AI-based simulation model for optimal placement of micro-hubs and cargo bike pick-up stations

Deliverable 2.3

Version 1.0

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Authors:	Benjamin Gaunitz, Silvia Torres Landaverde, Viola Süß (ULEI)

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List of abbreviations

AI	Artificial Intelligence
D	Deliverable
ETL	Extract, Transform, Load
FLP	Facility Location Problem
GIS	Geographic Information System
GUI	Graphical User Interface
LIS	Leipzig Information System
ML	Machine Learning
OSM	Open Street Map
POI	Point of Interest
T	Task

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Administrative information

Basic information on the SuCoLo project and this deliverable:

Project title	SuCoLo: Fostering sustainable consumer behaviour with inclusive bicycle logistics infrastructure in urban outskirts
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Purpose of the document

This document explains the findings from Task 2.3 with the aim to create an AI-based simulation model for the optimal placement of micro-hubs and cargo bike pick-up stations as a case study in the city of Leipzig, Germany. The objective of this task is to use available open data (see data catalogue from Deliverable 2.2) to develop this model and simulate the best possible location for micro-hubs and stationary cargo bike pick-up stations. Regarding the challenges delineated in Deliverable 2.1 *Review of challenges for sustainable goods logistics and delivery solutions in urban outskirts*, the proposed locations consider inclusivity, barrier-free and social aspects. Although the simulation model is trained primarily from data from Leipzig, it would still be able to be extended for use in municipalities outside of these geographic areas. Additionally, in Task 2.4, a software prototype for bike couriers for delivery scheduling and routing is developed and can be used as a supplement to a holistic logistics concept for outskirts. The model will be further refined and developed during the pilot project phase. Further cities, such as Merano, Italy and Dresden, Germany, will be added to the model. It is worth noting that while Dresden isn't a SuCoLo pilot city, it was chosen due to its excellent cycling infrastructure and comparability to Leipzig; thus, it is relevant to be used as a benchmark for comparison.

Executive Summary

This deliverable outlines the background and development of a simulation model that identifies optimal locations for pick-up stations for parcels, cargo bike rentals and micro-hubs in suburban or outskirt areas. These aforementioned stations are designed to improve the efficiency of last-mile logistics by integrating community aspects and delivery demands. The tool primarily targets urban delivery companies, promoting not only operational efficiency, but also the context-specific needs of outskirt residents. The simulation model takes the form as an app and is based on findings from a citizen survey in the Lützschena-Stahmeln district in Leipzig, Germany conducted in 2025. Resulting from this, three personas and user stories channeled the real-world requirements to the model. Interim results demonstrate that further refinement of the model is necessitated, and further iterative developments will be included in D4.3 *Reports on the research pilots' design, implementation and results*. In the end, the simulation model will be able to be found open access under the following link:

https://github.com/Logistics-Living-Lab

1. Motivation and background

There is a lack of shops and facilities for everyday goods and services on the outskirts of Leipzig (1). Especially older people often rely on cars for their daily tasks, as walking distances can be difficult for them. In contrast, many points of interest (POIs) are in the city center, which makes driving essential for people living on the outskirts. The SuCoLo project aims to provide more eco-friendly mobility, shopping, and delivery processes for these areas in order to connect them towards the 15-minute city ideal. Therefore, the development of simulation approaches is the subject of case studies in Leipzig, Germany, later in Merano, Italy, and Dresden, Germany.

For the city of Leipzig, a new delivery concept for goods for the outskirts is developed. The concept involves home delivery via a cargo bike courier, utilizing a mobile micro-hub for last-mile parcel delivery. However, the model can also identify suitable bikesharing locations and parcel pick-up stations. The pick-up station location is based on POIs and detailed population data of the citizens in the area. The simulation model contains dynamic, social factors and preferences of the residents, such as barrier-free access to facilities, average age structure, average income, etc.

In Merano, there are currently no decentralized self-service bicycle rental systems that would allow residents and tourists to easily use bicycles or cargo bikes for short trips. The simulation model can determine suitable locations for decentralized, station-based rental systems, considering geographic and urban characteristics.

The SuCoLo *Data catalogue of suitable and available (local) data sources/data sets* (Deliverable 2.2) forms the database for this task (2). Open data from the municipal platforms of Leipzig and Merano are used to identify available population data. In addition, geodata from Open Street Map (OSM) is used to identify potential POIs.

Based on this, the simulation model indicates the best possible location for micro-hubs or self-service bike pick-up stations in urban environments and outskirts. This is presented as a heatmap, since multiple locations may be suitable under different circumstances. To evaluate the model, the cities of Leipzig and Merano are chosen as case studies in SuCoLo.

