimodality", "mobility services", "MaaS", "modal split", "public transport", "ticket integration", "transport system", "urban mobility", "scheduling", "passenger transport", "infrastructure", "mobility hub", "cycle lanes", "urban road", "active modes", "micromobility", "sustainable mobility", "smart mobility", "acceptance", "push measures", "pull measures", "transport planning", "transport community", "engagement, community", "best practices" and "participatory planning". The title, abstract or the keywords should include at least one keyword per group. SCOPUS is the only search engine that was utilized in this process and revealed 8,943 documents that meet criteria or identification phase. As shown in **Figure 3**, the number of identified papers seem to surge after 2015.

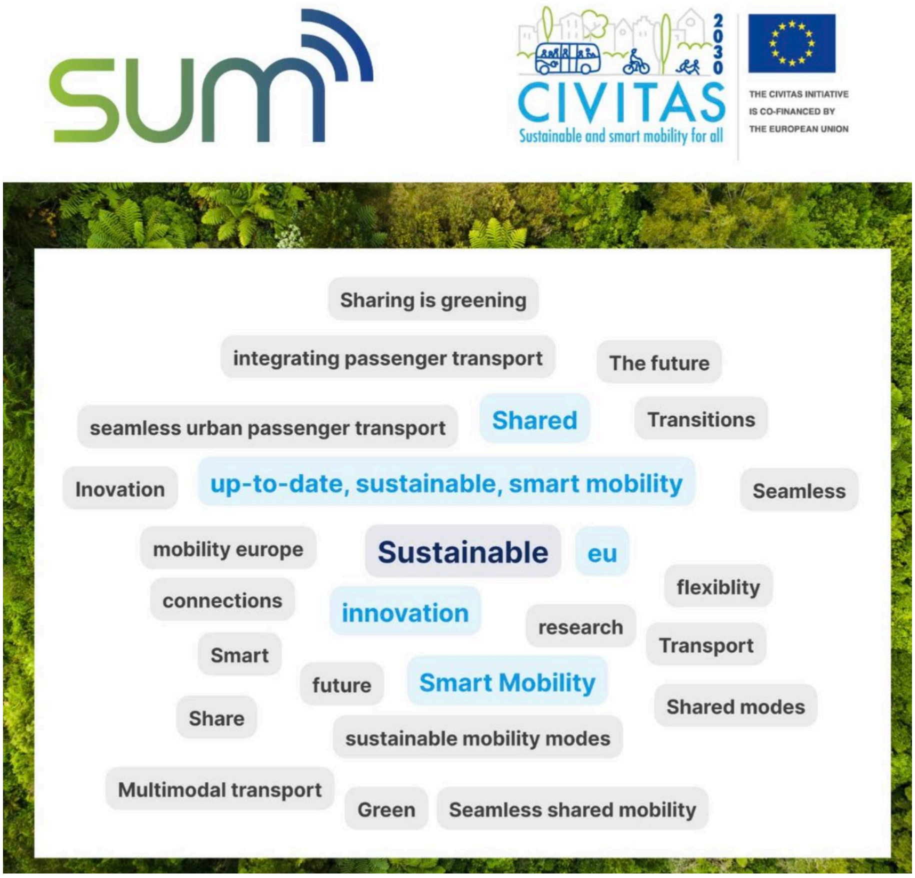


Figure 2: *Top keyword identifies in the SUM Kick-Off meeting.*

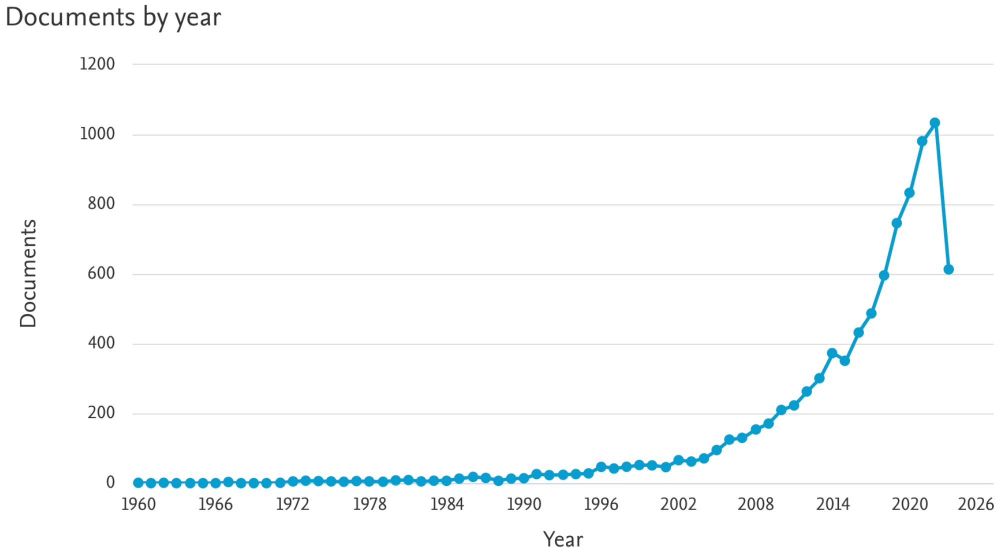


Figure 3. Identified document by year in SCOPUS (identification phase)

In the review phase, only the last decade's published articles (2015 – today) were considered, since micromobility and sustainable mobility are topics that concern modern societies. The subject areas which were considered are: Engineering, Social Sciences, Environmental Science, Computer Science, Energy, Earth and planetary Sciences, Business, Management and Accounting, Mathematics, Economics, Econometrics and Finance, Decision Sciences, Arts and Humanities, Multidisciplinary, Psychology. The language of the documents was English, and the publication stage is final. The source type was Journal. The total number of papers identified meeting all the previously mentioned exclusion/inclusion criteria amounted to 3,362 records. **Figure 4** shows the number of papers per year and per journal. Main journal sources are (a) Sustainability (Switzerland), (b) Transportation Research Part A Policy and Practice, (c) Science of the Total Environment, (d) Journal of Transport Geography and (e) Transport Policy. If the document is categorized by territories and affiliation, China and the Delft University of Technology emerge as the leading entities, respectively (see **Figure 5**). Finally, 20.7% of papers originate from Social Science, followed by Environmental Science papers at 18.5%, and Engineering papers at 17.0% (see **Figure 6**).

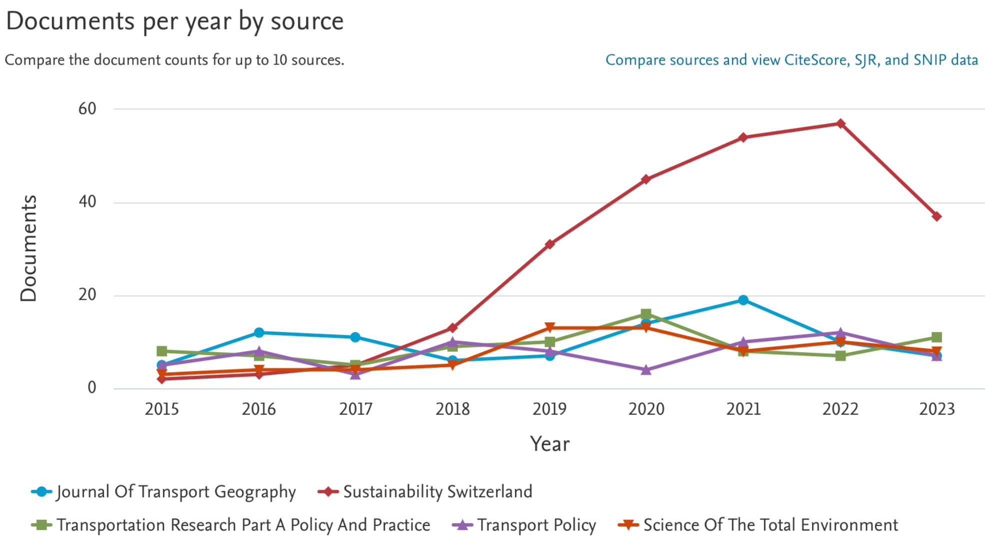
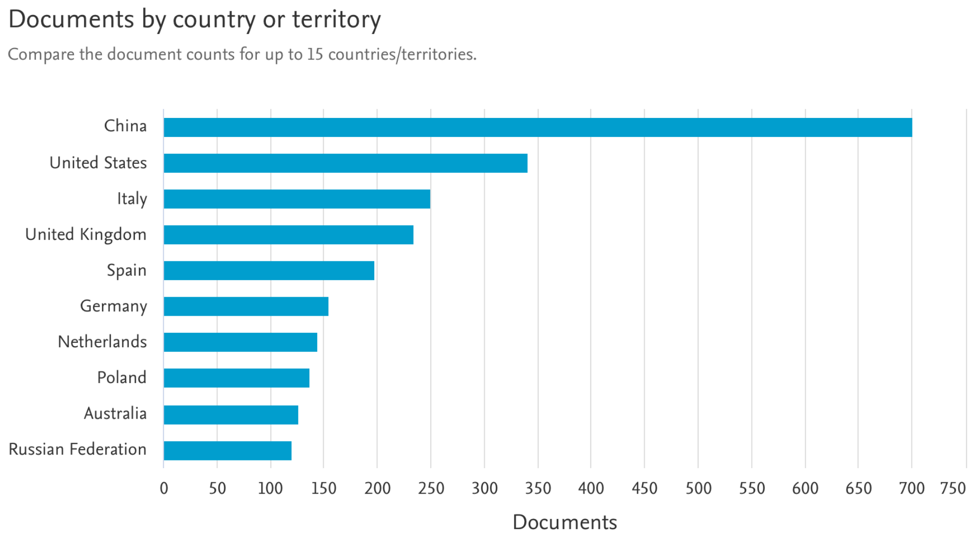
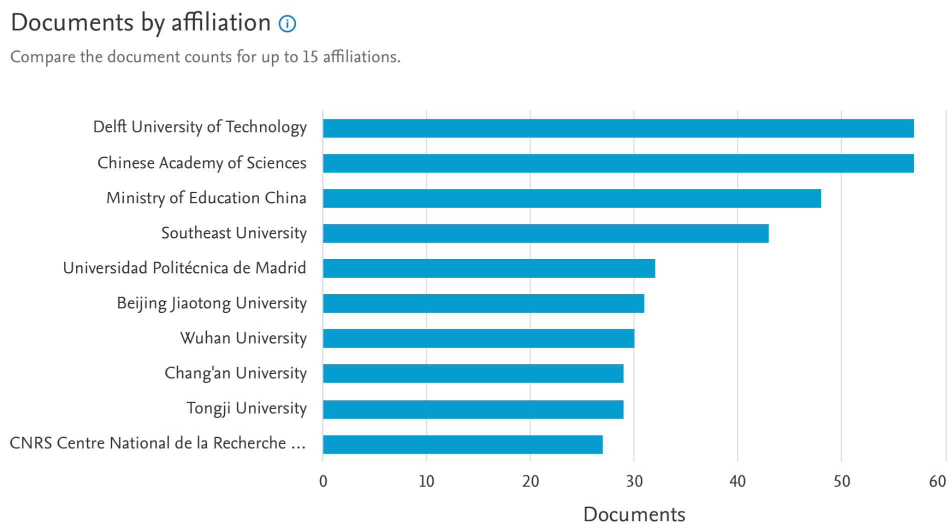


Figure 4. Reviewed documents by year and source in SCOPUS (review phase)



(a)



(b)

Figure 5. *Reviewed documents by (a) territory and (b) affiliation in SCOPUS (review phase)*

The next step was to analyze the selected papers and to understand at a high-level what main objectives and research questions they answer. Initially, the relevance of the remaining papers was assessed by examining their titles (first) and their abstracts (next). 191 documents remained at the end of the sub-process. The next step refers to full-text evaluations, so that the most suitable paper could be selected. A total of 62 papers were picked for a thorough studying and identification of KPIs, out of which 60 were finally eligible. From these, a plethora of environmental, social, economic, performance related KPIs were exported. In particular, the sample of KPIs was divided into Accessibility, Environment, Social/Demographics, Safety, Network/Infrastructure, Economic, Resilience, Technology. The final library of KPIs comprised 773 records. Naturally, significant overlaps among them arose. A Python script was developed for better handling of these records. This tool identifies keywords and groups together the KPIs used with similar naming, referring to the same concept to identify the frequency of those KPIs to support us in our final decision. In particular, we have grouped the KPIs under the same category using the clustering below. Accessibility indicators were aggregated together using the naming: accessibility, access time, waiting time, availability, parking, walkability, walking, pet friendly, inclusion, access, disabled, ridership, density, average commuting, bikeability, alternative, density, convenience. Those KPIs accounted for 13% of the total. Environmental KPIs: Emissions, CO2, CO, Gas, NOX, Land use, land, forest, vegetation, no2, fuel, petrol, waste, pollution, recycle, pollutants, air, noise, life cycle, environment, carbon, GHG, energy, deforestation, oil. 23% of all indicators were relevant to the environment. Social/Demographics KPIs are clustered by key words: community, acceptance, participation, education, job, work, literacy, involvement, employ, school, hospital, sex, social, socio, quality, equity, equality, policy, policies. Social/Demographics accounted for 9% of the KPIs. Safety indicators are grouped based on safety, accident, injuries, injury, death, crash, light, risk, security, fatalities, safe, crime, privacy, fatal. Safety related KPIs are about 6%. Network/Infrastructure: capacity, bus lane, bus service, mode, speed, road, crossing, sharing, autonomous, traffic, pave, public transport, signal, sharing, fleet, private car, motor, network, length, mobility, infrastructure, km, kilometer, sprawl, pedestrian, lane, sidewalk, modal, per thousand, journey, demand, distance, number of, travel time. 15% of the entire list of KPIs regards Network/Infrastructure. Economic indicators are classified based on the key words: income, cost, euros, afford, expenditure, expense, subsidies, resource, saving, price, revenue, fare, finance, financial, profit, profitability, investments, GDP. Out of the entire KPI list, 11% was economic specific. Resilience: Reliability, Satisfaction, frequency, service level, scalability, level of service, fleet age, age of vehicle, flexibility, accountability, survivability, productivity, attractiveness, efficiency, vulnerability, resilience, emergency, robust, readiness, maintenance, punctual. 5% of the KPIs referred to resilience. Ultimately, Technology is aggregated based on: Electronic ticket, technology, ticket, system, Information system, information, Open data, API, AVL, electronic, MaaS, on demand. Another 5% regards technology. The last 12% is miscellaneous.

