

KPIs and Methodological Framework

Project deliverable D5.1

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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. Intermodality, 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, public urban authorities.

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Deliverable executive summary

This Deliverable D5.1 aims at defining indicators and methods from existing simulation models and technological watch to assess the impact of solutions implemented in the SUM project's Living Labs. The document introduces a structured methodology comprising: (1) an impact analysis using regression models; (2) a multi-criteria decision analysis (MCDA) framework based on the PROMETHEE-GAIA method; and (3) a dynamic graphical interface to facilitate stakeholder engagement and decision-making. These tools are designed to quantify and visualize the effects of mobility measures across participant European cities.

1.1 Key words

Impact, methodology, KPI analysis, comparison, quantitative, qualitative, living lab assessment



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List of abbreviations and acronyms

Acronym	Meaning
AHP	Analytic Hierarchy Process
API	Application programming interface
CORPAS	COmplex PROportional ASsessment
ELECTRE	ÉLimination Et Choix Traduisant la RÉalité (Elimination and Choice Expressing the REality)
GAIA	Geometrical analysis for interactive aid
KPI	Key Performance Indicator
MaaS	Mobility as a Service
MAUT	Multi-Attribute Utility Theory
MCDA	Multi-criteria Decision Analysis
MULTIMOORA	MULTI-objective Optimization by Ratio Analysis plus the Full Multiplicative Form
NSM	New Shared Mobility
OEM	Original Equipment Manufacturer
ORESTE	Organisation, Rangement Et Synthèse de Données Relationnelles (Organization, Ranking and Synthesis of relational data)
PCA	Principal Component Analysis
PROMETHEE	Preference Ranking Organisation METHod for Enrichment Evaluations
PT	Public Transport
SMARTS	Simple Multi-Attribute Rating Technique using Swings
SUM	Seamless Shared Urban Mobility
SUMP	Sustainable Urban Mobility Plan
TNC	Transportation Network Companies
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
UTA	UTilités Additives (Additive Utility Functions)
UTADIS	UTilités Additives DIScriminantes (Discriminant Additive Utility Functions)
VIKOR	IseKriterijumska Optimizacija I Kompromisno ResenjelseKriterijumska Optimizacija I Kompromisno Resenje (Multi-Criteria Optimization and Compromise Solution)
WP	Work Package



2 Introduction

The core objective of this deliverable is to provide a comprehensive methodology for assessing the multifaceted impacts of mobility interventions (push/pull measures) by integrating KPI metrics and stakeholder inputs.

Section 3 of this [Deliverable D5.1](#) outlines the methodology used for different assessments. **Section 4** concludes with the implications and importance of these methodologies and **Section 5** outlines the next steps.

To achieve this, the Section 3 is structured into three main components:

1. **Impact Analysis:** This component applies regression models to estimate the effect of implemented push/pull measures on selected KPIs, comparing “before” and “after” intervention states. It quantifies both short-term behavioural changes and long-term structural effects on the mobility ecosystem.
2. **Multi-Criteria Decision Analysis Framework:** Using the PROMETHEE-GAIA method, this framework integrates diverse and sometimes conflicting evaluation criteria – including accessibility, safety, inclusiveness, and emissions – while accounting for stakeholder priorities. It enables transparent and adaptable decision-making analysis across different contexts.
3. **Graphical Interface:** A user-centric platform to visualize participant Living Labs data and its analytical results, allowing stakeholders to explore and compare the impact of different measures implemented. This tool will evolve dynamically as KPI data becomes available.

2.1 The objective of deliverable D5.1

The main objective of this document is to define a coherent set of Key Performance Indicators (KPIs) and establish a robust methodological framework for assessing the impacts of mobility solutions implemented in the SUM project’s Living Labs.

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

This report contributes to Work Package 5 (WP5), Task 5.2 of the project SUM, titled **"Impact Assessment, Knowledge Utilization, and Policy Recommendations."** Specifically, it addresses Task 5.2, **"Economic, environmental, social and technical assessment of the solutions implemented in Living Labs"** which includes two main deliverables:

- Sub-Task 5.2.1: Develop a framework of “Meta-observatory of new mobility solutions” based on the well-established Multi-Criteria Decision Analysis framework;
- And Sub-Task 5.2.2: Investigate the economic criteria with respect to the trade-off between long-term costly investments (e.g., new hubs design), and short-term cost reductions (e.g., service reconfiguration).

In addition, a graphical interface will be developed to visualize the results of the two analyses mentioned above. This interface will allow stakeholders to view and interact with the data collected, in order to be able to draw conclusions and help the decision-making process.



These deliverables are closely linked with several components of the project. They are associated with WP1, which focuses on defining the needs and key performance indicators (KPIs) for each Living Lab. Additionally, WP4 is involved in the Living Labs data collection plan and KPI measurement after implementation of different push/pull measures and technological integrations within WP2 and WP3. These Work Packages will provide the data required for the impact assessment: an exhaustive list of measures to be implemented, KPI metrics achievement before implementation, KPI metrics achievement after implementation.

The actual results and finding of this analysis will be the object of next related [Deliverable 5.2 “Overall impacts and cross-Living Labs comparison”](#).



3 Methodology and Theoretical Framework

3.1 Impact Analysis

This section outlines the methodology followed to assess the impact of push and pull measures – a set of Sustainable Urban Mobility Plan (SUMP) interventions was introduced in each Living Lab, combining restrictions on private car usage (push measures) with incentives for shared mobility adoption (pull measures) – implemented in the Living Labs aiming to increase the uptake of NSM solutions. A set of global and local KPIs were estimated before the implementation of these measures and will be recalculated after.

3.1.1 Purpose and Structure

Our analysis focuses on quantifying short- and long-term effects of the push and pull interventions through this set of KPIs, and on developing an interface to support stakeholder engagement and exploration of the results. The goal of this task is to estimate the impact of the measures and provide stakeholders with actionable insights into what worked, for whom, and under what conditions. The analysis follows a structured process that begins with baseline data collection, proceeds with the estimation of impacts, and concludes with the design of an interactive interface to communicate and explore the findings.

3.1.2 Short- and long-term impact assessment

The core objective of the analytical framework is to quantify the short- and long-term impacts of the implemented push and pull measures on the KPIs defined within the project. To this end, we adopt a regression-based approach to estimate the specific contribution of each push/pull measure to the observed variation in individual KPIs or subsets of KPIs across the Living Labs.

For each KPI or subset of KPIs, the normalised difference between the post- and pre-intervention values will be computed. This difference will serve as the dependent variable in a linear regression model, where the independent variables represent the set of implemented measures in each Living Lab. Each measure will be encoded as a binary variable indicating whether or not it was implemented at the respective Living Lab. An example of what this input to the model looks like can be visualised in

Table 1 Illustrative Example of Input of Regression Model.

<i>Living Lab (in which measures are implemented)</i>	<i>Parking Charging</i>	<i>Vehicle Sharing</i>	<i>...other push/pull measure</i>	<i>Change in KPI travel cost ratio (%)</i>
<i>Munich, Germany</i>	0	1	...	0.15
<i>Krakow, Poland</i>	1	1	...	0.40
<i>... other Living Labs</i>	...	...	...	...

Table 1 Illustrative Example of Input of Regression Model: 1 if measure was implemented at Living Lab and 0 otherwise

We will use a linear regression model with L2 regularization, also known as a Ridge regression model, because the number of push/pull measures, used as features, exceeds the number of Living Labs. This regularization technique is known to help address multicollinearity and hence reduce the risk of over-fitting in such high-dimensional settings.