2. Problem description and model formulation

Urban outskirts are generally not very well provided with infrastructure for everyday life as they lack fixed service facilities. As a result, people living in these suburbs have different needs from those living in the city center. Mobility, shopping, and consumer behavior require either travel or ordering online. These areas are generally sparsely populated, often with an older population and fewer commercial establishments. This is why people who live on the outskirts of the city produce significantly more emissions.

Most of the pick-up stations, especially parcel lockers, are located strategically within walking distance of residential areas, which makes them easily accessible and encourages their use. They are usually located near public transport stations, business centers, financial areas, workplaces, gas stations, shopping stores, or cultural centers. Any place where there is a high concentration of people with high internet shopping frequency is attractive. These conditions are met by densely populated, inner-city areas.

For this reason, an AI-based simulation model has been developed that can consider social factors and the needs of residents on the outskirts. This allows for more sustainable, inclusive and efficient delivery of goods outside the city center. The model supports determining a suitable location for an inclusive pick-up station or a bike rental station.

2.1. Model assumptions, data and parameters for Leipzig

There is a growing demand for last-mile delivery solutions, especially in low-density outskirts. Efficiently placing pick-up stations in these areas requires consideration of logistics performance, social accessibility, and demographic data. The model uses logistic regression and location knowledge to recommend high-potential pick-up sites. It evaluates infrastructure, accessibility, community needs and delivery history to suggest adaptable station placements that are optimized to cater to stated preferences (see below).

Citizen Personas

To identify potential user groups that would use the developed solutions, three different citizen personas were generated that would depict a typical citizen living in that area along with their wants, needs, values and fears. These personas are based on a citizen survey in 2025 in Lützschena-Stahmeln, Leipzig, Germany (*n* = 158). The three target groups have been identified include an elderly retired person, a family-oriented person who works from home and lives with his family, and a young student who prefers sports and entertainment.

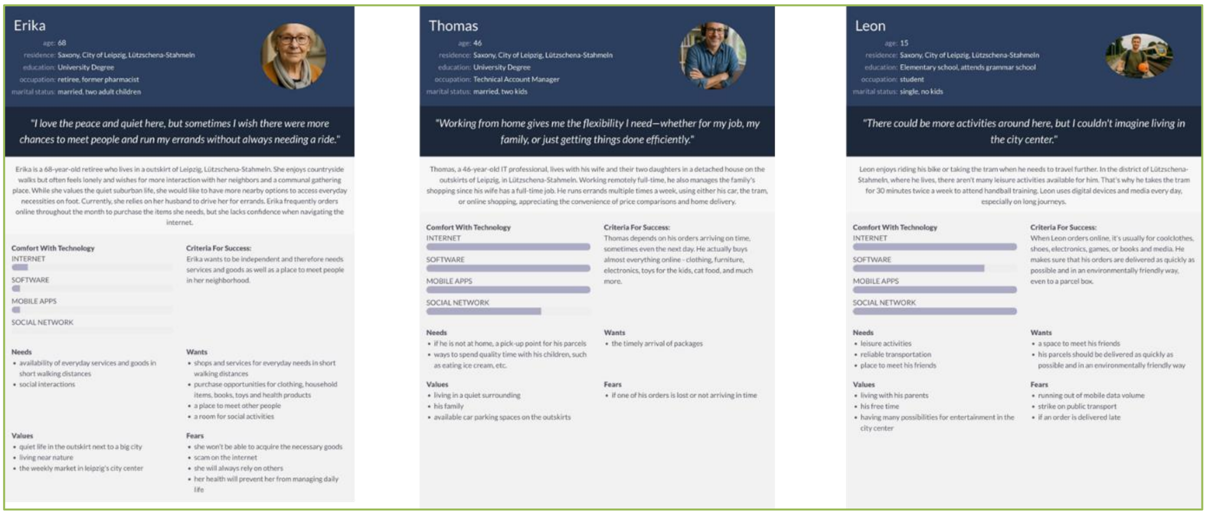


Figure 1 Three personas based on target groups

These findings can be transferred to the simulation model app as ready-made scenarios. According to their assumed requirements, features, demographics and preferences, differing weightings are transferred across the three different scenarios. Each scenario or persona then stands for a possible target group that can use the pick-up stations (table 1).