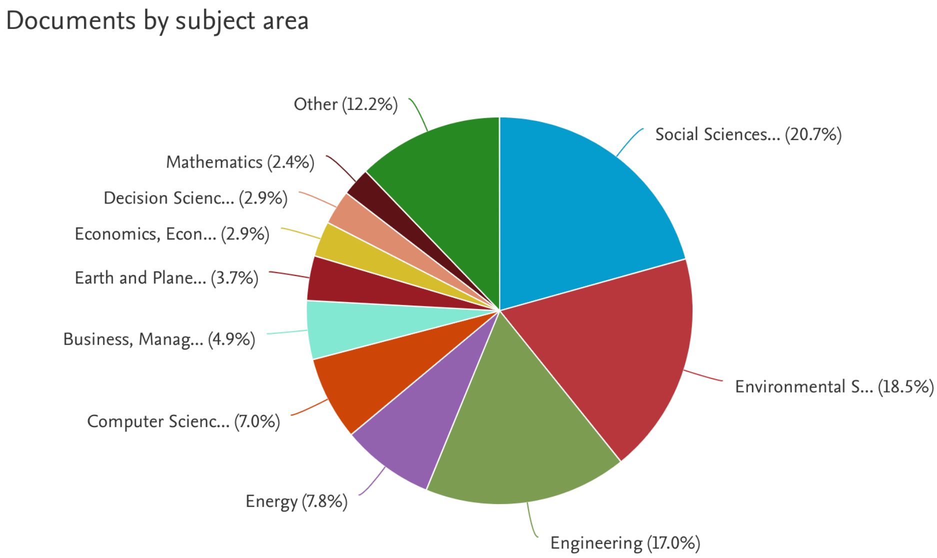


***Figure 6**. Reviewed documents by subject area in SCOPUS (review phase)*

3. Literature review on mobility indicators

We have identified three main areas of focus through the process of systematic literature review. The first evaluates public transport, shared mobility, and network performance. The second focuses on social factors and equity. The last one, concerns the sustainable urban mobility indicators.

3.1. Evaluation of Public transport, Shared Mobility & Network performance

In the first category, the city performance, the public transport system, the transit system, passengers' mode choice, and the spatial availability are studied.

Alonso et al. (2015) propose an analysis of **sustainability of urban passenger transport systems** based on available economic, social, and environmental indicators. The analysis is based upon indicators on a benchmarking approach and the methodology was applied to 23 European cities. The cities are clustered according to the sustainability analysis outcomes and the results allow us to determine the critical characteristics that enhance cities' sustainability.

An Urban Mobility Index (UMI) is introduced by Moeinaddini et el. (2015) to **evaluate transport in cities** in macro-level and **compare urban structure and car usage**. The variables regard: (1) urban population density, (2) length of road/ motorway/ public transport routes, (3) number of passenger vehicles, (4) number of passenger cars, (5) available parking spaces, (6) distance traveled on private vehicles, (7) public transport vehicles and vehicle km, (8) percentage of trips conducted by public transport/ bike/ walking, (9) average private motorized trip duration, (10) annual public transport journeys per inhabitant, (11) cost of public and private transport. The international association public transport data is used as a database, and cities can be measured against the best existing value to estimate UMI.

The study of Pinna et al. (2017) describes the **evolution of public transport systems** in 22 Italian cities. Three successive periods (2005, 2010, and 2015) are considered, and a set of 8 indicators referring to the presence or absence of infrastructure is utilized. These are: (1) indicator of bus network density, (2) indicator of demand for public transport, (3) indicator of Cycle lanes density, (4) indicator of cycle lanes for ten thousand inhabitants, (5) indicator of bicycle station density, (6) indicator of bicycle per thousand inhabitants, (7) indicator of car for ten thousand inhabitants and (8) indicator of station for ten thousand inhabitants.

Buenk et al. (2019) present a framework for an inventory of indicators against which to measure the **sustainability of transport systems**. A systematic review of the literature is used to develop a framework of 12 areas and 50 indicators of sustainability. The 12 areas of sustainability are: (1) Pollution, (2) Transport consumption, (3) Ecological and Geographical damage/impacts, (4) Initiatives for environmental protection, (5) Service Quality, (6) Accessibility & Availability, (7) Safety & Security, (8) Involvement, (9) Mobility, (10) Financial Perspective (11) Socio-economic, (12) Economic Productivity. Expert reviews, AHP and an Equally Weighted Average (EWA) methods are employed to allocate weights to the indicators and to validate the framework for microtransit systems. The framework contributes to the literature by identifying, categorizing, and integrating concepts related to sustainability in transport systems.

A Public Transport Sustainability Indicator List (PTSIL) is presented by Karjalainen et al. (2019) including 1) Environmental, 2) Economic, and 3) Social dimensions of sustainability to analyze the policy documents of public transportation agencies in Helsinki and Toronto. The PTSIL is used as connection between descriptive definitions of transportation sustainability and case specific sustainability performance assessments.

The study of Pirra and Diana (2019) concentrates on determining **how congestion impacts different traffic streams**, with particular attention to light-duty vehicles navigating within a city. It presents a data integration method. The essence of this lies in developing a distinct indicator centered on the time lost due to congestion. As concluded by the authors, this indicator proves to be pivotal for urban networks. It appears to have significant implications for other critical aspects of sustainability, including air pollution, noise emissions, energy efficiency, and health concerns.

Ammenberg and Dahlgren (2021) propose a methodology to **assess public transport technologies' sustainability performance** (including technical and short-term economic aspects), focusing on the public procurement of bus transports by Swedish regional authorities. The authors propose a multi-criteria assessment (MCA) method which is established in an iterative and participatory process, consisting of 4 key areas and 12 indicators. In particular, the assessment focuses on the 1) Technical, 2) Economic, 3) Environmental, and 4Social Performance. The process and MCA method are presented and discussed while in a companion article, the MCA method is applied to assess several bus technologies involving biodiesel, biomethane, diesel, electricity, ethanol, and natural gas.

Inturri et al. (2021) are investigating the correlation among **Public Transport use, user satisfaction and accessibility** using a spatial and statistical approach to find useful and simple indicators for sustainable mobility planning, in the city of Catania. The following steps are pursued to answer the research question. First, the zones of the study area are created, and a network model of the transit system is constructed. Following, the users' satisfaction is measured with a survey. The active and passive public transport acceptance (PTAL) is calculated. Spatial data is used to process the PTAL and quality indicators of user satisfaction. Ultimately, a statistical analysis is performed to correlate user satisfaction, transit ridership, and accessibility.

Arriagada et al. (2022) examine **public transport ridership** and **route choice** considering smart card data from Santiago, Chile. The authors develop random utility maximization (RUM) models that incorporate disaggregated and aggregated route choice strategies. They propose two strategies: (i) a disaggregated strategy, where passengers choose a specific sequence of initial-transfer-final stops while considering specific lines between them and (ii) an aggregated strategy, where passengers choose a specific sequence of initial-transfer-final stops while aggregating the common lines of each route section into a single alternative. Path- size logit models are estimated, built with alternatives from disaggregated and aggregated strategies, as well as a latent class model built from a combination of both.

A spatial approach to support the design of **Demand Responsive Shared Transport (DRST)** in urban areas with inefficient public transport and modal imbalance in favor of private cars is presented by Giuffrida et al. (2021). The Gini coefficient is used to measure the social equity of different scenarios, aiming to find a trade-off between ridership and coverage. Accessibility and social inclusion are the main pillars for the proposed DRST design, suggested for Acireale a small touristic city in Southern Italy, which includes the redesign of existing public transport bus lines and the implementation of flexible services.

Aston et al. (2021) aim to determine **whether the built environment factors affecting transit ridership** differ by mode for three multimodal networks, Amsterdam, Boston and Melbourne. The authors analyse the data using data aggregation, testing for threats to empirical validity including endogeneity of transit supply and demand and mode location bias, and conduct a cross-sectional multivariate analysis.

Eenoo et al. (2022) assess the extent to which the **mobility score can predict car use** and aim to contribute to the study of travel patterns in relation to accessibility, spatial context, and travel mode choice. Based on the data from the Flemish Travel Behaviour Survey, the authors analyse the effect of the interaction between the built environment, frequency of car use and vehicle kilometres travelled. The results illustrate that frequent and intensive car use is not an exclusive feature of suburban and rural residents in Flanders, or of those who travel long distances. In addition, the mobility score can predict the frequency of car travel but only in the inner city.

The study of Rong et al. (2022) apply a gradient boosting tree to uncover the relationships between the **actual public transport performance** and passenger satisfaction influenced by **individual perception.** These indicators that can describe the actual performance of the public transport system are actual travel time, average speed, standard deviation of speed, actual turning frequency, actual arriving frequency, actual stopping frequency, actual stopping time and actual dwell time. Perceptions are measured by the following variables: perceived travel time, perceived driving speed, perceived turning frequency, perceived waiting time, perceived stopping frequency, perceived stopping time and perceived dwell time.

Batarce et al. (2022) develop a methodology to characterize a **transit system's performance from the user's perspective**, based on objective information. The method is applied to six Latin American cities and is oriented to determine indicators representing different dimensions of the level of service. In particular, travel distance/ speed/ time, interpersonal and intrapersonal variability, actual and perceived travel time, waiting and walking time.

Serdar et al. (2022) perform a systematic literature review on studies which investigate the **resilience of urban transport networks.** Based on their conclusion, resilience should be considered as the intersect of six indicators used to evaluate transport services, namely reliability, vulnerability, risk management, survivability, flexibility, and robustness.

Aboul-Atta and Elmaraghy (2022) study the metro system aiming to find **a set of criteria that contribute to improving metro performance** and **increasing its efficiency**. Some standards are collected from 29 countries with metro systems that are considered successful as they meet the needs of their communities. The authors conduct a principal component analysis (PCA) and multiple regression analysis (MRA) and produce three mathematical equations that explain the impact of these standards in improving the performance and efficiency of the metro system.

The study of Skuzinski et al. (2023) introduces a methodology for **evaluating regional polycentricity** within **any metropolitan public transport system**. The overall approach involved defining policymaking zones for each transit provider, utilizing existing transit stop data to delineate these zones in the absence of reliable transit provider boundaries. Each zone encompasses a proportionate segment of the transport system population, labor pool, tax base, or other significant denominators. By applying the Herfindahl-Hirshman Index, originally designed to measure economic market concentration, to these zones, the geographical distribution of these shares is analyzed. This conceptualization can evaluate the level of polycentricity within the metropolitan areas, with values ranging from 10000 (indicating a perfectly monocentric MPTS with a single transit provider for the entire metropolitan region) to nearly zero (suggesting a highly polycentric MPTS with numerous overlapping providers).

Wei (2022) introduces a new **travel behavior indicator called stickiness** that shows the similarity of passengers' travel patterns when using the **transit service** over a certain period. The transit data of a smart card is used, taking into account demographics, time of the day, and trip specific details. The objective of this study is to empirically investigate the impact of weather conditions on this type of travel behavior.

The study of Yan et al. (2022) utilizes vehicle-specific power methodologies and **taxi trajectory data** within a 1 × 1 km grid to compute **emissions and revenue efficiency-related metrics**. Subsequently, entropy weight TOPSIS method is applied to determine the grids with the highest comprehensive ranking of indicators during the period, as a substitute for driver experience. The grid indicators that are considered in this study are: grid traffic state index, grid boarding points, grid order acquisition probability, grid order revenue and grid carbon emissions.

The study of Philips et al. (2022) focuses on **e-bikes**. It utilizes a spatial indicator which shows the **maximum capability to reduce CO2 emissions per person** if a serious percentage of private car kilometers will be replaced by e-bikes. Base population data, physical capability to travel by e- bike, and car use and trip length distribution data is synthesized for the indicator calculation. This indicator is estimated for every neighborhood of the UK considering the current mobility pattern and transport infrastructure.

3.2. Evaluation of social factors & equity

In the second category, the studies are focused on the social aspect of mobility, with regards to safety, social inclusion, accessibility, walkability, equity, infrastructure distribution, quality of life, and satisfaction.

The research of Rodrigues da Silva et al. (2015) assesses the **mobility conditions among cities in five Brazil regions**, utilizing the results obtained from the Index of Sustainable Urban Mobility. The Index comprises a hierarchical structure comprising 9 Domains, 37 Themes, and 87 Indicators. The main domains are 1) Accessibility, 2) Environmental aspects, 3) Social aspects, 4) Political aspects, 5) Transport infrastructure, 6) Non-motorized modes, 7) Integrated planning, 8) Urban circulation traffic and 9) Urban transport systems.

Appolloni et al. (2019) describe a methodology to **assess walkability.** The proposed methodology (Walking Suitability Index of the Territory–T-WSI) includes the development of 12 indicators associated with four main evaluation categories (Practicability, Safety, Urbanity and Appeal), and is applied to a case study in a medium-size town in central Italy. T-WSI can provide the assessment on each link of the local street network, comparing related performance levels, aggregating data at neighbourhood level and determining the overall walkability status.

Caroleo et al. (2019) **examine whether experimental applications based on gamification can co-produce more sustainable neighborhoods** through an impact evaluation method that departs from individual choices within the complex of urban mobility. This investigation is carried out within Mobility Urban Values, an EU research and innovation project. The Mobility Urban Values impact assessment methodological approach is based on an evaluation structured on indicators suitable for urban contexts.

Hamidi et al. (2019) assess the inequalities in **bicycle access to the main city transport hubs by developing a composite indicator based on accessibility measures** and **the Theil index of inequality**. This accessibility indicator brings together Bike Sharing System (BSS) availability, existence of mobility hubs, spatial dimension, and social background of different population groups, to develop an approach that captures the distribution of the potential access.

The research from Higgs et el. (2019) describes the development of the **Urban Livability Index (ULI)**, by capturing the spatial distribution of Melbourne, Australia variation in livability across all addresses within city. The ULI is synthesized based on the following metrics: (1) walkability, (2) social infrastructure mix, (3) public transport access, (4) large public open space (POS) access, (5) affordable housing, (6) local work opportunities.