The resulting model will allow us to associate a weight (regression coefficient) to each measure, providing an interpretable estimate of its contribution to the observed change in the KPI. This will help identify which interventions had the most significant influence on specific outcomes, and in which direction, and hence investigate whether the verified effect of each measure matched the potential effect predicted. Formally, for each Living Lab l , we define the model as:

$$\Delta KPI_l = \beta_0 + \sum_{m \in M} \beta_m I_{l,m}$$

where:

- ΔKPI_l is the normalised difference between the KPI before and after the implementation,
- M is the set of push and pull measures,
- $I_{l,m}$ an input parameter indicating whether the measure m was implemented in Living Lab l ,
- β_0 is a regression coefficient representing the intercept term,
- β_m is a regression coefficient representing the estimated impact of measure m on the KPI.

This approach offers a clear interpretation of the effect of each individual measure, making it straightforward to identify the specific contributions to changes in KPIs. It also provides an intuitive framework that can be easily communicated to stakeholders and integrated into the interface for further data exploration. An example of what this input to the model looks like can be visualised in Table 2.

Measure	<i>Parking Charging</i>	<i>Vehicle Sharing</i>	<i>...other push/pull measure</i>	<i>Mean Squared Error in Estimation of KPI Change</i>
<i>Regression Coefficients for Impact Estimation (β_k)</i>	0.26	0.14	...	0.00005

Table 2 Illustrative Example of Output of Regression Model

There are some difficulties that we account for. First, this method relies on sufficient variation in the implementation of measures across Living Labs. If a specific measure is implemented uniformly across all Living Labs, its individual impact might be difficult to isolate. Second, local KPIs selected by only a few Living Labs may not provide enough data points for robust estimation, making it difficult to reliably quantify the impact of individual measures on these KPIs. To address these limitations, we plan to run both univariate analysis for each individual KPI and multivariate analysis for a pool of KPIs that measure the same type of impact (e.g., environmental, societal, or economic). Grouping similar KPIs in this way will help reduce these risks while still allowing for interpretable and meaningful comparisons across Living Labs and measures, even when certain local KPIs have limited data. Furthermore, if the implemented measures alone do not sufficiently explain the observed differences in KPI outcomes, we will consider incorporating additional variables that capture the specific context of each Living Lab – such as population size, baseline modal split, or indicators of local mobility culture and habits – to improve the explanatory power and robustness of the analysis.

We also differentiate and quantify short-term and long-term impacts. KPIs that reflect user behaviour and perceptions, such as user satisfaction, perceived travel time, and intention level to use NSM modes, are expected to show quick responses and will provide insights into the immediate effectiveness of the measures. In contrast, KPIs related to structural or more gradual changes, such as greenhouse gas emissions, congestion and travel delay, and the energy consumption ratio, will help assess the longer-term sustainability and broader impacts of the interventions.

3.2 Multi-criteria Decision Analysis Framework

This section develops the methodological framework for evaluating sustainable mobility policies called “business activities” using the PROMETHEE-GAIA (Preference Ranking Organisation METHod for Enrichment Evaluations - Geometrical Analysis for Interactive Aid) method in a multi-city, multi-stakeholder context. As SUM Living Labs adopt diverse strategies to promote sustainable transport, decision-making becomes complex due to varying local objectives, political environments, and stakeholder priorities. Multi-Criteria Decision Analysis (MCDA) enables decision-makers to evaluate multiple, often conflicting, criteria in a structured way. PROMETHEE-GAIA is particularly well-suited for this purpose due to its capacity for handling both qualitative and quantitative data, and for facilitating participatory decision processes.

3.2.1 Foundations of Multi-Criteria Decision Analysis (MCDA)

Multi-Criteria Decision Analysis (MCDA) focuses on ranking concrete alternatives from best to worst based on multiple and often conflicting criteria. MCDA addresses the theory and methodologies capable of solving complex problems encountered across various domains such as management, business, engineering, science, and other human activities. Its primary objective is to structure and formalize decision-making processes in a transparent and coherent manner.

The need for MCDA comes from the inherent complexity of real-world decision problems, where the evaluation of potential alternatives must be carried out from multiple perspectives, sometimes involving subjective elements. Data can often be imprecise, uncertain or simply unavailable and most decision situations also involve multiple stakeholders with differing interests and priorities. MCDA provides a framework to structure these problems, enabling a comprehensive consideration of the multidimensional aspects and the variety of stakeholders involved through an aggregated evaluation.

Unlike simple decision-making, MCDA is a decision support activity, where the process leading to the decision is just as important as the outcome itself. MCDA methods generally involve several steps, including the identification and analysis of the problem, the formulation of alternatives, the development of relevant evaluation criteria, the construction of an evaluation matrix, and the aggregation of information to obtain an overall assessment. Criteria represent an operationalization of the decision-makers’ objectives and sub-objectives, enabling the assessment of each alternative’s contribution to specific goals.

Different types of decision problems can be addressed through MCDA, such as selecting the best alternative, ranking all alternatives, sorting or classifying alternatives into categories, or simply describing them according to a set of criteria. Methods such as PROMETHEE, ELECTRE, AHP, MAUT, TOPSIS, and VIKOR have been developed to meet these various types of decision problems. Ultimately, MCDA aims to make complex situations more transparent and to support the selection of an alternative that balances diverse and often conflicting objectives.

3.2.2 Comparison of Multi-Criteria Decision Analysis methods

This section presents a selection of commonly used MCDA methods and positions PROMETHEE-GAIA within this methodological landscape.

The Analytic Hierarchy Process (AHP) is one of the most widely applied MCDA methods. It is based on pairwise comparisons between criteria and alternatives, using a linguistic scale to assess relative importance. AHP produces a single synthesis score for each alternative, facilitating a straightforward ranking. While intuitive and easy to implement, AHP can become inconsistent with a large number of comparisons, and the scale's subjectivity may affect robustness.

ELECTRE (Élimination Et Choix Traduisant la REalité) is an outranking French method that handles incomparabilities and strong conflicts between alternatives. It relies on pairwise comparisons and defines thresholds for indifference, preference, and veto. ELECTRE is particularly useful when poor-quality data or strong disagreements between criteria need to be accounted for. Its relational preference structure and ability to express non-compensatory judgements make it robust, though potentially harder to interpret for non-experts.

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) ranks alternatives based on their geometric distance from an ideal solution. It is computationally simple and easy to interpret. However, it assumes full compensability between criteria and does not accommodate preference thresholds, which may be limiting in contexts involving qualitative judgments or stakeholder input.

VIKOR (ViseKriterijumska Optimizacija I Kompromisno Resenje) is a Serbian compromise ranking method that emphasizes proximity to the ideal solution, while considering the maximum regret. It is suitable for ranking and selecting alternatives under conflicting criteria, yet its results are sensitive to the range and distribution of data.

MAUT (Multi-Attribute Utility Theory) is a classical approach based on utility functions defined for each criterion. It aggregates these functions into a global utility score, assuming compensatory trade-offs. While MAUT is theoretically sound, it requires significant effort to elicit precise utility values and may be less practical when stakeholder input is qualitative or when preferences are imprecise.

Other notable methods include COPRAS (COMplex PROportional ASsessment), which evaluates alternatives in proportion to their distance from the best and worst values; MULTIMOORA (MULTI-objective Optimization by Ratio Analysis plus the Full Multiplicative Form), which combines several normalization techniques; and UTA/UTADIS (UTilités Additives/UTilités Additives DIScriminantes), which learn additive utility functions from training examples. ORESTE (Organisation, Rangement Et Synthèse de Données Relationnelles) and SMARTS (Simple Multi-Attribute Rating Technique using Swings) are ordinal-based techniques that require minimal input but offer less granularity.