Table 1 Persona for Model Use

Persona	Demographic	Preferences and Weightings (example)	Implication
Persona 01	Older person, possibly retired or has limited mobility	• "cafe"= 6 • "cafe_wheelchair"= 8 • "community_centre"= 8 • "community_centre_wheelchair"= 10 • "education_wheelchair"= 6 • "entertainment"= 8 • "entertainment_wheelchair"= 10 • "healthcare"= 6 • "healthcare_wheelchair"= 8 • "hospital"= 4 • "hospital_wheelchair"= 6 • "library"= 10 • "library_wheelchair"= 10 • "local_business"= 8 • "local_business_wheelchair"= 10 • "marketplace"= 10 • "marketplace_wheelchair"= 10 • "parcel_locker "= 5 • "parcel_locker_wheelchair"= 5 • "post_box"= 10 • "post_box_wheelchair"= 10 • "post_office"= 10 • "post_office_wheelchair"= 10 • "restaurant"= 8 • "restaurant_wheelchair"= 10 • "station"= 10 • "station_wheelchair"= 10 • "supermarket"= 8 • "supermarket_wheelchair"= 10	A socially active, accessibility-sensitive user. Pick-up stations in the neighborhood should be highly accessible and integrated into community-oriented environments.
Persona 02	Middle-aged family-oriented person, employed	• "gas_station"= 10 • "parcel_locker"= 10 • "post_office"= 10 • "restaurant"=10 • "bicycle_rental"= 4 • "post_box"= 8 • "station"= 6 • "shopping_centre"= 10 • "local_business"= 10 • "rental_service"= 4 • "marketplace"= 6 • "supermarket"= 10 • "entertainment"= 10 • "kiosk"= 6 • "cafe"= 10	This user values logistical efficiency. Ideal pick-up station locations should minimize detours, be close to transport infrastructure, and facilitate quick parcel access.

		• "community_centre"= 8 • "education "= 10 • "library"= 8 • "healthcare"= 6	
Persona 03	Teenager, student, technology enthusiast	• "parcel_locker"= 10 • "post_office"= 10 • "restaurant"= 4 • "bicycle_rental"= 10 • "post_box"= 4 • "station"= 10 • "shopping_centre"= 10 • "local_business"= 10 • "supermarket"= 10 • "entertainment"= 10 • "kiosk"= 2 • "cafe"= 4 • "community_centre"= 6 • "education"= 10 • "library"= 8	This is a convenience-driven user with a mild preference for socially vibrant areas. Suitable pick-up station locations should balance functionality and lifestyle.

All three personas value proximity to essential services (parcel lockers, post office, etc.). There is a strong trend toward integrating social infrastructure (cafés, markets, libraries, etc.). Accessibility (especially Persona 01) is critical for inclusivity. The model should support filtering and customization to each persona’s needs.

User Stories

Additionally, user stories were outlined that represent the requests of the bike courier companies who are the users of the simulation model app. With these user stories, the aim and functionality of the application are clearly defined. It serves as a guide to help software developers understand the app's content and is a basis for usability testing to further refine the app.

Table 2 User stories for bike courier company users of the app

Nr	User story
01	As a bike courier, I want to quickly navigate through the app So that everyone from my company can use it.
02	As a bike courier, I want to see suggested locations based on certain factors, like average age, population density, etc. So that I can create the target group of parcel deliveries in detail.
03	As a bike courier, I want to use the app update by new input factors (automatically) So that I can rely on actual information about finding a suitable location.
04	As a bike courier, I want to see in an easy way the ideal possible pick-up station locations for certain areas which fit into my delivery area So that I can plan new micro-hub locations regarding scheduling more efficient deliveries on urban outskirts.

App structure

The app is structured to:

- display a map
- display a control panel with
    - a city selector
    - a feature selection
    - an amenity selection
        - a wheelchair accessible selection
        - an apply button
        - a slider for weighting
    - a build model button
- contain three scenario buttons (scenario 1, 2 and 3)
- contain a reset button
- contain a legend

Data

The simulation model is based on open data. Spatial data and list data are processed. Subsequently, the input data of the model for the case studies are explained.

Table 3 List of Features

	Features
Demographics	"Average age", "Employed income", "Gross monthly wages", "Household income", "Households with 1 person", "Households with 2 people", "Households with 3 people", "Households with 4 people", "Households with 5 or more people", "Housing", "Other income", "Pensions", "Population density", "Total employed", "Total population", "Total unemployed", "Unemployment benefits"
Amenities	"parcel_locker_wheelchair", "gas_station", "shopping_centre_wheelchair", "parcel_locker", "local_business_wheelchair", "hospital", "post_office", "post_office_wheelchair", "entertainment_wheelchair", "restaurant", "bicycle_rental", "post_box", "townhall_wheelchair", "gas_station_wheelchair", "station", "shopping_centre", "local_business", "healthcare_wheelchair", "supermarket_wheelchair", "rental_service", "post_box_wheelchair", "marketplace", "community_centre_wheelchair", "marketplace_wheelchair", "supermarket", "entertainment", "kiosk", "cafe", "hospital_wheelchair", "library_wheelchair", "townhall", "education_wheelchair", "community_centre", "education", "cafe_wheelchair", "restaurant_wheelchair", "station_wheelchair", "kiosk_wheelchair", "library", "healthcare", "rental_service_wheelchair"

2.2. Input data for Leipzig

The city of Leipzig includes 63 city districts (3). The model is configured using population data for each district; thus, all districts are considered equally.