Rosas-Satizábal et al. (2020) investigate the **equity of access to employment and education** among **adult cyclists in Bogota**. It estimated a potential accessibility indicator and horizontal and vertical equality indicators. The potential accessibility is calculated using GIS-based trip distance decay functions. Equality indices such as Lorenz Curves, the Gini index, and the Palma Ratio are later utilized to assess whether the distribution of potential accessibility is fair.

Duran-Rodas et al. (2020) develop a framework for a qualitative and quantitative assessment to help decision-makers and the public **evaluate the allocation of BSS infrastructure**. The qualitative assessment aims to understand how underprivileged people perceive the spatial fairness of BSSs taking as case study non-motorized households in Strasbourg feeling socially excluded. The quantitative assessment helps to numerically determine which distribution rule (equity, equality, efficiency) the infrastructure of a BSS follows, and is applied in residential blocks inside the service area of the hybrid BSS in Munich, Germany. The results indicate that non-motorized individuals who felt socially excluded were less likely to talk about BSS at all.

The study of Pham et al. (2021) explores the **accessibility indicators** that affect the interactions between **users, transport service providers, and a platform operator**. The interactions among the three stakeholders are affected by physical and psychological indicators. More specifically, flexibility, comfort, safety, usefulness are the psychological indicators that affect the users. Physical indicators set by the platform operator and the transport providers are the travel time, waiting time, costs, fares, transfer locations, convenience, and flexibility. A conceptual framework to capture these interactions under Mobility as a Service context is developed.

Kinigadner and Büttner (2021) provide a theoretical framework, to identify interventions in the land use and transport system by means of accessibility. Regarding the purpose of planning for low carbon mobility options, they focus on the following two specifications of location-based accessibility: (1) Non-motorized accessibility and (2) Carbon-based accessibility. An **accessibility analysis** is applicable to a variety of tasks connected to the aim of **reducing transport-related emissions**.

Ryan and Pereira (2021) attempt to measure **door-to-door accessibility** to supermarket and healthcare services in three large metropolitan regions in Sweden. This study entails comparing objective indicators of accessibility to essential activities using different transport modes, individuals' personal perceptions of their ability to access significant out-of-home activities and the real mobility options available to them. According to their approach, other subjective indices which refer to accessibility are capability to negotiate the public transport system, capability to leave the home, capability to walk at a certain speed and capability to navigate the city.

The study of Stewart and Zegras (2022) presents two versions of an interactive mapping tool. One version displayed **isochrones and accessibility indicators**, such as the cumulative number of jobs reachable within a time limit. Whereas the other version illustrates **paths and travel time** indicators for a chosen origin and destination, in particular walk, wait, and in-vehicle time. By conducting small workshops, it is found that the accessibility version appears to alleviate skepticism and predispositions against upgrading bus services among car users.

Patil and Sharma (2022) introduce the concept of **Urban Quality of Life (UQoL**), using Principal Component Analysis (PCA) to rank 14 cities in India. UQoL is calculated based on the following indices: (1) basic amenities, (2) economic development, (3) safety and security, (4) transportation access, (5) environmental impact, (5) infrastructure development, (6) gender.

Anciaes and Metcalfe (2023) investigate whether **constraints to travel outside the local area** (>15 miles from home, or 24 km) **are associated with poor self-rated health**, and the extent to which the association is mediated by reduced social participation. The authors surveyed citizens in the North of England and conducted path analysis to test associations between these constraints, indicators of social participation (seeing family and friends frequently and being a member of clubs or societies), and self-rated health.

Azmoodeh et al. (2023) present an aggregated model to **calculate the level of capability** in two neighbourhoods in Tehran, Iran. The authors apply a Fuzzy-Based Decision-Making Method to Evaluate Social Inclusion in Urban Areas. The variables used for this research are in two dimensions, namely ‘Individual’ and ‘Environment’. Individual includes mainly demographic characteristics, ownership, disability. Environmental refers to the living environment, transport and mobility. The findings of this study assert the correlation between the living area and internal capability.

Guzman et al. (2023) address the topic of **travel, neighborhood, and social satisfaction** and how this affects life satisfaction. A multiple-cause multiple-indicator modeling approach was followed to understand the impact of cable car implementation in satisfaction, in Bogota Colombia. Both sociodemographic and transport characteristics are considered in this research. Results provide insights into comprehensive public transport projects in the context of social vulnerability.

Matos and Lobo (2023) study the **pedestrian mobility and accessibility** of an area in Brazil, underlining the fact that in developing countries motorized modes of transport are often prioritized and this creates a barrier effect in urban highways. The 4 indicators below are calculated to express the levels of mobility and accessibility: Pedestrian Mobility Ratio (PMR), Pedestrian Mobility on the Highway (PMH), Pedestrian Crossing the Highway (PCH) and the Footbridge Access Indicator (FAI). The data is collected through Origin and Destination Survey databases and the results indicate that pedestrian flows are significantly reduced.

An alternative concept of accessibility with competition has been introduced by Soukhov et al. (2023), defined as **spatial availability**. Spatial availability can be considered a more interpretable alternative to Shen-type accessibility. According to the authors, this measure relies on proportional allocation balancing factors such as the friction of distance and population competition. In this study, these factors served as a singular constraint akin to conventional gravity-based accessibility. Indeed, the proportional allocation of opportunities leads to a spatially available opportunities value designated for each origin. When aggregated, these values collectively represent the total number of opportunities within the region.

3.3. Sustainable Urban Mobility Indicators assessment

In the last category, the studies are focused on the qualitative and quantitative sustainable urban mobility indicators, the development of sustainability frameworks and indexes.

Garau et al. (2016) suggest a system of **quantitative indicators for evaluating urban mobility** in Cagliari in terms of public transport, alternative mobility options, and technological mobility services. The authors consider a synthetic indicator comprising of a large sub-set of indicators related to six variables: 1) public transport, 2) cycle lanes, 3) bike sharing, 4) car sharing, 5) private mobility support system and 6) public transport support system. A comparison among similar range cities is also performed to graphically benchmark results and drive decisions.

Mitropoulos and Prevedouros (2016) design a **sustainability framework that incorporates transportation vehicle characteristics**. The suggested indicators are grouped into six categories: 1) Emission and energy indicators, 2) Environmental sustainability indicators, 3) Technology performance sustainability indicators, 4) Energy sustainability indicators, 5) Economic sustainability indicators and 6) Users sustainability indicators. The proposed methodology combines life cycle impacts and a set of quantified indicators to assess the sustainability performance of seven popular light-duty vehicles and two types of transit buses.

Miller et al. (2016) introduce a **composite indicator framework to analyze public transit sustainability**. The ultimate output of this framework is a CSI index which is based on adding weighted sustainability categories to develop a single value that represents transit sustainability. Four categories are taken into consideration: 1) Environment, 2) Economy, 3) Society and 4) Transport system effectiveness. The authors also demonstrate the application of Monte Carlo simulation and stochastic tools to validate the performance rankings of the CSIs, based on a weighting scheme.

Olofsson et al. (2016) present a tool for **sustainability assessment** in Swedish cities, including a set of **hierarchical indicators** to measure sustainability with respect to 1) Efficiency, 2) Accessibility, 3) Safety, 4) Liveability, 5) Emissions, and 6) Resource use. The tool not only includes measurable indicators, but it also factors in subjective indicators about the perceived transport sustainability, to depict population's satisfaction.

Munira and San Santoso (2017) set out a comprehensive analysis of how people perceive different attributes of **sustainability of the existing transport operation** in Dhaka, Bangladesh. Based on literature review and expert's suggestions, 7 areas of sustainability, namely 1) Public transport efficiency, 2) Mobility, 3) Affordability, 4) Safety, 5) Equity, 6) Land use, and 7) Pollution) and 14 indicators are selected to evaluate overall sustainability performance of the existing transport network through an index value. The variations of perception among different social groups of the respondents are further investigated by t-test and one-way ANOVA analysis.

Cavalcanti et al. (2017) aim to **identify the sustainability indicators of urban mobility projects** in the metropolitan region of Curitiba in Brazil, through a sustainability assessment method. The Urban Mobility Project Sustainability Index (UMPSI) was determined for such projects, as well sub-indices for 1) Environmental, 2) Social, and 3) Economic aspects, in order to verify their contribution in all of the three sustainability dimensions.

Diez et al. (2018) propose a methodology for **assessing the cost effectiveness of SUMPs**. The method estimates the cost of CO_2 saved, using sustainable transport modes in the city of Burgos, Spain. A total number of 29 framework indicators to be applied to the measures implemented is proposed, belonging into 5 sustainability areas, namely 1) Economic, 2) Energy, 3) Environmental, 4) Social, and 5) Transport.

Lopez-Carreiro and Monzon (2018) propose a quantitative methodology for **assessing the smartness of urban transportation systems**. The authors have developed the Smart Mobility Index, based on a benchmark approach and provide a tool to compare cases according to how close their transport systems come to being socially, environmentally and economically sustainable, as well as technologically innovative. The methodological procedure identifies four indicators for each of the four smartness dimensions considered, namely 1) Sustainability, 2) Environment, 3) Economy, and 4) Innovation.

The study of Zope et al. (2019) have developed a **monitoring tool to evaluate the sustainability of urban transport systems** in India. The authors conduct a comparative analysis based on a general indicator called Composite sustainable transport index. This quantitative index is based on 7 dimensions, namely 1) Population density, 2) Vehicular characteristics, 3) Travel characteristics, 4) Modal characteristics, 5) Air pollution, 5) Noise pollution, 6) Fatalities and disabilities and 7) Non-motorized quality.

Fernandes et al. (2019) develop a **sustainability indicator that integrates traffic-related externalities** as means of traffic congestion, noise, greenhouse gases (GHG) and nitrogen oxides emissions, health impacts and road crash related costs, and adjusted to local contexts of vulnerability. The proposed methodology is tested in a commuting corridor with three main alternative routes.

A **multi–criteria assessment framework for urban air mobility** is suggested by Haddad et el. (2020). The authors present an approach for the selection of indicators for a multi-criteria analysis for the assessment of UAM, in a case study of Upper Bavaria, Germany. The scenarios were assessed based on different levels; based on main indicators: 1) Environmental, 2) Socio–economic and 3) Transport based, and sub–indicators, resulting from the KPI selection process. The main indicators are defined according to the city's objectives and the sub–indicators are selected following an expert assessment.

Regmi (2020) conducts a **pilot study to assess the urban mobility of four Asian cities**, namely Greater Jakarta, Kathmandu, Hanoi and Colombo. The applied methodology considers 10 urban transport indicators, which constitute the sustainable urban transport index. The indicators included in the methodology are: (1) the extent to which transport plans cover public transport, intermodal facilities and infrastructure for active modes, (2) modal share of active and public transport in commuting, (3) convenient access to public transport service, (4) public transport quality and reliability, (5) traffic fatalities per 100,000 inhabitants, (6) affordability – travel costs as part of income, (7) operational costs of the public transport system, (8) investment in public transport systems, (9) air quality in city and (10) greenhouse gas emissions from transport.

Chen and Silva (2021) propose a comprehensive and up-to-date framework to **assess smart transport development in cities**. A systematic literature review is conducted to identify the most used indicators and important indices and five new ones are proposed. The final evaluation framework contains 43 indicators belonging to three main subsets to show different transport sub-systems in a city, namely 1) Private transport (including walking and cycling), 2) Public transport and 3) Emergency transport systems. In each subsystem, the authors further classify the indicators into three themes: 1) Accessibility, 2) Sustainability and 3) Innovation. The proposed evaluation framework is applied in eleven English metropolitan areas.

Bebber et al. (2021) develop and validate a scale to evaluate **mobility according to the sustainable dimensions** established by the United Nations Sustainable Development Goals. The final scale resulted in 21 attributes distributed in 6 dimensions through exploratory and confirmatory factor analysis. The six dimensions considered on common mobility are (1) Walkability, (2) Transit Safety, (3) Safety, (4) Attractiveness and Environmental Quality, (5) Infrastructure and Technology for Drivers, and (6) Alternative Routing. Those related to specific users are (7) Transportation infrastructure and services and (8) Alternative transportation infrastructure. The survey was applied to residents of a medium-sized city located in the South of Brazil, called Caxias do Sul.

Daimi and Rebai (2022) propose a sustainability governance framework **to assess the public transport companies in developing countries** considering governance criteria, namely transparency and accountability. Economic, environmental, social, and institutional dimensions are involved through a set of up-to-date Specific, Measurable Attainable, Realistic and Timely (SMART) indicators. A numerical illustration is provided at the end to evaluate three public transport companies from Tunisia to give an overview of the framework implementation using simple additive weighting method.

The study conducted by Reche et al. (2022) delved into the interaction **between the characteristics of the urban environment and the air pollution associated with mobility**, as well as the **health impacts** resulting from exposure to traffic derived PM2.5 and NO2. The research focused on 12 European cities, namely Barcelona, Budapest, Florence, Krakow, Madrid, Milan, Paris, Porto, Thessaloniki, Warsaw, Zagreb and Zurich. To describe the road environment, 7 meaningful indicators were defined and used. These are: (1) mean daily traffic volume/total area of the city, (2) kilometers of primary and secondary roads/kilometers of cycleways and footways, (3) mean distance between primary roads and residential buildings, (4) percentage of green and outdoor leisure areas, (5) number of public transport stops/total area of the city: using the tags highway, (6) index of distribution of public transport stops and (7) implementation of low emission zones.

Ghafouri-Azar et al. (2023) develop the **sustainable transport planning index (STPI)**, using multi-criteria decision analysis method. Existing discrete indexes are combined to create this integrated index, including 1) Social, 2) Economic, and 3) Environmental indicators. The weight of each indicator is determined through the analytical hierarchy process, where expert judgment is used to assess the relative importance of each indicator. As case study model, the STPI model has been applied to the public transport system of the United Kingdom from 2007 to 2019.

Menendez and Ambühl (2022) discuss the **different transport design and operational measures** in Zurich, leading to an integrated perspective promoting sustainable transportation. Their study focuses on the three main elements composing an integrated plan: measures discouraging private motorized transport, measures encouraging public transport, and measures encouraging human-powered transport.

Zapolskytė et al. (2022) introduce **a hierarchical evaluation model to evaluate the smartness of urban mobility systems** to compare the smartness level of Vilnius, Montreal, and Weimar mobility systems. The hierarchical model consists of indicators belonging to five main factors: (1) Motor travel and congestion reduction measures, (2) Pollution abatement measures, (3) Travel safety and accident reduction measures, 4) Traffic management tools and services and 5) Smart infrastructure measures. A hybrid multi-criteria decision-making (MCDM) method was used to calculate the significance of the selected indicators and to compare urban mobility systems.