PROMETHEE-GAIA distinguishes itself by balancing methodological rigor with interpretability. As an outranking method, it supports partial preference structures and avoids oversimplification through forced compensation. The GAIA plane enhances stakeholder understanding by visually mapping the relationships between alternatives and criteria, making it particularly valuable in participatory contexts.

In summary, AHP excels in accessibility and simplicity, ELECTRE in robustness against poor data, TOPSIS and VIKOR in quick synthesis, and MAUT in theoretical completeness. PROMETHEE-GAIA offers a unique combination of transparency, flexibility, and participatory potential, making it especially suited to the complex evaluations found in sustainable urban mobility planning.

3.2.3 PROMETHEE-GAIA Method

PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluations) and GAIA (Graphical Analysis for Interactive Assistance) appear particularly well-suited for the evaluation of transport policies across different cities involving multiple stakeholders, for several reasons supported by the literature.

Firstly, PROMETHEE is a Multi-Criteria Decision Analysis method that can handle both quantitative and qualitative criteria (Bauk et al., 2015). This is crucial in the context of urban transport policies, where evaluations are not limited to numerical data (such as costs or travel times), but must also integrate qualitative aspects such as perceived environmental impact, quality of life, or social acceptability among different stakeholder groups. The AHP (Analytic Hierarchy Process) method has even been used in conjunction with PROMETHEE to account for a set of qualitative sub-criteria, and the validation of PROMETHEE results using AHP showed no critical differences in the ranking solutions (Bauk et al., 2015). This suggests robustness in PROMETHEE's ability to handle diverse types of criteria.

Secondly, PROMETHEE allows for the incorporation of user perceptions. Transport policy evaluation necessarily involves multiple stakeholders such as citizens, businesses, public authorities, who hold diverse perspectives and preferences. As an outranking method, PROMETHEE supports the construction of preference relations between alternatives (in this case, transport policies) based on how each criterion is valued by these stakeholders (Anagnostopoulos et al., 2003).

Thirdly, GAIA, which is used in conjunction with PROMETHEE, provides an interactive visual modelling technique. This graphical dimension is essential for facilitating communication and enhancing understanding of evaluation results among stakeholders, who may vary widely in their technical expertise. The GAIA plane makes it possible to visualize both the policies and the criteria, helping to identify trade-offs and areas of convergence among stakeholder preferences.

Finally, the application of PROMETHEE and GAIA in the evaluation of transport projects demonstrates their relevance to complex decision problems. These often involve demographic, social, urban, economic and environmental dimensions, all of which are directly pertinent when evaluating transport policies at the city scale level.

3.2.4 Model Building and Data Collection

The construction of the decision model is a critical phase in the application of the PROMETHEE-GAIA method. It involves the precise definition of the evaluation framework, the selection and structuring of relevant data, and the preparation of the mathematical operations necessary for performing the Multi-Criteria Decision Analysis.

The evaluation framework is structured as a multi-scale multi-criteria system, designed to bridge the gap between high-level strategic goals and the operational details of individual business activities. It relies on a 4-layers architecture where business activities are described in terms of the measures they implement (such as infrastructure development, pricing schemes or MaaS services), each of which contributes to specific KPIs reflecting measurable project outcomes. These KPIs are then aggregated into broader strategic goals, capturing overarching policy objectives such as emission reduction, public transport quality or multi-modality. The model supports flexible analysis, allowing for both detailed assessments at the KPI level and higher-level strategic evaluations based on goals, while also accommodating sensitivity analysis and uncertainty modelling.

This section outlines the process step by step, from the initial problem formulation to the final preparation of data for PROMETHEE application.

3.2.4.1 Definition of Alternatives and evaluation criteria

The first step consists of identifying the 4 layers of the model architecture. In the context of the SUM project, we identified these 4 components:

1. Business activities

BA 1	Integrated Mobility Service Platform (MaaS)	    
BA 2	Demand-Responsive and On-Demand Mobility	  
BA 3	Mobility Hub Development	   
BA 4	Active Mobility Promotion	  
BA 5	Incentive-Based Programs	   
BA 6	NSM Integration into Mobility Ecosystem	  
BA 7	Public Engagement and Awareness Initiatives	 
BA 8	Enhanced Data Collection and Analysis	
BA 9	Electric and Low-Emission Infrastructure Expansion	  
BA 10	PT Scheduling and Frequency Optimization	 

Table 3 MCDA Framework component 1 business activities

2. Push and pull measures

Each Living Lab or city has implemented push and pull measures.

Push/pull measures introduced in the Living Labs
Push interventions
Congestion charges
Parking charges
Restricted parking
Limited traffic zone / Pedestrianisation of streets
Parking supply management
Speed limits
Pull interventions
Mobility hubs (see task T3.2)
Scheduling integration in MaaS services (see task T2.3)
Ticketing integration in MaaS services (see task T3.4)
Improved NSM infrastructure, e.g. bike lanes & "park & ride"
On demand vehicle sharing action plan
Nudging (gamification or rewards)
Dynamic pricing of NSM
Improved information about the availability of shared modes
Introduction of new NSM services (ex. bike-sharing)
Introduction of new PT infrastructures/lines (ex. e-buses, LRT)
Streets retrofitting/introduction of priority lanes
Dedicated parking spaces for carsharing/micromobility
Widening PT geographical area
Central PT planning and construction program

Table 4 MCDA Framework component 2 push and pull measures



These push and pull measures are going to be categorized thanks to the previously mentioned business activities. The mapping between these push and pull measures and their introduction in the Living Labs is still a work in progress.

3. Goals

Goals have been defined for the project and represent Living labs needs and priorities for the SUM project.