Chatziioannou et el. (2023b) develop a Cross Impact Matrix Multiplication Applied to Classification (MICMAC) approach to **assess, contextualize, and rank SUMPs** that each municipality in Europe may implement. Through a qualitative study that involved a narrative literature review and in-depth discussions with experts, the Sustainable Urban Mobility Indicators (SUMIs) are designed, namely 1) The Affordability of public transport for the poorest, 2) Accessibility of public transport for mobility impaired groups, 3) Air pollutant emissions, 4) Noise hindrance, 5) Road deaths, 6) Access to mobility service, 7) Greenhouse gases, 8) Congestion and delays, 9) Energy efficiency, 10) Opportunity for active mobility, 11) Multimodal integration, 13) Satisfaction with public transport, and 14) Traffic safety.

Pignatelli et al. (2023) aim at developing an **interactive dashboard** that facilitates decision-making in sustainable mobility planning. To do so, a multidisciplinary GIS-based framework was developed. This tool allows the **continuous spatial evaluation of 8 KPIs** that are utilized in the city of Turin, namely 1) Quality of land, 2) Intramodality urban facilities, 3) Total final thermal energy consumption for residential building operations, 4) Total final electric energy consumption for residential building operations, 5) GHG emission from energy used for all-purpose in residential buildings operation, 6) Air quality - particulates <10mu concentration (PM10), 7) Albedo and 8) Availability and proximity. The results from the estimation of this indicators have been published in a story-telling interactive dashboard revealing the strengths and weaknesses of the city.

Hussain et al. (2023) develop an **indicator-based framework for assessing the sustainability of smart mobility and tourism in rural areas**. The goal is to evaluate the effectiveness of initiatives towards sustainable mobility development and tourism, to examine the overlap of between KPIs related to mobility and rural tourism, and ultimately to assess how these KPIs will support the United Nations' sustainable development goals. The indicators collected from the existing literature and AURORAL project are categorized into relevant sustainability dimensions, namely 1) Social, 2) Environmental, 3) Economic and 4) Technology.

4. Specification of Living Lab needs

This section reports the outcomes of Task T1.2 on the ‘’ Specification of living lab needs’’. The aim of the task was to analyze the LLs through the prism of shared mobility and define their needs to move towards a next era of mobility, providing sustainable mobility options, increased accessibility, and promote equity. Through this task, we not only looked at the common needs of LLs but we also paid special attention to the specificity of each LL. Based on the current situation and the existing sustainable mobility plan (SUMP), if any, under implementation, each LL ranked its most important needs to , which allowed us to align them with the different objectives of the SUM project, i.e. the reduction of congestion, the introduction of new mobility services and the integration and smooth cooperation with the existing services. In the following subsections, the LLs’ needs, perspective and vision on sustainable mobility are presented.

4.1. Munich LL

4.1.1. LL Needs

- **Needs regarding the reduction of congestion**
  Munich aims to have at least 80% of transportation within the city by 2025 covered by zero-emission vehicles, local public transport, walking, and cycling. Another sub-goal is to increase the share of public transport to 30% of the modal split by 2030. The shared mobility strategy supports this goal by offering 2,500 stationary sharing parking spaces and the construction of 200 mobility points (Source: Mobility strategy 2035).

- **Needs regarding the environmental indicators**
  The city of Munich aspires to attain climate neutrality by 2035. As a significant proportion of greenhouse gas emissions in the state capital of Munich are attributed to the transport sector (around 18%), the goal of climate neutrality is above all also a goal of the transport transition (Source: Mobility strategy 2035).

- **Needs regarding the noise hindrance**
  The needs regarding the noise hindrance in Munich are based on the EU Environmental Noise Directive, which was transposed into German law by the addition of sections 47 a to f of the Federal Immission Control Act. The City Council of the City of Munich has decided to base the update of the noise action plan on reference values of 64 dB(A) for LDEN and 54 dB(A) for LNIGHT. Exceeding these reference values is the basic prerequisite for the examination of noise protection measures in an affected area (Source: Department for climate and environmental protection).

- **Needs regarding the improvement of mobility services**
  A significant need regarding the improvement of mobility services is the better integration of shared mobility with public transportation. This measure involves both structural and procedural aspects. Shared mobility offerings must be better located and visible within public transportation, as well as more effectively integrated into the schedules of public transit. Future measures will also focus on ensuring quality of life and the common good, which are the guiding principles of Munich’s Mobility Strategy 2035.

- **Needs regarding the accessibility**
  In Munich, 99,8% of the population live within 600 meters or 1,200 meters (in the case of railway stations) of a stop with at least 20 public transport departures per day (Source: Deutschlandatlas). With regard to barrier-free mobility, the City Council has decided on a comprehensive approach for the barrier-free remodeling of platforms and stops in Munich (Source: Building department).

4.1.2. Perspective and vision on sustainable mobility

Munich has a SUMP which can be found at SUMP. The Mobility strategy 2035 (SUMP) policy framework for mobility and traffic strategy in Munich has the following main goals in line with our project: accessibility, high quality of stay in public (street) space, improve the efficiency, safety, and ease of transport. Increase the modal split of Public Transport up to 30%. In January 2022, the City Council passed a resolution to conduct the first stage of the shared mobility strategy until 2026. It is embedded within the Mobility Strategy 2035. The overall goal is to develop a city-wide service level for shared mobility offers. The central starting point for this is better networking of mobility offers with each mode, the intersection with urban and open space planning, the cooperation of the city and the surrounding area as well as the implementation of suitable push and pull measures.

4.2. Athens Penteli LL

4.2.1. LL Needs

- **Needs regarding the reduction of congestion**
  There is (considerable) traffic congestion during peak hours in main primary roads of the municipality.

- **Needs regarding the environmental indicators**
  The share of electric vehicles currently represents less than 1%. Considering also that (conventional) car use percentages are high (exceeding 70% of the modal split), it may be implied that there are issues related to greenhouse gas emissions and other pollutants.

- **Needs regarding the noise hindrance**
  Noise hindrance appears on the primary road network of the municipality (car engine sounds, horns, etc.)

- **Needs regarding the improvement of mobility services**
  Residents are not satisfied by the frequency of public transport routes. There are a few routes and the connection of the LL with metro or suburban railway stations is insufficient. Until now local public transport was on hold. Furthermore, car sharing services are absent.

- **Needs regarding the accessibility**
  Accessibility is one of the major issues encountered in the LL of Penteli. Sidewalks (when they exist) are not accessible, especially by people with disabilities. There are obstacles like trees, lamps, litter bins, along the road segments, hindering active movement. Moreover, tactile paving and curb ramps are mainly missing.

4.2.2. Perspective and vision on sustainable mobility

Strengthening the identity of the municipality of Penteli through a policy of transformation of public space and mobility networks, with the aim of promoting equality in transport between all social groups and promoting active mobility, such as. walking, bicycling, micromobility, and other flexible collective transportation modes. Enhancing and improving the quality of transportation, fit into Penteli's attractive natural and urban environment, and allow residents and visitors to enjoy the community by promoting economic development within the community, improving the quality of life, and the health of all residents.

4.3. Jerusalem LL

4.3.1. LL Needs

- **Needs regarding the reduction of congestion**
  In order to reduce private car usage and therefore reduce congestion, the Ministry of Transportation published modal-split targets for Jerusalem that call for 75% sustainable modes and 25% private cars by 2040.

- **Needs regarding the environmental indicators**
  Jerusalem's current CO^2 emission level is 1.32 tons per person and the target has been set to 0.5 tons per person by 2040. The current energy efficiency is 1.4 MJ/km and the target is 0.8 MJ/km by 2040. The pollutant emissions index for 2019 was 0.24kg PM2.5 per resident per year and the target value is 0.05kg PM2.5 by 2040.

- **Needs regarding the noise hindrance**
  Since national and local authorities do not track the level of noise within cities in Israel there are no current target or values available.

- **Needs regarding the improvement of mobility services**
  Travel via public transit in Jerusalem is twice as time-consuming on average as travel in a private car. Plans call for narrowing this gap by increasing the availability of priority bus lanes. There are currently 38 meters of priority bus lanes per 1,000 people. The 2040 target is 150 meters per 1,000 people.

- **Needs regarding the accessibility**
  Currently, 73% of the city's population is within a 5-minute walk from a transportation station. The target is 90% by 2040.

4.3.2. Perspective and vision on sustainable mobility

Jerusalem LL vision is to improve residents' quality of life in the research area (Yuvalim, Ganim, Masuaa) through prediction analysis and implementation of an effective, equitable and sustainable shared mobility system. This improvement will allow everyone to reach their destination in a comfortable, reliable, safe, and fast manner. Improved mobility will serve as a catalyst for the economic and social development of the research area.

4.4. Geneva LL

4.4.1. LL Needs

- **Needs regarding the reduction of congestion**
  In the frame of the Regional Climate Plan for 2030, Great Geneva Region aims to reduce traffic car by 40% until 2030.

- **Needs regarding the environmental indicators**
  In the frame of the Regional Climate Plan for 2030, Great Geneva Region aims to reduce air pollution by 60% until 2030 and reach carbon neutrality in 2050.

- **Needs regarding the noise hindrance**
  No specific needs for Geneva in terms of noise hindrance.

- **Needs regarding the improvement of mobility services**
  Geneva needs greater synergies among public transport services and sustainable modes, such as shared bikes or cars and private bikes.

- **Needs regarding the accessibility**
  Geneva regions needs to increase sustainable modes accessibility by developing a network of Mobility hubs, to steer a shift from personal car.

4.4.2. Perspective and vision on sustainable mobility

In the Cantonal Climate Plan, the canton of Geneva states the following goals:

- 40% reduction in road traffic and 60% decrease in CO2 emissions by 2030
- Carbon neutrality by 2050

TPG (public transport of Geneva) plays an active role in the achievement of these goals, pursuing the following objectives:

- Bus fleet electrification by 2030
- Network development via the extension of two tram lines (tram lines 15 and 17) to suburban areas where car usage remains predominant
- Collaboration with shared mobility partners for the development of communication, pricing and infrastructure for the deployment of mobility hubs, enhancing complementarity and not competitivity between shared modes and PT.

This latter point will be addressed with the SUM technologies targeting better access to sustainable transport services for all.

4.5. Rotterdam LL

4.5.1. LL Needs

- **Needs regarding the reduction of congestion**
  Enhanced Public Transportation: Improving public transportation services, including increasing frequency, expanding routes, and ensuring reliable and punctual services, can encourage more people to choose public transport over private cars. Investments in the development of an integrated and efficient public transportation system can provide viable alternatives to car travel during peak hours.

  Shared Mobility Initiatives: Promoting shared mobility initiatives can help reduce the number of vehicles on the road during peak hours. Encouraging commuters to share rides or use shared vehicles can lead to a more efficient use of available road capacity and reduce overall congestion.

- **Needs regarding the environmental indicators**
  Low-Emission Modes of Transportation: Encouraging the use of low-emission modes of transportation is essential to reduce greenhouse gas emissions. This includes promoting cycling, walking, and using public transportation as sustainable alternatives to private cars.

Urban Planning for Sustainable Mobility: Effective urban planning that prioritizes sustainable mobility is crucial. Creating compact, mixed-use neighborhoods that reduce the need for long-distance travel and promote active transportation can contribute to emission reduction. This includes developing infrastructure that facilitates cycling, pedestrian-friendly streets, and well-connected public transportation networks.

Behavior Change and Awareness: Encouraging behavior change and raising awareness about the environmental impact of transportation is important. Educational campaigns, incentives for sustainable travel choices, and information about the benefits of low-emission modes of transportation can help shift attitudes and promote greener transportation habits.

- **Needs regarding the noise hindrance**
  Implementing noise reduction measures is crucial to address the needs of residents affected by noise pollution. This includes the installation of noise barriers along busy roadways, soundproofing buildings, and implementing noise insulation measures in areas close to transportation hubs or industrial zones.

  Public Transportation Noise Mitigation: The need for noise mitigation measures for public transportation, such as trams and buses, should be addressed. Ensuring that vehicles are well-maintained, using noise-reducing technologies, and implementing quiet zones in densely populated areas can help minimize noise disturbances.

- **Needs regarding the improvement of mobility services**
  The need for smooth integration between cycling and walking infrastructure and public transportation networks. This includes providing secure bicycle parking facilities at public transport stations and improving pedestrian access to transit hubs, allowing for easy transfers between modes of transport.

- **Needs regarding the accessibility**
  Ensuring that public transportation and shared mobility services are accessible to individuals with mobility challenges or disabilities.

4.5.2. Perspective and vision on sustainable mobility

Rotterdam's perspective and vision on sustainable mobility extend to remote areas, aiming to connect peri-urban regions with the city center. The city is committed to ensuring that nobody is left behind in the adoption of SUM. It recognizes that living in suburban areas can limit job and study opportunities, social integration, and access to administrative rights. In order to address these challenges, Rotterdam will use the technologies developed in SUM to support travelers in making informed travel decisions and improving accessibility for all.

4.6. Krakow LL

4.6.1. LL Needs

Based on the Development Strategy Document for Krakow, the main needs and objectives for the city in the future have been identified.

- **Needs regarding the reduction of congestion**
  Reducing inter-district vehicle transit traffic within the 3rd city road ring. Striving for reliability of the public transport system in conjunction with the introduction of public transport prioritisation over individual transport. Planned objectives include:

- An increase in the number of P+R parking spaces to 4,070 in 2030 (against 873 in 2023).
- Increase in the number of passengers using agglomeration rail (7,05 million in 2022).
- An increase in the share of public transport in the modal split distribution to 38-42% in 2030 is expected.

- **Needs regarding the environmental indicators**
  Based on the assumptions of the Covenant of Mayors for Climate and Energy, Krakow aims for at least a 30% reduction in greenhouse gas emissions by 2030 relative to 2018, at least an 80% reduction by 2040 and to achieve climate neutrality no later than 2050

  Based on the Air Quality Plan for the Małopolska Region, the goal is to achieve permissible levels of air pollutants like PM10, PM2.5, benzo (a) pyrene, nitrogen dioxide and ozone. Planned actions in Krakow include:

  - Implementation of a low emission zone in Krakow based on Euro emission standards,
  - Launch of a transport emission monitoring system including current information on traffic in the city of Krakow.