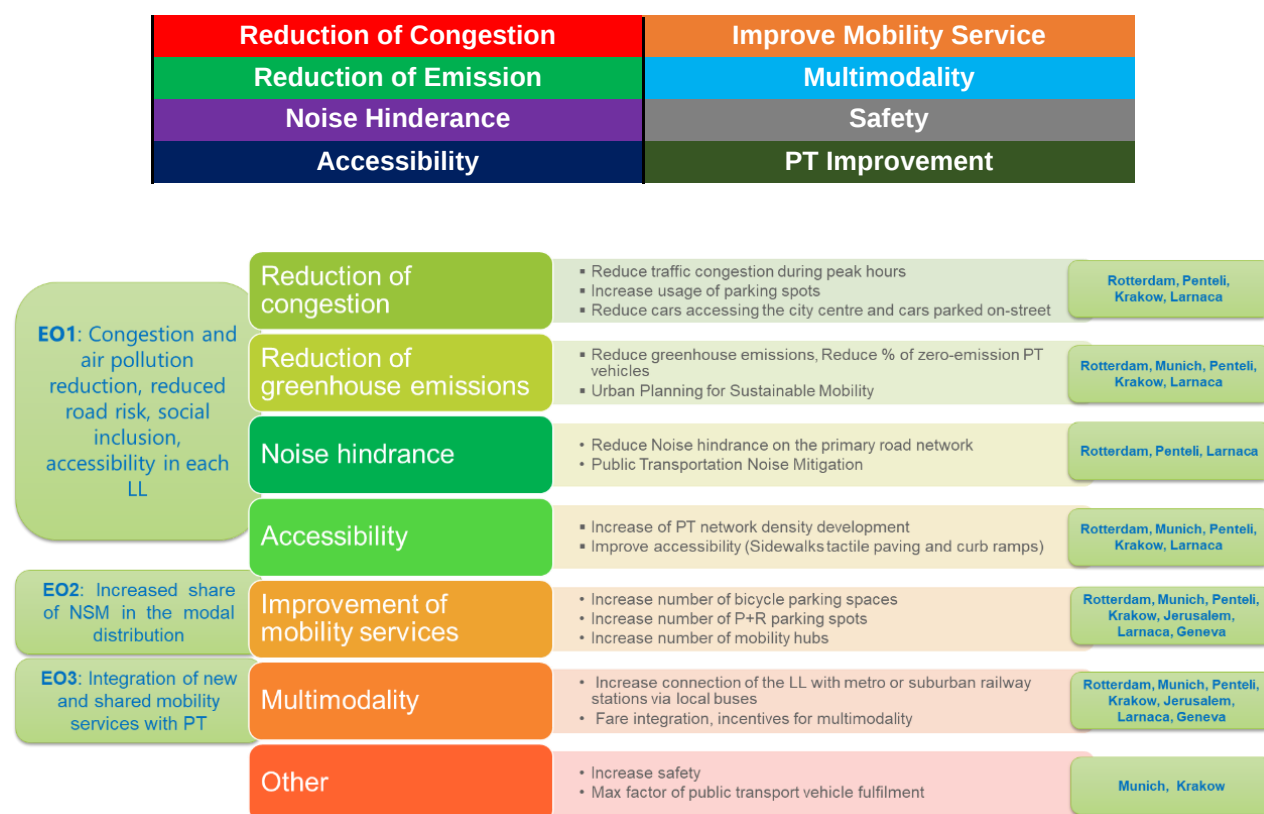


Table 5 MCDA Framework component 3 Goals

4. KPIs

These goals can be evaluated thanks to a combination of KPIs that are measured before and after the implementation of the push and pull measures.

Goals	KPIs used to evaluate goals (from D1.2_KPI Review)				
Reduction of Congestion	Average congestion and delay index	Car access to city centre	Usage of parking spots		
Reduction of Emission	Modal split	CO2 emissions	Energy efficiency	Air pollution	
Noise Hinderance	Modal split	Type of vehicles	Noise Hindrance		
Improve Accessibility	Level of integration	Acceptance rate	Intend to use	Access time by walking	Accessibility ratio



Improve Mobility Service	share (%) of road length adapted for active mobility	Number of mobility hubs	Number of bicycle parking space	Number of P+R parking spots	
Improve Multimodality	Number of available services per mobility hub	DTD travel time for multimodal transport modes sequences	Travel cost ratio	Level of integration	
Improve Safety	Perceived safety	User satisfaction			
Improve Public Transport	Travel time	Perceived travel time in NSM +PT	Perceived affordability	Social welfare	

Table 6 MCDA Framework component 4 KPIs

The availability of these KPIs plays a critical role in ensuring the robustness and comparability of the results. The PROMETHEE method requires a complete dataset for each business activity in order to compute preference flows and visualize trade-offs in the GAIA plane. When a KPI linked to a goal is missing, it disrupts the balance of the evaluation making it impossible to fairly assess that goal in comparison to others. Therefore, goals with incomplete KPI data cannot be fully assessed.

This has practical implications for the analysis across different Living Labs. As each Living Lab may have different levels of data completeness due to varying local implementations or project progress, the sets of KPIs used to define goals can differ accordingly. Consequently, the outcomes of the PROMETHEE-GAIA analysis are not strictly comparable across Living Labs unless the same set of KPIs is available. It is important to acknowledge that the insights generated are context-dependent and constrained by the availability of relevant and reliable data at the time of analysis.

To accommodate this reality, a degree of flexibility is necessary in the selection of KPIs. While a consistent set of indicators is ideal, adjustments may be made based on what is available in each Living Lab. In the final deliverable D5.2, we will document which KPIs were used per goal and per Living Lab, as well as any instances where goals were excluded due to missing data. The availability of data at the time of writing this final report may also determine which KPIs will be used in the analysis. This will allow readers to interpret the results with a full understanding of their data-driven limitations and ensure traceability of the analysis.

3.2.4.2 Structuring the Evaluation Matrix

Once the alternatives and criteria are defined, a **performance matrix** is constructed, where each alternative is evaluated against each criterion. The values in this matrix can come from:

- Empirical measurements (e.g., emissions in tons/year): KPIs will come from experiments from each Living Lab
- Expert judgement or stakeholder ratings (standardized to numerical scales).

3.2.4.3 Criteria Weighting and sensitivity analysis

Each criterion is then assigned a weight representing its relative importance in the decision process. This can be determined:

- By decision-makers individually or through consensus,

- Through structured methods such as AHP, direct rating, or entropy weighting,
- In participatory settings via stakeholder workshops.

Weights are normalized so that their sum equals 1.

After doing the evaluation process described in the following section, a sensitivity analysis will be conducted on the weights assigned to the criteria since it is essential to assess the robustness of the ranking. This process involves systematically varying one or more weights to observe how these changes affect the final ranking of alternatives. It allows us to identify which criteria have the most influence on the ranking and which are relatively stable. If minor changes in weight lead to significant shifts in ranking, it indicates that the criterion is highly sensitive and may play a decisive role in the evaluation. If the overall ranking remains consistent despite such variations, the model can be considered robust. Sensitivity analysis also helps to detect potential tipping points where preferences might change, offering valuable insights for negotiation and consensus-building among stakeholders.

3.2.4.4 Preference Functions

PROMETHEE requires a **preference function** $P_j(a,b)$ for each criterion j , which quantifies the degree of preference of alternative a over b with respect to criterion j . It transforms the difference of performance $d_j(a,b)=f_j(a)-f_j(b)$ into a value between 0 and 1, representing the strength of the preference.

There are six classical preference functions (Brans et al., 1986):

Type	Description	Parameters
1. Usual	Any non-zero difference implies strict preference	None
2. U-shape	Preference exists only beyond a certain threshold	Indifference threshold q
3. V-shape	Preference increases linearly from 0 to 1	Preference threshold p
4. Level	Step function with indifference and preference thresholds	q, p
5. V-shape with indifference	Linear with flat zone for small differences	q, p
6. Gaussian	Smooth curve based on standard deviation-like shape	s (slope)

Table 7: Six classical preference functions for PROMETHEE method

Depending on the KPIs, different preference functions will be defined for each criterion, according to the suitability. Level functions are suitable for 1–5-point scale qualitative criteria while V-shape functions are suitable for continuous quantitative criteria.

3.2.4.5 Pairwise Preference Index

Once a preference function is defined for each criterion, the **global preference index** $\pi(a,b)$ is calculated as the weighted sum of preferences:

$$\pi(a,b) = \frac{1}{\sum w_j} \sum_{j=1}^k w_j P_j(a,b)$$

Where:

- **a** and **b** are two alternatives,
- **k** is the number of criteria,
- w_j is the weight of criterion **j**,
- $P_j(a,b) \in [0,1]$ is the preference function value for criterion **j**.

3.2.4.6 Computation of Positive and Negative Preference Flows

PROMETHEE aggregates the pairwise preferences into global outranking flows for each alternative **a**, over the entire set of alternatives **A**, with $|A|=n$

Positive Flow (Φ^+):

$$\Phi^+(a) = \frac{1}{n-1} \sum_{i=1}^n \pi(a,b) \text{ with } a \neq b$$

This measures how much alternative **a** outranks the others.