  Also, based on the Act on Electromobility and Alternative Fuels, the percentage of zero-emission public transport vehicles in relation to total amount of vehicles should be 30% until 2028.

- **Needs regarding the noise hindrance**
  Reducing noise emissions by continuing with the following measures: quieting tram tracks, purchasing modern tram and bus rolling stock (including electric), using road surfaces with limited noise emissions, limiting the permissible speed of car traffic and using noise barriers only if there is no alternative.

- **Needs regarding the improvement of mobility services**
  Development of environmentally neutral micromobility, bicycle paths, rented bicycles and e-scooters. An increase in the share of cycling in the modal split to 13-17% in 2030 and an increase in the share of the use of personal mobility devices in the modal split is assumed.

- **Needs regarding the accessibility**
  Territorial and qualitative development of public transport systems: pre-metro, tramway lines (including the implementation of ring road investments connecting existing sections of the network to increase reliability) and bus lines (including BRT and/or the designation of dedicated inter-district bus lanes along the most important transport routes). Integration of transport systems with priority given to rail transport. Further privileging public transport in urban traffic and ensuring better accessibility and adequate frequency of public transport courses. The goal is for at least 90% of Krakow's residents to have access to Krakow's public transport stops (bus and tram combined) within a distance of no more than 400m.

4.6.2. Perspective and vision on sustainable mobility

Based on the SUMP, the vision has been planned until 2033 with a perspective until 2045 and is as follows: "Kraków Metropolis an area of integrated and sustainable transport system ensuring safety for all traffic participants, serving to create a better quality of life for residents and co-created with their participation."

The assumptions of the SUMP are to implement a policy aimed at meeting the needs of residents close to where they live and to ensure high-quality access to places of employment, education, health care and leisure. The policy, implemented through a system of inter-municipal transport and spatial linkages, provides the basis for improving the development opportunities of the inhabitants of the Krakow Metropolis while respecting the principles of environmental protection and pursuing the goal of climate neutrality. Further details can be found in Krakow SUMP.

4.7. Coimbra LL

4.7.1. LL Needs

- **Needs regarding the reduction of congestion**

Considering peak congestion hours and locations where it occurs, the needs of the Coimbra LL revolve around reducing car dependency for short trips in urban areas, with a particular focus on journeys between residences and schools.

- **Needs regarding the environmental indicators**

Increasing the number of public transportation users by reducing the number of private vehicles in circulation through the introduction of new transportation systems is expected to reduce the negative environmental impact of transport. In addition, the LL is focused on implementing public policies that restrict the use and access of private transportation in areas of high demand with available public transportation.

- **Needs regarding the noise hindrance**

Preserving urban areas from noise generated by car traffic by reducing the number of vehicles and their speed, through the adoption of tactical urbanism techniques.

- **Needs regarding the improvement of mobility services**

The increase and enhancement of infrastructure associated with soft mobility, such as cycling/scooter use and walking, are among the primary concerns in the city's development and transformation of public spaces. Efforts are being made to seek sources of public funding to facilitate their implementation.

- **Needs regarding the accessibility**

Through the work with the SUMP, map out and ensure a framework for how the city will work with sustainable urban mobility for the future.

4.7.2. Perspective and vision on sustainable mobility

Mobility in Coimbra is primarily based on individual transportation. Currently, there is a transformation in the city's mobility paradigms, as the LL is currently in the final stages of constructing the Mondego Mobility System. This system will enable the implementation of a new transportation system in the geographic area of the municipalities of Coimbra, Lousã, and Miranda do Corvo, optimizing the use of resources allocated to the project. Simultaneously, it will promote sustainable mobility, leveraging available resources and accumulated knowledge for the region, its residents, and visitors. It actively encourages the implementation of innovative mobility solutions, integrated urban services, and environmental protection. Moreover, it contributes effectively and coherently to social inclusion and gender equality.

The arrival of this new high-performance and high-quality transportation system will necessitate the restructuring and adaptation of the existing public transportation system. This is to create a complementary network, enhancing efficiency and reach, capable of improving current service levels and attracting new users to public transportation.

In parallel with all the infrastructure work being carried out in the transportation sector, Coimbra and its region are implementing fare integration among all operators. This aims to establish a true Mobility as a Service (MaaS) system, with the goal of presenting an exemplary, functional, and accessible public transportation service in the near future. This service is intended to achieve real gains in competitiveness and attractiveness, with a direct impact on reducing the number of vehicles in circulation and parked within the city.

4.8. Larnaca LL

4.8.1. LL Needs

Larnaca LL identifies five different categories of needs, which are described below:

- **Needs regarding the reduction of congestion**

The needs for overcoming congestion in Larnaca LL include the reduction of cars accessing the city center and the reduction of the cars parked on-street (fact that contribute to create situations of congestion due to occupancy of roads; significant portion).

- **Needs regarding the environmental indicators**

The large amount of CO2 emissions occurring from the transport sector and the 0% sharing schemes in Larnaca's Municipality, need to be addressed.

- **Needs regarding the noise hindrance**

A need for protecting and conserving sensitive areas from noise generated by vehicles using road infrastructure is raised.

- **Needs regarding the improvement of mobility services**

A need to increase the total amount of pedestrianized areas and of the total length of bicycle network and sidewalk enhancement is raised for Larnaca LL.

- **Needs regarding the accessibility**

Guarantee adequate accessibility to Larnaca through the optimisation of the transport offer and the development of an integrated mobility system is essential for the Larnaca LL. Based on the SUMP, by 2030 Larnaca should have removed 50% of the architectural barriers.

4.8.2. Perspective and vision on sustainable mobility

Based on the above needs of Larnaca LL the perspectives and visions on sustainable mobility focuses on reduce the congestion in the city center and thus the reduction of car-use, while providing people with more alternatives modes (NSM) for traveling through a MaaS platform. In addition, Larnaca aims to reduce fuel consumption and emissions, through the use of environmentally friendly modes (e.g., shared bicycles), in a such ways that the ecosystem can regenerate.

4.9. Fredrikstad LL

4.9.1. LL Needs

- **Needs regarding the reduction of congestion**

Reduce the number of cars into the city center using push/pull interventions such as toll road measure.

- **Needs regarding the environmental indicators**

An ongoing, multi-year partnership (Bypakke Nedre Glomma), which is a mobility improvement plan for the larger urban area, including the adjacent city Sarpsborg. This plan involves the state roadworks, the state, railways, the county administration, as well as the two municipalities' administrations. The current instalment of the plan focuses on actions that will contribute to a specific goal of 0% growth in climate emissions – despite the expected rapid population growth.

- **Needs regarding the noise hindrance**

Follow up on the adopted urban and street use plan that addresses the needs.

- **Needs regarding the improvement of mobility services**

Investigate and facilitate the integration of transportation modes to create a more seamless experience for travelers, including pedestrians, cyclists, public transportation users, and shared mobility options

- **Needs regarding the accessibility**

Through the work with the SUMP, map out and ensure a framework for how the city will work with sustainable urban mobility for the future.

- **Needs regarding the multimodality**

Publicize the measures for increased shared modality while involving the citizens and relevant stakeholders in the process.

4.9.2. Perspective and vision on sustainable mobility

Fredrikstad LL vision is to reduce the congestion in the city centre while people will be offered more alternatives modes of travelling. Furthermore, the city aims to reduce fuel consumption and emissions in such ways that the ecosystem can regenerate. SUM will explore the NSM potential of offering completely free NSM services in Fredrikstad LL. Another goal for the LL is to reduce the number of cars in the city center and facilitate zero growth by shifting the increase in travelers to sustainable public and shared modes of transport.

5. Standardized Impact Evaluation Framework

At this stage, the establishment of a framework is imperative for effectively tracking and comparing the impacts of the measures that will be implemented within the SUM project. CIVITAS has already created an evaluation framework (Engels et al., 2020), entitled CEF. The main objective of the CEF was to examine what works and what does not, and to comprehend the reasons why (Borgato et al., 2023). The CEF has undergone iterative validation and refinement in collaboration with CIVITAS projects throughout successive phases of CIVITAS. The SUM project incorporates the core principles of CEF and introduces a more specific framework, the Standardized Impact Evaluation Framework (SIEF), to assess whether the project's primary objectives will be met upon completion. SUM aims to facilitate a minimum 25% shift of daily private car users to NSM modes and/or Public Transport in each LL. Hence, variations in the modal split undermine the main project outcome, upon which the development of SIEF is based. Modal split, as a reference indicator, provides the shares (%) of each transport mode. Modal split can consider either trips, passenger kilometers or vehicle kilometers. These encompass various dimensions of the project's overarching objective. The SIEF will monitor each of these dimensions to facilitate comprehensive discussions regarding the effectiveness of SUM measures within each. Of course, the findings of the Systematic Literature Review are utilized as a valuable input to form this framework. In other words, the SIEF is a tool to track and evaluate the performance of LLs, before, during and after the implementation of the planned SUM measures.

5.1. Overview

CEF divides the evaluation phase of SUMPs into two distinct components: (a) process evaluation and (b) impact evaluation (Engels et al., 2020). The **process evaluation** assesses the planning, execution, and operational processes of implemented measures to comprehend the reasons behind their success or failure, including the influence of information, communication, and participation. It explores how measures were implemented, identifies barriers and facilitators throughout implementation, and explores the impact of supporting activities on the implementation process, as well as their contribution to mitigating undesired consequences. The **impact evaluation** encompasses the assessment of diverse technical, social, economic, environmental, and other effects resulting from the mobility measures implemented by cities. It seeks answers to key questions such as:

- What are the impacts of individual measures or integrated packages, as determined through pre- and post-implementation measurements of selected indicators?
- Why do we observe changes in these indicators, considering the specific contribution of the measures and potential external influences?

The SIEF incorporates both evaluation phases. It is based on four distinct horizontal levels, namely: policies, transport system, modal split (main project outcome), and impacts - sustainability assessment. The SIEF is summarized in **Figure 7**.

LLs can implement push or pull policies and measures to cause changes in the mobility patterns. Innovation transport modes can be integrated for this purpose, while the involvement of local communities will contribute to transformations in the mobility culture existing in each city. Yet, implemented measures may be unacceptable by the citizens or there may be reluctance to use the new transport modes and technologies. Hence, it is crucial to measure both the actual level of policy implementation in each LL as well as how people perceive these policies. This approach creates two different vertical dimensions: actual vs perceived. As can be interpreted, the first horizontal level refers to the process evaluation phase.

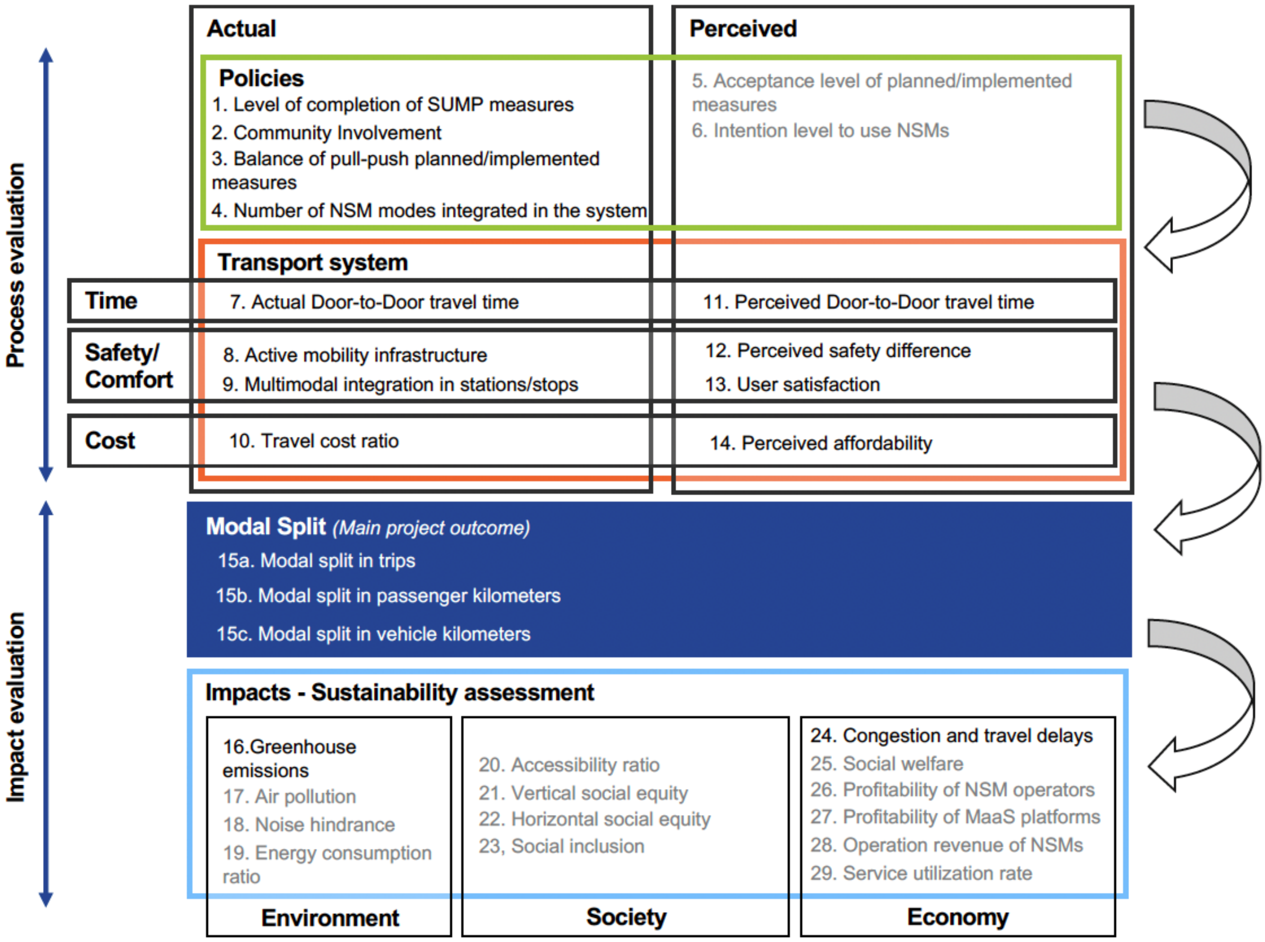


***Figure 7**. Presentation of the SIEF and its associated indicators (local indicators are highlighted with grey color)*

The primary objective of all sustainable mobility policies is to reinforce the performance of the transport system towards sustainability. Transport system is the second horizontal dimension of SIEF. Moreover, there are three different horizontal sub-dimensions that should be considered, namely: travel time, cost and safety. In essence, sustainable mobility policies aim to encourage individuals to opt for other transportation modes over private cars, with the objectives of achieving faster, safer, and more cost-effective alternative travel options. Based on this approach, multiple indicators were integrated in the SIEF. The majority of them test the differences between NSM modes and/or Public Transport vs private car. Again, the actual and perceived differences should be measured. This choice extends the vertical dimensions to the second horizontal level. Indeed, travelers tend to change their mobility habits based on their time or safe perception. If they do not "feel" the positive changes in the performance of a transport system that aspires to be sustainable, they are more likely to keep using their cars. Hence, no variations will be observed in the modal split, which comprise the third horizontal dimension of the SIEF. Hence the impacts evaluation phase starts in the third horizontal level.