Negative Flow (Φ^-):

$$\Phi^-(a) = \frac{1}{n-1} \sum_{i=1}^n \pi(b,a) \text{ with } a \neq b$$

This reflects how much alternative **a** is outranked by the others.

Net Flow (Φ):

$$\Phi(a) = \Phi^+(a) - \Phi^-(a)$$

A high net flow indicates a preferable alternative.

3.2.4.7 Ranking: PROMETHEE I and II

- **PROMETHEE I** uses Φ^+ and Φ^- separately to establish a partial ranking. This may include:
 - strict preference (if $\Phi^+(a) > \Phi^+(b)$ and $\Phi^-(a) < \Phi^-(b)$)
 - indifference (equal flows),
 - incomparability (one better on Φ^+ and the other better on Φ^-).
- **PROMETHEE II** uses the net flow $\Phi(a)$ to derive a complete ranking from best to worst.



3.2.4.8 Notes on Interpretation

- The scale of $\emptyset$ is relative: comparisons are only meaningful within the set of evaluated alternatives.
- Differences in $\emptyset$ values indicate the strength of the preference but not absolute utility.
- In PROMETHEE I, incomparability is an important feature because it is reflecting real-world complexity and uncertainty.

3.2.5 Visualization and Principal Component Analysis (PCA)

3.2.5.1 GAIA plane

The GAIA plane is constructed from the weighted evaluation matrix using a dimensionality reduction technique conceptually similar to PCA. It projects both alternatives and criteria into a lower-dimensional space (typically two dimensions), allowing decision-makers to:

- Observe the relative positioning of alternatives,
- Understand conflicts or alignments between criteria (based on the angle between vectors),
- Identify the decision axis (pi vector), which reflects the direction of the most preferred alternatives given the weights.

GAIA is especially effective in facilitating communication with stakeholders, offering a geometric intuition of the trade-offs involved in multi-criteria decisions. However, the plane is specific to PROMETHEE's internal logic and weighting scheme.

3.2.5.2 Role of PCA as an External Validation Tool

While the GAIA plane serves as a core graphical tool for interpreting the results of PROMETHEE, it can be enriched and validated through the use of PCA.

PCA is a statistical technique used to reduce the dimensionality of a dataset while preserving as much variance as possible. When applied to the same evaluation matrix (without PROMETHEE specific transformations), PCA:

- Identifies principal components as linear combinations of criteria that explain the largest variation in the data,
- Reveals correlations between criteria,
- Clusters alternatives based on similarity of performance profiles.

Unlike GAIA, PCA is purely data-driven and does not integrate criteria weights. This can be used as an external validation tool to check:

- Whether the direction of the decision axis in GAIA aligns with the principal components,
- Whether clusters of alternatives identified in PROMETHEE rankings are consistent with those in the PCA plot,
- If certain criteria dominate the variance and may unduly influence the PROMETHEE outcomes.

By comparing GAIA and PCA visualizations, we will be able to have more information, and we can gain deeper insights:

- If both planes show similar patterns, this reinforces the robustness of the results.
- If differences arise, this may indicate overweighting or dominance of specific criteria in PROMETHEE.
- PCA may suggest the need to refine the criteria set (by identifying redundancies).

In summary, PCA enhances the transparency of the PROMETHEE-GAIA process by offering an external statistical check. It supports a multi-angle interpretation of complex decision problems and strengthens the reliability of conclusions drawn from the Multi-Criteria Decision Analysis.

3.2.6 Data collection

This section describes the data that will be used to carry out the Multi-Criteria Decision Analysis, including the weighting of criteria and the evaluation matrix

3.2.6.1 Weights

To determine the weights of the evaluation criteria, interviews are conducted with stakeholders for each of the project's Living Labs. During these interviews, each stakeholder will be asked to define their priorities, as illustrated in the following table, using the direct weighting method.

According to your organization's role and responsibilities, could you please score the importance of following objectives? With a perspective of the greatest benefits to users and citizens	
Goals of Project SUM	Score of importance for each goal (from 0 to 100)
<u>Reduction of Congestion</u>	0-100
<u>Reduction of Emission</u>	0-100
<u>Noise Hinderance</u>	0-100
<u>Improve Accessibility</u>	0-100
<u>Improve Mobility Service</u>	0-100
<u>Improve Multi-modality</u>	0-100
<u>Improve Safety</u>	0-100
<u>Improve Public Transport</u>	0-100

Table 8 Interview question to define the weights for MCDA analysis

These weights are then normalized and used in the PROMETHEE method as ratios of importance.



3.2.6.2 Scoring: Integrating Qualitative and Quantitative Evaluations

A key strength of the proposed methodological framework lies in its ability to integrate both qualitative and quantitative assessments into a coherent Multi-Criteria Decision Analysis. This dual approach ensures that both stakeholder perceptions and empirical data are meaningfully incorporated into the evaluation process.

3.2.6.2.1 Qualitative Evaluation: Capturing Local Knowledge and Perceptions

The first level of analysis involves a qualitative evaluation, which is essential in contexts where subjective judgements, contextual nuances, and local priorities strongly influence policy outcomes. This evaluation is conducted with the active participation of local stakeholders such as municipal authorities or transport operators through structured interviews operated by WP5.3.

Stakeholders are invited to:

- Express their perceptions regarding the effectiveness of each policy measure
- Identify context-specific constraints or enablers that may not be reflected in quantitative data

Overall, how effective do you believe the Push and Pull measures are in achieving their objectives?

1. Not effective at all
2. Slightly effective
3. Moderately effective
4. Quite effective
5. Extremely effective

Goals of SUM Project	BA1: Integrated Mobility Service Platform (MaaS)	BA2: Demand-Responsive and On-Demand Mobility	BA3: Mobility Hub Development	BA4: Active Mobility Promotion
Reduction of Congestion	1-5	1-5	1-5	1-5
Reduction of Emission	1-5	1-5	1-5	1-5
Noise Hinderance	1-5	1-5	1-5	1-5
Improve Accessibility	1-5	1-5	1-5	1-5
Improve Mobility Service	1-5	1-5	1-5	1-5
Improve Multimodality	1-5	1-5	1-5	1-5
Improve Safety	1-5	1-5	1-5	1-5
Improve Public Transport	1-5	1-5	1-5	1-5

Table 9 Interview questions to define qualitative evaluation – local knowledge and perceptions



To ensure comparability, qualitative assessments are formalized using standardized rating scales that are later translated into numerical inputs for PROMETHEE. This allows the qualitative data to be included in the same analytical structure as the quantitative data.

This process also facilitates stakeholder engagement, increases the transparency of the evaluation, and enhances the legitimacy of the results.

3.2.6.2.2 *Quantitative Evaluation: Evidence-Based Assessment*

The second level of analysis consists of a quantitative evaluation based on objective and measurable data. These data include indicators mentioned in section 3.2.4.1 Definition of Alternatives and evaluation criteria.

Quantitative indicators are normalized and structured into an evaluation matrix, allowing PROMETHEE to perform pairwise comparisons and generate rankings of the policy alternatives.

The accuracy and completeness of the quantitative dataset are essential for ensuring analytical robustness.

3.2.6.2.3 *Comparing the two evaluation sets*

By integrating both types of evaluation, the methodology provides a more comprehensive understanding of the trade-offs involved in sustainable mobility policy decisions. A key added value lies in the ability to compare the qualitative and quantitative results:

- Do stakeholder preferences align with the evidence-based outcomes?
- Are there significant discrepancies between perceived and actual impacts?
- Which alternatives perform consistently well across both assessments?

Such comparisons help ensure that the selected alternatives are not only technically sound but also socially accepted.

This layered evaluation enhances the transparency, robustness, and inclusiveness of the decision-making process and reinforces the role of MCDA not just as a ranking tool, but as a true decision support system.

3.2.7 Implementation Tools and Process of MCDA

The successful application of the PROMETHEE-GAIA method and its complementary analyses relies on the use of appropriate tools for both computation and visualization. In this methodological framework, two main software environments are used in combination: **Visual PROMETHEE** for the implementation of the PROMETHEE-GAIA analysis, and **R** for conducting the Principal Component Analysis (PCA).

3.2.7.1 Visual PROMETHEE: Decision Analysis Software

Visual PROMETHEE is a dedicated software platform designed specifically for Multi-Criteria Decision Analysis using the PROMETHEE and GAIA methods. It offers a user-friendly interface for:

- Defining evaluation matrices (alternatives-criteria),
- Defining and adjusting criteria weights,
- Selecting appropriate preference functions and setting thresholds,

- Running PROMETHEE I and II analyses,
- Generating and interacting with the GAIA plane.

The software supports both partial and complete rankings, and provides graphical outputs such as ranking bars, GAIA bi-plots, and sensitivity analyses. In the context of this project, Visual PROMETHEE will be used to perform all PROMETHEE-related calculations and visualizations, including the management of multiple stakeholder weight configurations for city-specific assessments.

3.2.7.2 Complementary Statistical Analysis via PCA

In parallel, the R programming environment is used to conduct Principal Component Analysis (PCA). This open-source statistical language provides flexibility and precision for exploring the structure of the evaluation data. PCA is implemented using well-established R software packages such as FactoMineR (Lê et al., 2008), allowing:

- Analysis of the correlations between criteria,
- Visualization of the alternatives in a reduced-dimensional space,
- External validation and interpretation of GAIA patterns.

Using R ensures full control over data pre-processing, normalization, and interpretation, while enabling integration with other statistical techniques if needed. It also allows us to have complementary visualizations.



3.3 Graphical interface

The stakeholder interface is a central component of this task, designed to facilitate the exploration, interpretation, and communication of the project's analytical results. Its main goal is to provide an accessible and interactive environment where stakeholders – such as city planners, policy-makers, and mobility service providers – can examine the impact of implemented measures across different Living Labs.

The interface will present both the input data (implemented measures, selected KPIs, and city-specific characteristics) and the analytical results (estimated impacts, and comparisons across cities). Special emphasis will be placed on clarity and transparency to ensure the results can inform future mobility planning and decision-making.

3.3.1 Key Features

The graphical interface will focus on the goals and objectives below. Some examples of visualizations foreseen can be observed in Appendix A: Non-contractual examples of data presentation in the graphical interface .

3.3.1.1 Analyse and compare KPIs and Living Labs results

The platform will allow users to view key performance indicators (KPIs) for each Living Lab, both before and after intervention (see **Erreur ! Source du renvoi introuvable.**), along with visual indicators that highlight changes (increase vs decrease). The cross-city analysis will compare the performance of different KPIs across multiple Living Labs (Figure B:), with the flexibility to filter by specific KPI (Figure C) or by categories such as environmental, societal, or economic.

Additionally, city context insights of each Living Lab will be displayed, to help understand the differences in KPI values (smaller city, higher density, etc). This multifaceted approach will empower stakeholders to make informed decisions based on the performance of interventions across different contexts.

3.3.1.2 Comprehensive short- and long-term economic impact assessment

The goal is to provide a clear and thorough evaluation of the economic, environmental, social, and technical impacts of mobility solutions implemented across various participating Living Labs. This will include the outputs from the regression models defined in Section 3.1 Impact Analysis, that estimate the contribution of each push/pull measure to the key performance indicators (KPIs).

An interactive visualization interface will be developed to facilitate the exploration of these results. The interface will link specific push/pull measures implemented in each Living Lab to the corresponding impact ratios (Figure D:), allowing users to examine how each measure contributes to individual KPIs as well as aggregated KPI by domain or categories (e.g., social, economic, environmental).

3.3.1.3 Multi-Criteria Decision Analysis with different stakeholders' perspective

Leveraging the PROMETHEE method described in section 3.2 Multi-criteria Decision Analysis Framework, the platform will evaluate and compare alternative solutions based on multiple criteria. The platform will allow users to compare multiple solutions based on a set of predefined criteria and goals that align with the broader project objectives. The user will also have the possibility to view results from different perspectives (different stakeholders' viewpoints, see Figure E:, Figure F, Figure G:). For example, city planners might prioritize economic impacts, while environmental advocates could focus on emissions' reduction.

In addition, the platform will provide dynamic features to customize the weights of individual criteria to simulate how stakeholder priorities could influence the ranking of different solutions. This interactive feature allows for an analysis of multiple scenarios by testing various combinations of criteria weights and hence helps the decision-making process.

3.3.1.4 Dynamic data for turnkey graphical interface

Taking into consideration that the KPIs after implementation are scheduled to be available by the end of the project, the platform needs to be dynamic and ready to be integrated with the KPIs values as the data collection process is completed. This data collection process is described in deliverables D4.1 and D4.2 by every participant Living Lab.

The development process of the interface will be done with hypothetical values; different results will be considered so that the charts and maps are updated accordingly. As the KPI values become available for every Living Lab, the data will be integrated and the results of the impact and the Multi-Criteria Decision Analysis previously described will be updated automatically. The goal is that the graphical interface results evolve as data becomes available. There will be mention of expected and missing KPIs, so that stakeholders can view the results and are informed about the Living Lab data collection status.

3.3.2 Technical Implementation

The development of the interface will be guided by principles of usability, accessibility, and transparency. It will be designed to accommodate both expert users and non-technical stakeholders. The visualizations will be interactive and explanatory, using intuitive charts, maps, and filters to support data exploration.

The platform will be available online as a web application, it will be accessible through the existing SUM project websites which are available at: sum-project.eu and sum-odp.eu.

Regarding the technical stack, modern frameworks will be used in order to deliver a modern and flexible platform:

- Python environment for the back-end API, to deliver data and run model calculations for data analysis
- Nodejs environment for front-end web application, with dynamic visualization libraries like Leaflet for maps and D3 for charts.
- PostgreSQL database, which will save the KPIs data and also the analysis results
- The website will be hosted within INRIA infrastructure and publicly available during the development process. When the graphical interface is ready to go live, we will synchronize with SUM project stakeholders to make sure the resources remain available after the end of the project.
- The web interface will comply with the visual identity of the project, as specified in deliverable *D6.1 Plan for dissemination and exploitation*
- Its content will be available in English by default, with the possibility to add new languages if required in the future
- A back-office will be available only for administrators, to fill the KPIs values for every Living Lab as they become available, and then execute the models to update the data analysis results. A link with the SUM deliverable D1.5 Open Data Platform database will be considered.



4 Conclusions

The methodology described in this deliverable provides a rigorous and participatory framework to assess the complex impacts of NSM solutions within the SUM project. By combining KPI metrics, stakeholder perceptions, and contextual indicators, it enables a deeper understanding of performance and impacts. This allows to clarify what is working, where it is effective, and why the observed outcomes occur.

A key requirement of this methodology is the availability and quality of data: pre and post implementation KPI values and the actual measures implemented by every Living Lab. The robustness and comparability of both the regression-based impact analysis and the PROMETHEE-GAIA evaluation are directly dependent on the availability and consistency of these datasets.