The fourth horizontal level of SIEF contains indicators related to the impacts of modal shifts (if so). Three new vertical dimensions have emerged: environment, society, and economy. Besides, sustainability encompasses the intersection of these dimensions. It assesses the indirect impacts of implemented policies. Additionally, the last level of SIEF takes into account SUMI indicators, which is a more aggregated monitoring framework of mobility status of a city (Borgato et al., 2023; Chatziioannou et al., 2023a, 2023b). The SUMI indicators offer a comprehensive perspective on the condition of all pertinent factors related to mobility within a city, illustrating both the effects of mobility on urban environment quality and the attributes significantly shaping the sustainable mobility system. These changes can be either mid-term or long-term and may not be monitored within the SUM project in some LLs. This necessitates the estimation and the assessment of the transport system and policy assessment indicators (direct impacts) that are contained in the SIEF to project (or suspect) potential environmental, societal and economic benefits, which may emerge.

5.1.1. Global indicators

The SIEF contains both global and local indicators. Global indicators will be utilized to compare the performance of the LLs in different phases of the SUM project. The global indicators are the key indicators, which help to understand and compare the impacts of SUM measures (Borgato et al., 2023; Engels et al., 2020). A total of 13 global indicators have been incorporated into the SIEF framework, namely: 1) level of completion of SUMP measures, 2) community involvement, 3) balance of push-pull implemented measures, 4) actual door-to-door travel time, 5) active mobility infrastructure, 6) multimodal integration in stations/stops, 7) travel cost ratio, 8) perceived door-to-door travel time, 9) perceived safety difference, 10) user satisfaction, 11) perceived affordability, 12) greenhouse emissions and 13) congestion and travel delay. As previously mentioned, modal split in terms of trips, passenger kilometers and vehicle kilometers will be measured in all LLs **at least twice**: before and after the implementation of SUM measures. Intermediate measurements will be taken place only in the actual indicators, related to the performance of the transport system and the implementation of policies. The majority of the global indicators rely on the data that are collected from SUM survey, and which has been developed in the WP1 in order to monitor the mobility status of the LLs. Therefore, the SIEF leverages the knowledge acquired from the project's data collection processes. All global indicators will be measured at city level, so that changes in the mobility status of a LL can be observed within the SUM project.

5.1.2. Local indicators

The SIEF is a flexible assessment framework. Each LL has been given the autonomy to construct its own SIEF by selecting local indicators for monitoring. The local indicators are either intermediate indicators, which use further information to derive in more detail the impact of the sustainable mobility measures, or additional indicators which help to understand specific aspects of the impact of a measure. There are 14 indicators available for selection: 1) acceptance level of planned/implemented measures, 2) intention level to use NSM modes, 3) air pollution, 4) noise hindrance, 5) energy consumption ratio, 6) accessibility ratio, 7) vertical social equity, 8) horizontal social equity, 9) social inclusion, 10) social welfare and 11) profitability of NSM operators, 12) profitability of MaaS platforms, 13) Operation revenue of NSMs and 14) service utilization rate. The last seven indicators refer to the indirect impacts of SUM measures, while the other two refer to direct impacts. The objectives and priorities of each LL should be considered in order to select the most suitable set of indicators in each case. Local indicators will not be used for comparison but for understanding and evaluating the effectiveness of the implemented measures.

5.2. Indicators' specification

The SIEF constitutes the evaluation plan of the SUM project. In the next steps, data collection and monitoring techniques are presented to inform the data collection process of the LLs. The definition, the mathematical equation and the required datasets are provided for each of the indicators that is included in the SIEF. A list of the input variables has been included in Appendix A.

These specifications provide additional guidance, not only to LLs in their calculation of these indicators but also to facilitate the export of comparative results. This pertains to the primary data source adopted across all LLs: the WP1 SUM survey conducted at the outset of the project, encompassing a minimum of 200 participants per LL. Hence, the baseline scenario is before the implementation of the measures. To mitigate the influence of other factors, further investigation will be conducted into the interplay among the actual level of implemented policies, their impacts, and survey participants' perceptions. By eliminating anticipated effects (see **Figure 8**), the effectiveness of SUM measures can be substantiated.

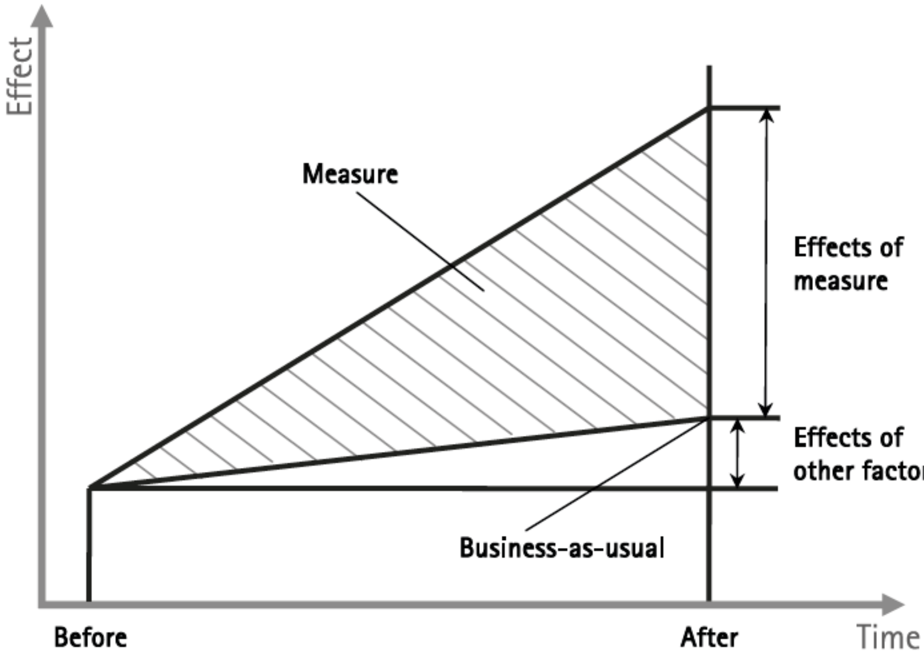


***Figure 8**. Evaluation time framework (before and after refers to when WP1 SUM survey is conducted)*

Source: (Engels et al., 2020)

5.2.1. Level of completion of SUMP measures

It is the share (%) of SUMP measures implemented within the SUM project in each LL. The SUMP time plan of each LL should be considered to determine which action had to be completed in each time frame.

Mathematical equation

$$Comp_{i,j} = \frac{impM_j}{M_j} \times 100 \quad (1)$$

Where:
I: set of Living Labs,
J: set of time frames,
M_j: set of measures that are planned to be implemented at time frame j,
$Comp_{i,j}$: level of completion of SUMP measures in Living Lab at time frame j [%],
$impM_j$: implemented measures at time frame j [#],

Required datasets
- Records, SUMP monitoring frameworks, etc.

5.2.2. Community involvement

It is the number of participatory planning or public engagement activities that have been organized in each LL. These activities may not be necessarily related to the SUM project. LLs should provide a list with the events that have been organized. The engagement of the community in each event needs to be comprehensively explained.

5.2.3. Balance of pull - push planned/implemented measures

It is defined as the ratio between planned or implemented pull measures over the planned or implemented push interventions in each LL.

Mathematical equation

$$Bl_{impl,i,j} = \frac{impM_{pull,j}}{impM_{push,j}} \quad (2)$$

$$Bl_{plan,i,j} = \frac{planM_{pull,j}}{planM_{push,j}} \quad (3)$$

Where:
I: set of Living Labs,
J: set of time frames,
$Bl_{impl,i,j}$: balance of pull-push implemented measures in Living Lab at time frame j [fraction],
$Bl_{plan,i,j}$: balance of pull-push planned measures in Living Lab at time frame j [fraction],
$impM_{pull,j}$: budget for implemented pull measures at time frame j [euros, or other national currencies],
$impM_{push,j}$: budget for implemented push measures at time frame j [euros or other national currencies],
$planM_{pull,j}$: budget for planned push measures at time frame j [euros or other national currencies],
$planM_{pull,j}$: budget for planned pull measures at time frame j [euros or other national currencies].

Required datasets
- Records, SUMP monitoring frameworks, etc.

5.2.4. Number of NSM integrated in the system

It is total number of NSMs that have already been integrated in the transport system of each LL. This can be done either by ticket integration system or by physical infrastructure that facilitates intermodal transitions and seamless trips (e.g., mobility hubs). This indicator necessitates a thorough justification explaining why each NSM should be regarded as part of the transport system.

5.2.5. Acceptance level of planned/implemented measures

It is the share (%) of respondents who accept the planned/implemented interventions in each LL (rates 4, 5, and 6).

Mathematical equation

$$Accp_i = \frac{1}{N} \times n_{(accp_n > 3)} \times 100 \quad (4)$$

Where:
I: set of Living Labs,

N: survey respondents in Living Lab i,
$Accp_i$: share of respondents who accept the implemented interventions in Living Lab I [#],
$n_{(accp_n>3)}$: number of respondents who rated acceptance higher than 3 [#].

Required datasets
- SUM survey before and after

5.2.6. Intention level to use NSMs

It is the share (%) of respondents who intend to use or continue using NSM modes in each LL (rates 4, 5, and 6).

Mathematical equation

$$Int_{m,i} = \frac{1}{N} \times n_{(int_{m,n}>3)} \times 100 \quad \mathbf{(5)}$$

Where:
I: set of Living Labs,
N: survey respondents in Living Lab i,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),
$Int_{m,i}$: share of respondents who intend to use transport mode m in the future in Living Lab I [%],
$n_{(int_{m,n}>3)}$: number of respondents who rated intention to use transport mode m higher than 3 [#].

Required datasets
- SUM survey before and after, section B.

5.2.7. Actual door-to-door travel time

It is the actual door-to-door travel time using NSM + PT (alternative modes) over the actual door-to-door travel time using a private car (considered as the dominant mode) at peak/off-peak hours in each LL. This indicator includes actual in-vehicle, waiting (or transfer), and access/egress time for alternative modes and an average parking time for private car.

Mathematical equation

$$DDt_{act,i} = \frac{\sum_{j=1}^{5} \frac{ddt_{act,alt,j}}{ddt_{act,car,j}}}{5} = \frac{\sum_{j=1}^{5} \frac{t_{wait,j} + t_{walk,j} + t_{act,alt,j}}{t_{park,j} + t_{act,car,j}}}{5} \quad \mathbf{(6)}$$

Where:
I: set of Living Labs,
J: set of 5 critical routes selected in Living Lab i; all of them should include main arterials with congestion points for better sampling.
$DDt_{act,i}$: actual door-to-door travel time ratio in Living Lab i,
$ddt_{act,alt,j}$: actual door-to-door travel time in minutes using alternative transport modes (NSM + PT) in route j,
$ddt_{act,alt,j}$: actual door-to-door travel time in minutes using a private car in route j [minutes],
$t_{walk,j}$: mean walking time in minutes for an alternative transport mode in route j (based on waiting for time distributions provided by shared mobility operators or frequencies per station/stops) [minutes],

$t_{wait,j}$: mean walking time (access + egress) in minutes for an alternative transport mode in route j (based on the public transport network coverage in the destination and origin point) [minutes],
$t_{park,j}$: mean parking time (finding a spot) in minutes for a private car in the origin of route j (use of empirical distribution or other approximations) [minutes].
$t_{act,alt,j}$: actual in-vehicle travel time in minutes using alternative transport modes (NSM + PT) in route j; congestion delays should be considered [minutes],
$t_{act,car,j}$: actual in-vehicle travel time in minutes using private car in route j; congestion delays should be considered [minutes].

Required datasets

- 5 critical routes to collect sample travel times before and after implementation of measures
- In-vehicle travel times considering congestion. Google Maps, traffic data, and other apps can provide an approximation.
- PT Frequencies in stops and stations to estimate mean waiting times
- PT network, stops/stations and coverage to estimate mean walking time from/to these facilities.
- Waiting time distributions from shared mobility service operators
- In-vehicle time distribution from shared mobility service operators
- PT travel times from telematic applications. Google Maps can also be used.
- Estimation of parking time especially in central urban areas.

5.2.8. Active mobility infrastructure

It is the share (%) of road network length with bike lanes, traffic calming measures (30 km/h or less), or pedestrian zones in each LL over the total road network length.

Mathematical equation

$$R_{am,i} = \frac{L_{pv} + L_{bl} + L_{z30} + L_{pz}}{L_{rn}} \quad (7)$$

Where:
I: set of Living Labs,
$R_{am,i}$: share (%) of road length adapted for active mobility,
$L_{pv,i}$: length of road network with wide sidewalk (more than 2 m;not if in a pedestrian zone) [km],
$L_{bl,i}$: length road network with bike lanes (not if in a 30 km/h zone) [km],
$L_{z30,i}$: length in km of road network in 30 km/h zone [km],
$L_{pz,i}$: length in km of pedestrian zone(s) [km],
$L_{rn,i}$: total length in km of city road network (excluding motorways) [km].

Required datasets

- Total length of bike lanes. Open spatial data in Local Repositories or OSM.
- Total length of roads with sidewalks higher than 0.6 m,
- Total length of traffic calming,
- Total length of pedestrian zones
- Total urban road network length.

5.2.9. Multimodal integration in stations/stops

It is the average percentage (%) of available transport modes (NSM + PT) at mobility hubs in relation to the total number of transport modes operating in each LL. If there is no mobility hub, then the result is 0%.

Mathematical equation

$$MI_i = \sum_{s=1}^{S} \frac{m_s}{M} \times 100 \quad (8)$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services).
S: set of mobility hubs in Living Lab i, if any.
MI_i: multimodal integration of Living Lab i [%],
m_s: number of modes available in the mobility hub s [#].

Required datasets
- Identification of mobility hubs, i.e., interchange points,
- Available modes per mobility hub,
- Available transport modes in the entire transport system. Provide a refined definition of what constitutes the transport system of the Living Lab.

5.2.10. Travel cost ratio

It is the mean travel cost of using NSM + PT over the mean travel cost of using private car in each LL. In private car, mean parking cost and fuel cost are only considered.

Mathematical equation

$$CR_{PT,i} = \frac{\frac{p_{ticket}}{D_{PT}}}{\frac{p_{park}}{d_{car}} + c_{car}} \quad (9)$$

$$CR_{NSM,i} = \frac{c_m}{\frac{p_{park}}{D_{car}} + c_{car}} \quad (10)$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),
$CR_{PT,i}$: travel cost ratio of public transport vs car in Living Lab I [fraction],
$CR_{PT,i}$: travel cost ratio of NSM vs car in Living Lab I [fraction],
c_{car}: the average cost per km of using a private car [euros],
c_m: the average cost per km of transport mode m. In an NSM where passengers pay based on travel time, an average speed can be used to estimate the distance covered [euros],
p_{ticket}: the price of the public transport ticket [euros],
D_{PT}: average distance of public transport trips [km],
D_{PT}: average distance of private car trips [km].

Required datasets
- Ticket prices of public transport.
- An average parking cost per urban area of the city
- Cost rates of shared mobility services.

- Vehicle composition of private cars, consumption rate per vehicle type and fuel cost.

5.2.11. Perceived door-to-door travel time

It is the perceived door-to-door travel time using NSM + PT (alternative modes) over the actual door-to-door travel time using a private car (considered as the dominant mode) at peak/off-peak hours in each LL.

Mathematical equation

$$DDt_{perc,i} = \frac{1}{N} \times \sum_{n=1}^{N} \left(\frac{med(ddt_{perc,alt,n})}{med(ddt_{perc,car,n})} \right) \quad \mathbf{(11)}$$

Where:
I: set of Living Labs,
N: survey respondents in Living Lab i,
$DDt_{act,i}$: perceived door-to-door travel time ratio in Living Lab I [fraction],
$ddt_{act,alt,j}$: perceived door-to-door travel time for respondent n using alternative transport modes (NSM + PT), where the median number of the selected interval is used [minutes],
$ddt_{act,alt,j}$: perceived door-to-door travel time in minutes of respondent n using a private car, where the median number of the selected interval is used [minutes].

Required datasets
- SUM survey before and after

5.2.12. Perceived safety difference

It is the mean difference of perceived safety ratings for each NSM mode over the perceived safety ratings of private car in each LL.

Mathematical equation

$$DPsafe_{i,m} = \frac{1}{n} \times \sum_{n=1}^{N} (psafe_{m,n} - psafe_{car,n}) \quad \mathbf{(12)}$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services).If no NSM, the perceived safety of bicycles and public transport is (pre)checked.
N: survey respondents in Living Lab i,
$DPsafe_{i,m}$: perceived safety difference of NSM m in Living Lab I [rate],
$psafe_{alt,n}$: perceived safety of NSM m as scored by respondent n [rate],
$psafe_{car,n}$: perceived safety of private car as scored by respondent n [rate].

Required datasets
- SUM survey before and after
- Available transport modes in the entire transport system. Provide a refined definition of what constitutes the transport system of the Living Lab.

5.2.13. User satisfaction

It refers to the share (%) of satisfied users (rates 4, 5, and 6) by the provided NSM + PT services in each LL.

Mathematical equation

$$SF_i = \frac{n_{(sf_n>3)}}{N} \quad \mathbf{(13)}$$

Where:
I: set of Living Labs,
N: survey respondents in Living Lab i,
SF_i: share of satisfied users by the provided NSM + PT services in Living Lab I [%].
$n_{(sf_n>3)}$: number of respondents who rated satisfaction higher than 3 [#].

Required datasets
- SUM survey before and after

5.2.14. Perceived affordability

It is the perceived share (%) of the monthly household budget spent in travelling.

Mathematical equation

$$Aff_i = \frac{1}{N} \times \sum_{j=1}^{J} n_j * med(aff_j) \times 100 \quad \mathbf{(14)}$$

Where:
I: set of Living Labs,
N: survey respondents,
J: set of affordability intervals,
Aff_i: perceived affordability in Living Lab i [%],
n_j: number of respondents selected the affordability interval j [#],
$med(aff_j)$: median percentage of affordability interval j [%].

Required datasets
- SUM survey before and after

5.2.15. Modal split

Modal split in transport planning refers to the distribution of trips, passenger kilometers, or vehicle kilometers among different transport modes within a LL.

Mathematical equation

$$P_{m,i} = \frac{X_m}{\sum_m^M X_m + X_{car}} \quad \mathbf{(15)}$$

$$X_m = TR_m = \frac{PKM_m}{\overline{D_m}} = \frac{VKM_m \times \overline{occ_m}}{\overline{D_m}} \quad \mathbf{(16)}$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services).
$P_{m,i}$: modal share of transport mode m in Living Lab i [%],
TR_m: total trips (one passenger/traveler) of using transport mode m [trips or pax],
PKM_m: total passenger kilometers of using transport mode m [million pax * km],
VKM_m: total vehicle kilometers of using transport mode m [millon veh * km],
$\overline{D_m}$: mean trip distance using transport mode m [km]
$\overline{occ_m}$: mean occupancy rate using transport mode m [km].

<u>Required datasets</u>
- SUM survey before and after
- occupancy rates per transport mode
- distance matrix, mean travel distance per transport mode, or distance distribution per transport mode.

5.2.16. Greenhouse emissions

It is the well-to-wheel CO2 emissions (in tons) of all passenger transport modes per inhabitant in each LL.

<u>Mathematical equation</u>

$$G_i = \frac{(\sum_{m,v} A_{m,v} \times (\sum_{ck} S_{mvk} \times C_{mvkc} \times I_{vk} * (T_k + W_k) \times (1 + f_{noGHG}))) \times 1000}{cap} \quad (17)$$

Where:
I: set of Living Labs,
M: set of transport modes,
V: set of vehicle types,
K: set of fuel/energy types (petrol, diesel, biofuel, electricity, hydrogen, etc.)
C: set of emission class,
G_i: greenhouse gas emissions in Living Lab i [tonnes of CO2 / cap. per year],
T_k: tank to wheel CO2 emission of fuel/energy type k [kg/lt or kg/kWh],
W_k: well to Tank CO2 equivalent emission of fuel/energy type k [factor],
$A_{m,v}$: activity volume described in vehicle kilometers driven by transport mode m and vehicle type v [million veh * km],
S_{mvk}: share of fuel/energy type k per vehicle type v and per transport mode m [%],
C_{mvkc}: share of emission class c per fuel type k per vehicle type v and per transport mode m [%],
I_{vk}: energy intensity per distance traveled for vehicle type j and fuel type k [lt/km or MJ/km or kWh/km],
cap: number of inhabitants in the urban area [#],
f_{noGHG}: non-CO2 GHG correction (CO2 equivalent) [factor].

<u>Required datasets</u>
- vehicle - km of passenger vehicles per mode
- vehicle fleet composition per fuel type per mode
- fuel consumption and energy content
- number of inhabitants

5.2.17. Air pollution emissions

It is well-to-wheel air pollutant emissions (in tons) of all passenger transport modes per inhabitant in each LL. NOx, NO2 and PM2.5 are taken into consideration.

Mathematical equation

$$EHI_i = \frac{\sum_s E_{eq_s} \times (\sum_{mv} A_{mv} \times (NE_m + \sum_{ck} S_{ck} \times E_{mvkc} \times I_{vk})) \times 1000}{cap} \qquad \mathbf{(18)}$$

Where:
I: set of Living Labs,
M: set of transport modes,
V: set of vehicle types,
K: set of fuel/energy types (petrol, diesel, biofuel, electricity, hydrogen, etc.)
C: set of emission class,
EHI_i: emission harm equivalent index [kg PM2.5 eq./ cap per year]
E_{eq_s}: emission substance type PM2.5, equivalent health impact value [factor]
E_{mvkc}: emission of pollutants per vkm driven by transport mode m and vehicle type v for fuel type k, emission class c [g/km]
A_{mv}: activity volume described in vehicle kilometers driven by transport mode m and vehicle type v [million veh * km]
S_{mvk}: share of fuel/energy type k per vehicle type v and per transport mode m [%]
NE_m: non-exhaust emissions of pollutant (transport mode) m per distance traveled [g / km] (= 0 for NOx)
I_{vk}: energy intensity per distance traveled for vehicle type j and fuel type k [lt/km or MJ/km or kWh/km]
cap: capita or number of inhabitants in the urban area [#]
Multiplication by 1000 for conversion of units from g to kg

Required datasets
- vehicle - km of passenger vehicles per mode
- vehicle fleet composition per fuel type per mode
- number of inhabitants

5.2.18. Noise hindrance

It is the number of people exposed to different noise bands (i.e., 55–59, 60–64, 65–69, 70-74, > 75 dB) in each LL. Noise measurements in critical should be conducted, so that this indicator can be measured.

Mathematical equation

$$NI_i = \frac{\sum_i HFL_{den_i} * (\sum_m W_{nm} * P_{nm})}{\sum_m W_{nm} * P_{nm}} \qquad \mathbf{(19)}$$

Where:
I: set of Living Labs,
N: set of noise bands,
M: set of transport modes,
NI_i: noise hindrance index of Living Lab i [% of population],
P_{im}: population exposed to noise band n because of transport mode m (road, rail, airplane) [#],
W_{nm}: high annoyance weight factor for transport mode m and noise band m [%],
HFL_{den_n}: hindrance factor at average Ldeni level of the relevant noise band n [factor].

Required datasets
- Noise measurements
- Population data

5.2.19. Energy consumption ratio

It is the total energy consumption per km of only the passenger transport modes in each LL.

Mathematical equation

$$\mathrm{E_i} = \frac{(\sum_{\mathrm{mv}} \mathrm{A_{mv}} (\sum_{\mathrm{k}} \mathrm{S_{jk}} \times \mathrm{I_{jk}} \times \mathrm{EC_k}))}{\mathrm{PKM}} \quad \mathbf{(30)}$$

Where:
I: set of Living Labs,
M: set of transport modes,
V: set of vehicle types,
K: set of fuel/energy types (petrol, diesel, biofuel, electricity, hydrogen, etc.)
C: set of emission class,
E_i: energy consumption rate for passenger transport in Living Lab i [MJ/km],
PKM_m: total passenger kilometers [million pax * km],
S_{vk}: share of fuel type k per vehicle type j [%],
I_{jk}: energy intensity per distance driven for vehicle type j and fuel type k [l/km or MJ/km or kWh/km],
A_{mv}: activity volume described in vehicle kilometers driven by transport mode m and vehicle type v [million veh * km]
EC_k: fuel energy content for fuel k [MJ/l or MJ/kg].

Required datasets
- vehicle - km of passenger vehicles per mode
- vehicle fleet composition per fuel type per mode
- fuel consumption and energy content
- number of inhabitants

5.2.20. Accessibility ratio

It is the accessibility provided by NSM and/or Public Transport over the accessibility private by private car that is considered as the dominant transport mode. This indicator is estimated per zone of each LL. Maximum and minimum values can also be considered as reference points to describe potential changes.

Mathematical equation

$$RA_{k,i} = \frac{A_{k,m}}{A_{k,car}} = \frac{\sum O_l \times \exp(-C_{kl,m})}{\sum O_l \times \exp(-C_{kl,car})} = \frac{\sum O_l \times \exp[-(t_{ks} + t_{sp} + t_{sl})]}{\sum O_l \times \exp(-T_{kl,car})} \quad \mathbf{(20)}$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),
K: set of origin zones,
L: set of destination zones,
S: set of metro/tram/suburban railway station or mobility hubs within (or near) the origin zone,

P: set of metro/tram/suburban railway station or mobility hubs within (or near) the destination zones,
$RA_{k,i}$: accessibility ratio of origin zone k in Living Lab i,
$A_{k,i,m}$: accessibility in origin zone k in Living Lab i using transport mode m [#],
$A_{k,i,car}$: accessibility in origin zone k in Living Lab i using private car [#],
O_l: represents the activities (e.g., opportunities, land uses or the point of interests) existing in zone j. Therefore, accessibility can be estimated for different activity types per Living Lab.
C_{kl}: cost function, i.e., travel time (T_{kl}) from origin zone k to destination zone l [hours]. Cost function can be further specified based on the characteristics of the travel mode and the transport system existing in each Living Lab,
t_{ks}: access time, from the origin zone k to the nearest metro/tram/suburban railway station s (only for accessibility estimations using public transport, NSM or combination of them) [hours],
t_{sp}: in-vehicle time, i.e., is the time travelled via the fixed route transport network from station s to egress station p. Required transfers can be included as an additional variable or with the form of penalty included in the in-vehicle time [hours],
t_{pl}: egress time, from the nearest metro/tram/suburban railway station p to destination zone l (only for accessibility estimations using public transport, NSM or combination of them) [hours].

Required datasets
- public transport network, bus/metro lines, stops/stations, etc.
- land uses, activities, points of interests, etc.
- travel times based on congestion events (if congestion is considered)
- road network, cycle network for access/egress trips.
- other variables which affect the accessibility.

5.2.21. Horizontal social equity

It refers to the distribution of accessibility level among individuals, groups or geographic areas considered equal in capabilities and requirements. The calculation of the GINI index is required.