This framework not only guides the evaluation within task 5.2 within WP5, but also builds on the work conducted in WP1 (definition of KPIs and goals) and WP4 (data collection and KPI measurement). Its integration into a dynamic, interactive graphical interface ensures that insights are made accessible to decision-makers, supporting scalable, data-driven, and inclusive urban mobility planning across Europe.

5 Future work

At this stage of the project, a key limitation is the current unavailability of post-implementation KPI data. As the estimation of impact relies on comparing the "before" and "after" states, the absence of this data restricts the possibility of performing the core regression analysis and drawing robust conclusions regarding the effectiveness of the implemented measures.

In the meantime, we will begin a preliminary analysis of the available "before" KPI data. This will include exploring the structure and distribution of the indicators across Living Labs, identifying patterns and outliers, and considering potential groupings of KPIs by thematic category (e.g., environmental, societal, economic). These insights will support the early design of visualisation components in the stakeholder interface.

Additionally, the development of the interface will begin with the integration of available data and the design of foundational functionalities, including dashboards and visual summaries of baseline conditions. In addition, hypothetical data for post-implementation data will be used when required through the development process. This groundwork will ensure a smooth transition once the post-implementation data becomes available.

The bulk of the impact assessment – particularly the regression analysis aimed at isolating the effect of specific measures – and the Multi-Criteria Decision Analysis will be carried out once the after data is delivered. This upcoming data integration phase will be critical for completing the methodological work-flow and for enabling meaningful stakeholder interaction with the results. The results and conclusions will be part of future Deliverable D5.2 Overall impacts and cross-Living Labs comparison.

6 References

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Appendix A: Non-contractual examples of data presentation in the graphical interface

The following are graphical presentations of analysis from KPIs values. The graphical interface will be updated automatically as data becomes available. The values presented below are hypothetical, only for visualization purposes and do not represent actual results.

Disclaimer : KPI Dashboard, the list of KPIs and its values are fake, only for design purposes

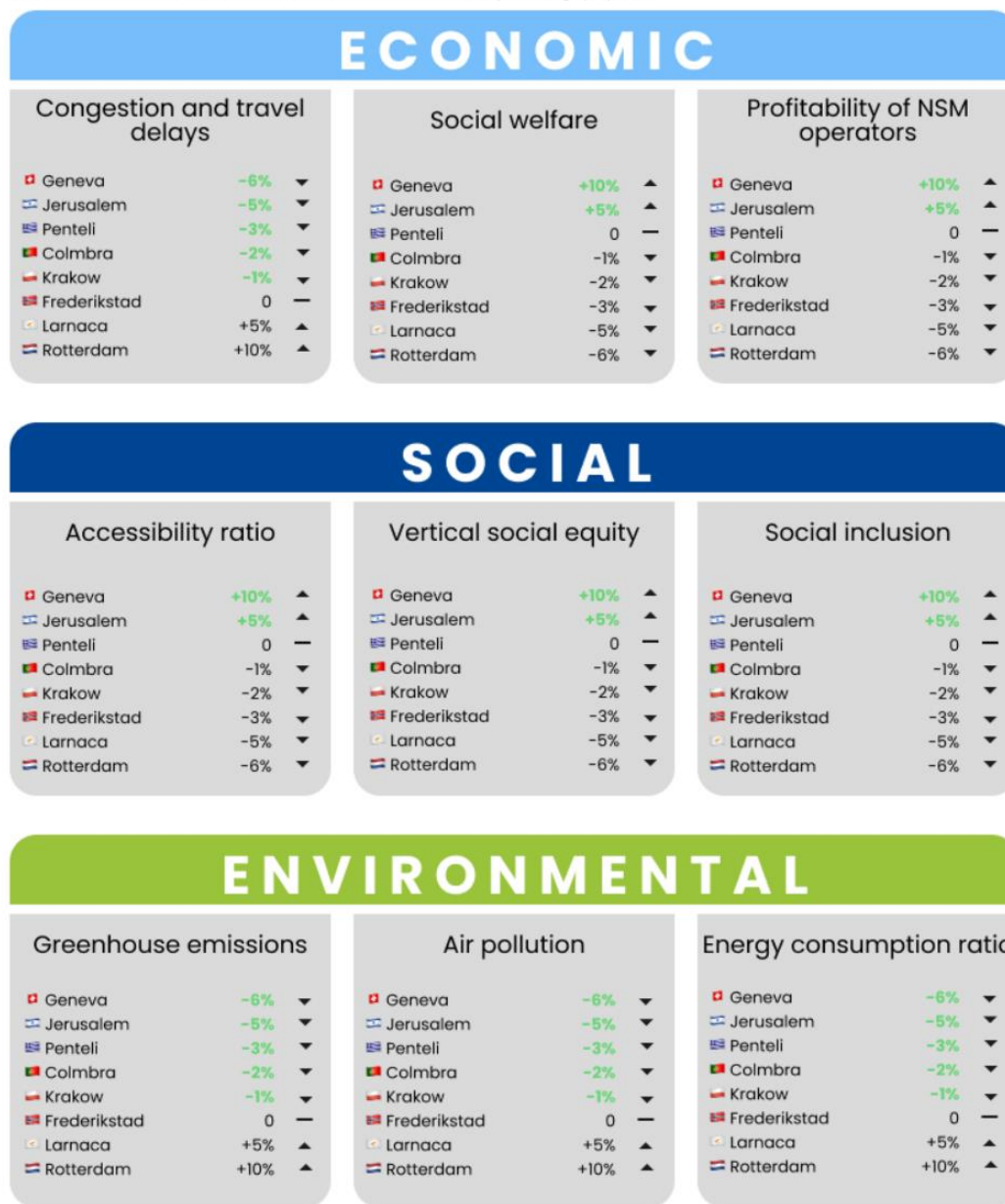


Figure A: Example of KPIs Dashboard, displaying the global results at a glance (non-exhaustive list with hypothetical values)

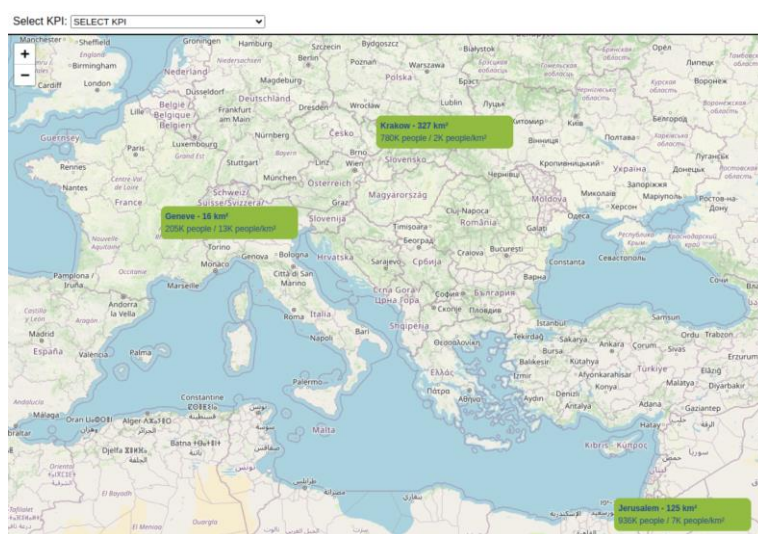


Figure B: Example of participant Living Labs and city context (surface and population)

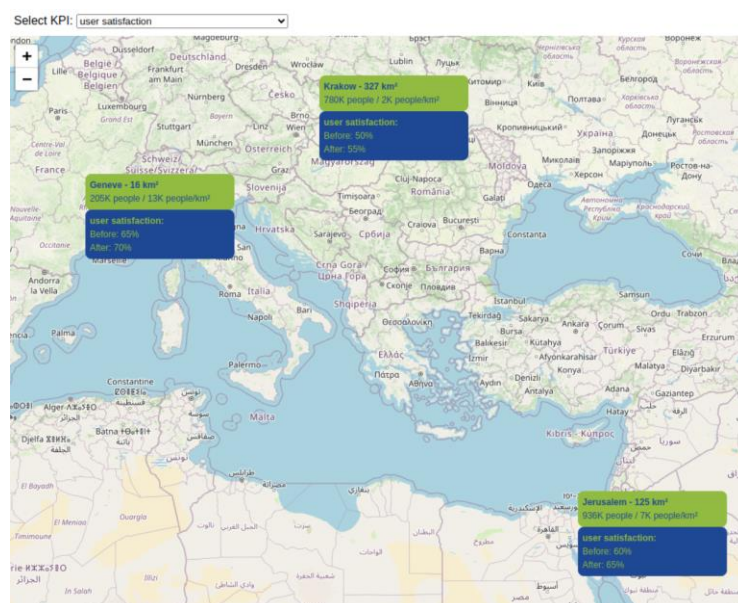


Figure C: Example of visualization of selected KPI for every Living Lab (before and after value)

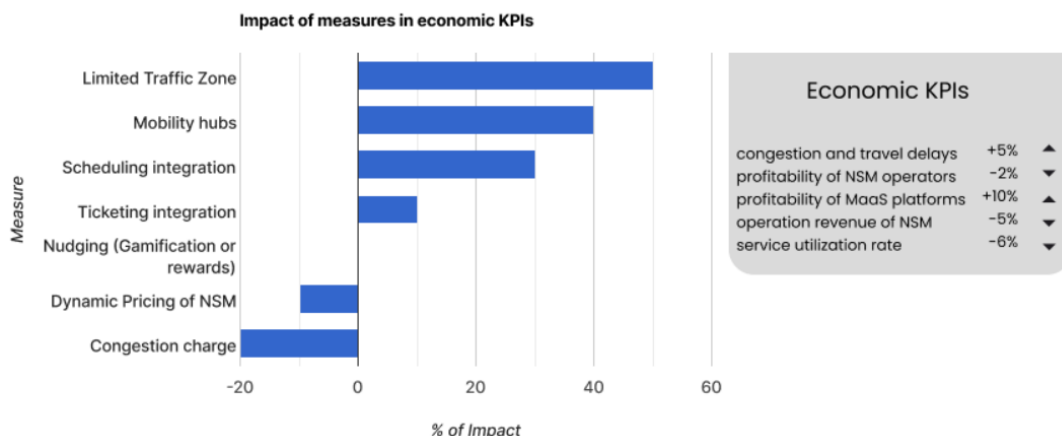


Figure D: Example of Impact assessment - identify how each measure impacted the economic results for a Living Lab

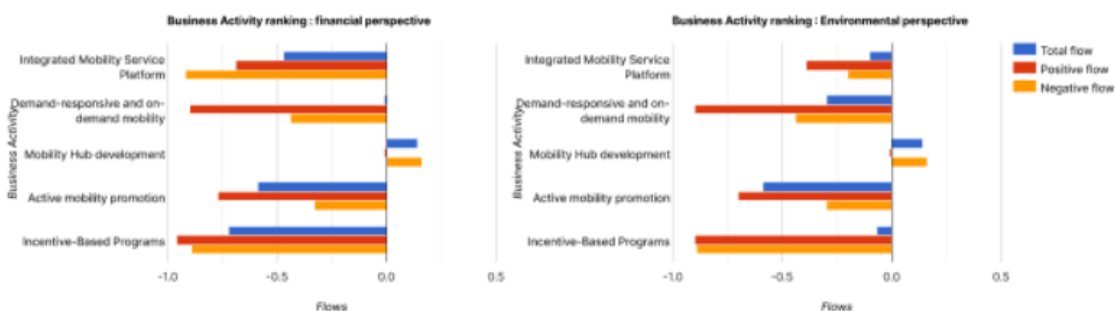


Figure E: Example of Multi-Criteria Decision Analysis - business activities ranking for total flow, comparing financial and environmental perspective

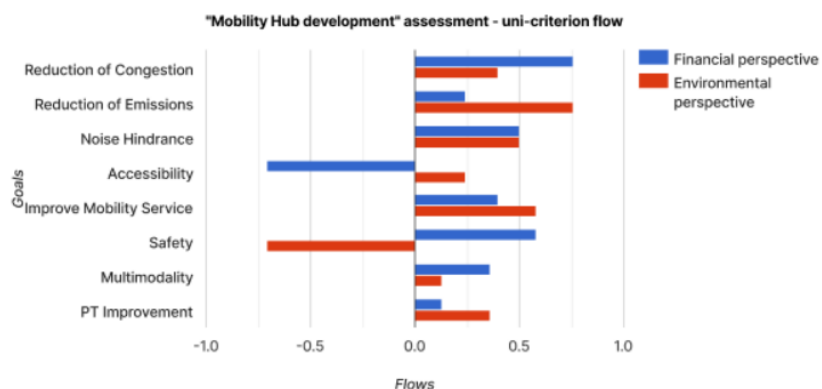


Figure F Example of business activity uni-criterion flow, goals weights by different perspectives

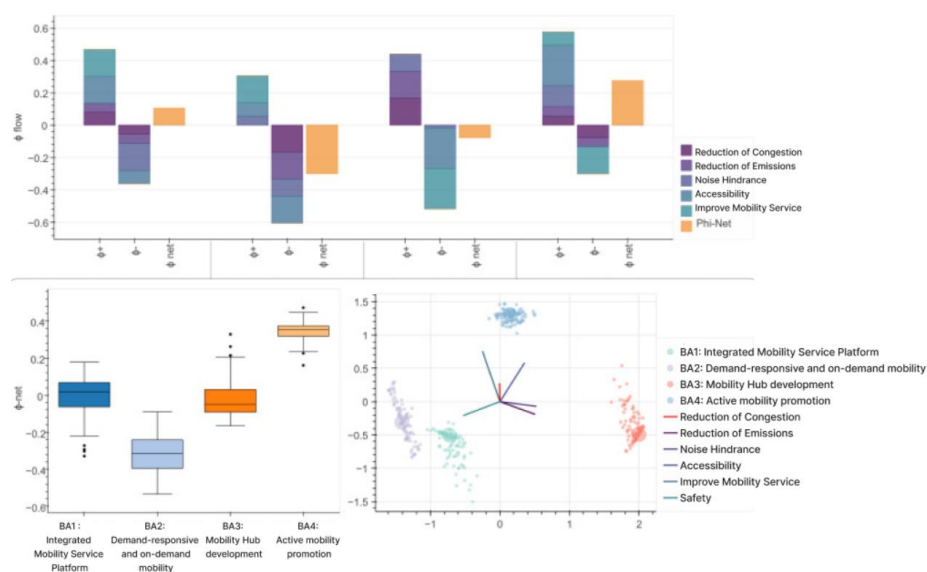


Figure G: Example of other PROMETHEE method visual presentations foreseen, using GAIA graphical presentation¹

¹ Visuals adapted from visual presentations displayed in Article PROMETHEE Cloud resources: <https://www.sciencedirect.com/science/article/pii/S2193943824000098>