Mathematical equation

$$G_{i,m} = 1 - \sum_{k=1}^{K} (X_k - X_{k-1}) \times \left(P_{A_{k,m}} + P_{A_{k-1,m}}\right) \quad \mathbf{(21)}$$

$$G_{i,car} = 1 - \sum_{k=1}^{K} (X_k - X_{k-1}) \times \left(P_{A_{k,car}} + P_{A_{k-1,car}}\right) \quad \mathbf{(22)}$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),
K: set of origin zones,
$G_{i,m}$: Gini index of Living Lab i (if transport mode m the only option) [#],
$G_{i,car}$: Gini index of Living Lab i (if private car is the only option) [#],
X_k: the cumulative proportion of population in the origin zone k [%]. Specific social groups can be considered.
$P_{A_{k,m}}$: cumulated proportion of the accessibility (estimated based on the previous indicator) of the origin zone k using transport mode m [%].
$P_{A_{k,car}}$: cumulated proportion of the accessibility (estimated based on the previous indicator) of the origin zone k using private car [%].

Required datasets
- accessibility estimations,
- sociodemographic data (e.g., population, social groups) with spatial reference.

5.2.22. Vertical social equity

It refers to the distribution of accessibility level among individuals, groups or geographic areas that differ in needs and abilities in each LL. The calculation of the Bivariate Local Moran's I is required.

Mathematical equation

$$I_{i,k,m} = \frac{\left(A_{k,m} - \overline{A_m}\right)}{\frac{\sum_{k=1}^{k}\left(Inc_k - \overline{Inc}\right)^2}{K}} \times \sum_{j=1}^{n} W_{kl}\ \left(Inc_k - \overline{Inc}\right) \quad \mathbf{(23)}$$

$$I_{i,k,car} = \frac{\left(A_{k,car} - \overline{A_{car}}\right)}{\frac{\sum_{k=1}^{k}\left(Inc_k - \overline{Inc}\right)^2}{K}} \times \sum_{j=1}^{n} W_{kl}\ \left(Inc_k - \overline{Inc}\right) \quad \mathbf{(24)}$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),
K: set of origin zones,
L: set of neighbor zones,
$I_{i,k,m}$: Bivariate Local Moran's I statistic for zone k in Living Lab i, (if transport mode m is the only option) [#],
$I_{i,k,car}$: Bivariate Local Moran's I statistic for zone k in Living Lab i, (if private car is the only option) [#],
$A_{k,m}$: accessibility (estimated based on the previous indicator) of the origin zone k using transport mode m [#],
$\overline{A_{car}}$: mean accessibility of using transport mode m (considering all the zones of the Living Lab) [#],
$A_{k,car}$: accessibility (estimated based on the previous indicator) of the origin zone k using private car [#],
$\overline{A_{car}}$: mean accessibility of using private car (considering all the zones of the Living Lab) [#].
Inc_k: mean income of origin zone k [euros]
$\overline{Inc}$: mean income (considering all the zones of the Living Lab) [euros]
W_{kl}: spatial weights between zone k and neighbors l (queen contiguity weights can be preferred) [fraction].

Required datasets
- accessibility estimations,
- sociodemographic data (e.g., population, social groups) with spatial reference.

5.2.23. Social inclusion

It is the inclusion of Public Transport and/or NSM services to persons with reduced mobility, considering the vehicles/stations/stops that are accessible and comfort to those groups in each LL.

Mathematical equation

$$Incl_i = \frac{\sum modalweight_m \times Incl_m}{100} \quad \mathbf{(25)}$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),
F: set of inclusivity features (e.g., number of trains, buses, or stations/stops with visual/auditory announcement systems, number of trains or buses with low floors, number of trains with specially designed spaces for people with special needs),
$Incl_i$: inclusivity of Living Lab i considering all transport modes [%],
$modalweight_m$ = users of mode m / total users * 100 [%],
$Incl_m$: inclusivity of mode m = p_{fm} [# or %]
p_{fm}: average of inclusivity feature f of mode m [# or %]

Required datasets
- trains/buses characteristics
- stations/stops characteristics

5.2.24. Congestion and travel delays

It is the average ratio between of travel time at peak hours and off-peak hours considering all transport modes in each LL. A sample of 5 main traffic corridors is determined to measure it. The modal shares are utilized as weights to derive a mean value about travel delays.

Mathematical equation

$$CD_i = MS_{road} \times \frac{(\sum_{j=1}^{3}(\frac{CT_j * PHT_j}{FFT_j}))}{\sum_{j=1}^{3} CT_i} + MS_{pt} \times \frac{(\sum_{k=1}^{3}(\frac{PT_k * PTPHT_k}{PTOT_k}))}{\sum_{j=1}^{3} PT_k} \quad (27)$$

Where:
I: set of Living Labs,
J: set of selected travel corridors in the road network,
K: set of selected travel corridors in the transit network (e.g., bus lanes, tram corridors),
CD_i: Congestion and delay index - percentage delay during peak hours of Living Lab i [% of delay],
CTi: number of car trips during peak hours on main road corridor i [#],
$PHTi$: car travel time during peak hours on main road corridor i [minutes],
$FFTi$: off-peak car travel time on main road corridor i [minutes],
PT_k: number of trips by public transport during peak hours on transit corridor k [#],
$PTPHT_k$: public transport travel time during peak hours on main road corridor k [minutes],
$PTOT_k$: optimal public transport travel time on main road corridor k [minutes],
MS_{road}: share of transport modes travelling using the road network [%],
MS_{pt}: share of transport modes travelling using the transit network [%].

Required datasets
- car travel time peak hour
- car travel time off peak hour
- traffic flow in pcu per hour in 10 main road corridors
(PT travel times can be imported too)

5.2.25. Social welfare

It is defined as the total profits of passengers using NSM and Public Transport, expressed in time savings, plus the total profits of transport operators (ridership minus the cost of operation). In other words, it is the consumer surplus plus the producer surplus.

Mathematical equation

$$SW_i = \sum_{m=1}^{M} (CS_m + PS_m) \quad \mathbf{(28)}$$

$$CS_m = (TS_m * Rid_m) * VoT \quad \mathbf{(29)}$$

$$PS_m = R_m - C_m \quad \mathbf{(30)}$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),
SW_i: social welfare of Living Lab I [euros],
CS_m: consumer surplus by using transport mode m (total travel time savings) [euros],
PS_m: producer surplus (profits) of transport mode m [euros],
TS_m: mean travel time savings per passenger (after the implementation of SUM measures or integration of new shared mobility mode) [hours/pax],
Rid_m: total ridership of transport mode m [pax]
VoT: value of time [euros/h]
R_m: total revenues of transport mode m [euros],
C_m: total operational cost of transport mode m [euros].

Required datasets
- Value-of-Time estimations
- Data per NSM about ridership, travel time, etc.
- Data about operational cost and total revenues.

5.2.26. Profitability of NSM operators

It is the annual change (%) in total profits (ridership minus the cost of operation) of all NSMs that have been integrated in the transport system of each LL.

Mathematical equation

$$dPS_{i,m,t} = \frac{PS_{m,t} - PS_{m,t-1}}{PS_{m,t-1}} \times 100 \quad \mathbf{(31)}$$

$$PS_{m,t} = R_{m,t} - C_{m,t} \quad \mathbf{(32)}$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),
T: years (or months),

$dPS_{i,m.t}$: annual change in total profits in year t for transport mode m in Living Lab i [%],
$PS_{m,t}$: operator surplus (net profits) by using transport mode m in time frame t [euros],
$R_{m,t}$: total revenues of transport mode m in time frame t [euros],
$C_{m,t}$: total operational cost of transport mode m in time frame t [euros].

Required datasets
- Data per NSM about ridership, travel time, etc.
- Data about operational cost and total revenues.

5.2.27. Profitability of MaaS platforms

It is defined as the percentage change in total profits month-over-month, where total profits are determined by the aggregate net income generated from all integrated transport services minus the operational costs incurred by the MaaS platform itself.

Mathematical equation

$$dPS_{i,p,t} = \frac{PS_{p,t} - PS_{p,t-1}}{PS_{m,t-1}} \times 100 \quad \mathbf{(33)}$$

$$PS_{p,t} = aggR_{p,t} - C_{p,t} \quad \mathbf{(34)}$$

Where:
I: set of Living Labs,
P: set of MaaS platforms existing in the transport system.
T: selected time frame (e.g., months, years, etc.),
$dPS_{p.t,i}$: annual change in total profits in year t for MaaS p in Living Lab i [%],
$PS_{p,t}$: operator surplus (net profits) by using transport mode m in time frame t [euros],
$aggR_{p,t}$: aggregate revenues of transport mode m in time frame t, considering all services [euros],
$C_{p,t}$: total operational cost of MaaS platform p in time frame t [euros].

Required datasets
- Data about operational cost and total revenues.

5.2.28. Operation revenue of NSMs

Revenue Per Month (€/Month) for NSM services per LL is a metric that represents the total income generated/or/predicted to be generated from the service within a month. It aggregates earnings from all operational activities related to the NSM service, including user/passenger fees per trip (which can be based on time, distance, or a flat rate), subscription fees, and any other associated service charges. It provides insight into the service's monthly performance, understanding the service's market position.

Mathematical equation

$$oR_{i,m,t} = (P_{use,m} \times U_{daily,m} \times D_{month,m} \times F_m) + S_{month,m} \quad \mathbf{(35)}$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),

T: selected time frame (e.g., months, years, etc.),
$oR_{i,m,t}$: operation revenue per day generated by the transport mode (or shared mobility service) m in a specific time frame t in Living Lab i [euros/day],
$P_{use,m}$: ticket price per use [€] for transport mode m; this could be calculated based on distance [€/km], time [€/min], or a flat rate per trip, depending on the service's pricing model,
$U_{daily,m}$: the average number of times a single fleet of by the transport mode m (or shared mobility service) is used per day [rides/day],
D_{month}: Number of Operational Days in the Month represents the total number of days the service was available for use in the month,
F_m: fleet size of the transport mode (or shared mobility service) m,
$S_{month,m}$: monthly subsidy (€/Month) for the transport mode (or shared mobility service) m.

Required datasets
- Data per NSM about ridership, travel time, etc.
- Data about operational cost and total revenues.

5.2.29. Service utilization rate

This metric denotes the proportion of operational vehicles within the entire fleet, calculated typically on an hourly or daily basis but often averaged over a month or year for comparative analysis. It serves as a benchmark for assessing fleet utilization efficiency.

$$SuR_{i,m,t} = \left(\frac{actfl_{m,t}}{avfl_{m,t}}\right) \times 100 \quad (\mathbf{36})$$

Where:
I: set of Living Labs,
M: set of NSM + PT modes integrated into the transport system (e.g., micro-mobility, car-sharing, ride-hailing or shuttle services),
T: selected time frame (e.g., months, years, etc.),
$SuR_{i,m,t}$: service utilization rate of transport mode m in time frame t in Living Lab i [%].
$actfl_{m,t}$: active vehicle fleet of transport mode m in time frame [veh],
$avfl_{m,t}$: available vehicle fleet of transport mode m in time frame [veh]

Required datasets
- Data per NSM about ridership, requests, etc.

6. Conclusions and next steps

This deliverable presents a KPI-driven evaluation framework, defined within the SUM project, that allows cities to measure the achieved impacts through the means of the deployment of technological advances and sustainable actions, as well as the progress achieved towards the compliance of city targets established in shared mobility urban plans.

The core principles of the CEF framework that has been developed in CIVITAS have been adopted, and a more specific framework, the Standardized Impact Evaluation Framework (SIEF), has been introduced, to assess whether the project's primary objectives will be met upon completion. The framework incorporates two distinct evaluation components: (a) process evaluation and (b) impact evaluation. The process evaluation assesses the planning, execution, and operational processes of implemented measures, explores how measures were implemented, identifies barriers and facilitators throughout implementation, and explores the impact of supporting activities on the implementation process, as well as their contribution to mitigating undesired consequences. The impact evaluation assesses several technical, social, economic, environmental, and other effects resulting from the implementation of the proposed mobility measures.

The SIEF is based on four distinct horizontal levels, namely policies, transport system, modal split (main project outcome), and impacts - sustainability assessment. A total of 13 global indicators have been incorporated into the SIEF framework: 1) level of completion of SUMP measures, 2) community involvement, 3) balance of push-pull implemented measures, 4) actual door-to-door travel time, 5) active mobility infrastructure, 6) multimodal integration in stations/stops, 7) travel cost ratio, 8) perceived door-to-door travel time, 9) perceived safety difference, 10) user satisfaction, 11) perceived affordability, 12) greenhouse emissions and 13) congestion and travel delay. Furthermore, the LLs have also the autonomy to select local indicators that will be used for understanding and evaluating the effectiveness of the implemented measures. 9 indicators have been made available for selection: 1) air pollution, 2) noise hindrance, 3) energy consumption ratio, 4) accessibility ratio, 5) vertical social equity, 6) horizontal social equity, 7) social inclusion, 8) social welfare and 9) profitability of NSM operators.

The proposed SIEF framework consists of a broad, flexible and replicable methodology that has been established to guide decision-makers in how to face the main challenges of the analysis, i.e., quantification of the results or determining the main goals to evaluate. This relies on a list of available indicators (merging literature and previous experiences) that helps cities to select the most suitable ones according to the objectives to be reached. Cities are thus capable of mapping the KPIs with the expected targets or smart city urban plans: not only by choosing them from the pre-defined list, but by also adapting the indicators or the components of the evaluation framework to their requirements.

Regarding next steps, as part of the project we will extract and analyze the data per city as a before and after analysis, but also among the cities, to draw conclusions about similarities and differences. Through that the impact of the applied measures will be validated and conclusions will be drawn on city and thematic area (social, economic, environmental). At a basic level, this validation can be conducted via a continuous discussion with partners responsible for the implementation and the evaluation of the measures (i.e. the Living Labs), the local representatives as well as relevant stakeholders. Such activities (that are also part of the process evaluation) will allow for a better understanding of why the reported impacts occurred. To present the main evaluation conclusions in a structured way, the following aspects should be discussed:

- Validated impacts, including the key results regarding the measure’s impact, referring to quantitative observations and qualitative appraisal,
- Expected long-term impacts of the measure,
- Implementation factors, including key barriers, drivers, corresponding actions, and the role of supporting activities,

- Main lessons learned as an integrated conclusion of the impact and process evaluation findings.

Bringing all evaluation findings together in a structured way is an important task in each project, which contributes to the wider community's knowledge of evidence-based solutions. The findings from different cities will allow to draw more specific conclusions on the impacts and implementation aspects of a type of measure as well as conclusions on the development of efficient urban strategies.

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