Open Data from the Leipzig Information System (LIS) (4) published between 2021 to 2024 has been used as input data for the simulation model. The latest data available from the past two years was applied, and missing data has been added. The files used were downloaded from the LIS (accessed in January 2025). Only small-scale data was retrieved so that the data could be used on a district basis.

Table 4 Input Data from LIS (5)

File Name (orig.)	District Features
Wohnungsbestand (Jahreszahlen, kleinräumig)	"Housing"
Geodaten der Ortsteile der Stadt Leipzig	“coordinates”
Nettoeinkommen (Jahreszahlen, kleinräumig)	"Household income"
Personenhaushalte (Jahreszahlen, kleinräumig)	"Households with 1 person", "Households with 2 people", "Households with 3 people", "Households with 4 people", "Households with 5 or more people"
Einwohner (Jahreszahlen, kleinräumig)	"Total population"
Einwohnerdichte (Jahreszahlen, kleinräumig)	"Population density"
Bruttoeinkommen (Jahreszahlen, kleinräumig)	"Gross monthly wages"
Beschäftigte (Jahreszahlen, kleinräumig)	"Total employed"
Arbeitslose (Jahreszahlen, kleinräumig)	"Total unemployed"
Wohnberechtigte Einwohner nach Alter (Jahreszahlen, kleinräumig)	"Average age"
Lebensunterhalt (Jahreszahlen, kleinräumig)	"Employed income", "Unemployment benefits", "Other income", "Pensions"

To identify potential POIs in Leipzig, a database query was carried out at OSM. A POI can be, for example, a bus stop, a kindergarten, a grocery store, etc. The following properties can be specified for each POI, such as location (coordinates), name, address, wheelchair access, and other properties.

3. Simulation Model

The app analyzes urban areas, especially less dense outskirts, to suggest high-potential sites for pick-up station placement (parcel and bikesharing pick-up) based on factors such as accessibility, foot traffic, proximity to delivery hotspots, and available infrastructure. The preferred locations can change over time, and the app can suggest new locations. It can integrate social features such as user needs, community events, and opportunities for collaboration with neighborhood groups (e.g., shared spaces, local businesses). The app promotes community-building by encouraging stations that double as informal social gathering points, helping couriers and residents connect.

3.1. Data preparation

The raw data from the LIS and OSM (6) cannot be used directly but must first be processed for further use and analysis. This process involves cleaning, extracting, transforming, and loading the raw data into a format that the simulation algorithm can understand. In doing so, the following steps have been taken:

- **Extract, Transform, Load (ETL) Process:** Extract, transform, and load data into backend systems (Redis for fast access, Elasticsearch for search and analytics)
- **Data Cleaning:** Normalize and structure spatial and demographic features
- **Feature Selection:** Includes "nearest", "count", and "present" categories for dynamic features and district-level static features

This data preparation is necessary for further use of the data.

3.2. Model Framework

The model operates on a docker architecture:

- **Input data** contains spatial and list data from open data platforms, such as OSM, LIS or South Tirol open data.
- **Databases** for static features and dynamic feature queries.
- **Backend** is organized with a web framework which manages APIs and data access.
- **Frontend** provides an interactive interface and runs model simulations.
    - **Logistic Regression**: Computes suitability scores for pick-up station locations.

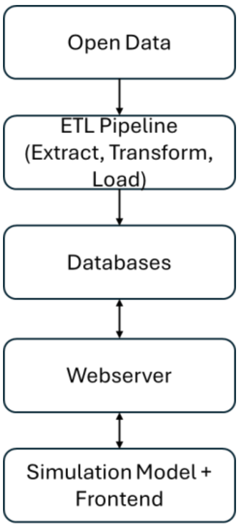


Figure 2 Simulation Model Framework

Data flows from input data to the ETL pipeline, which prepares data for processing. The databases are used for storage, pre-processing, and queries. The backend manages the interfaces and the data requests and transfers, while the frontend generates the user interface and simulation calculations.

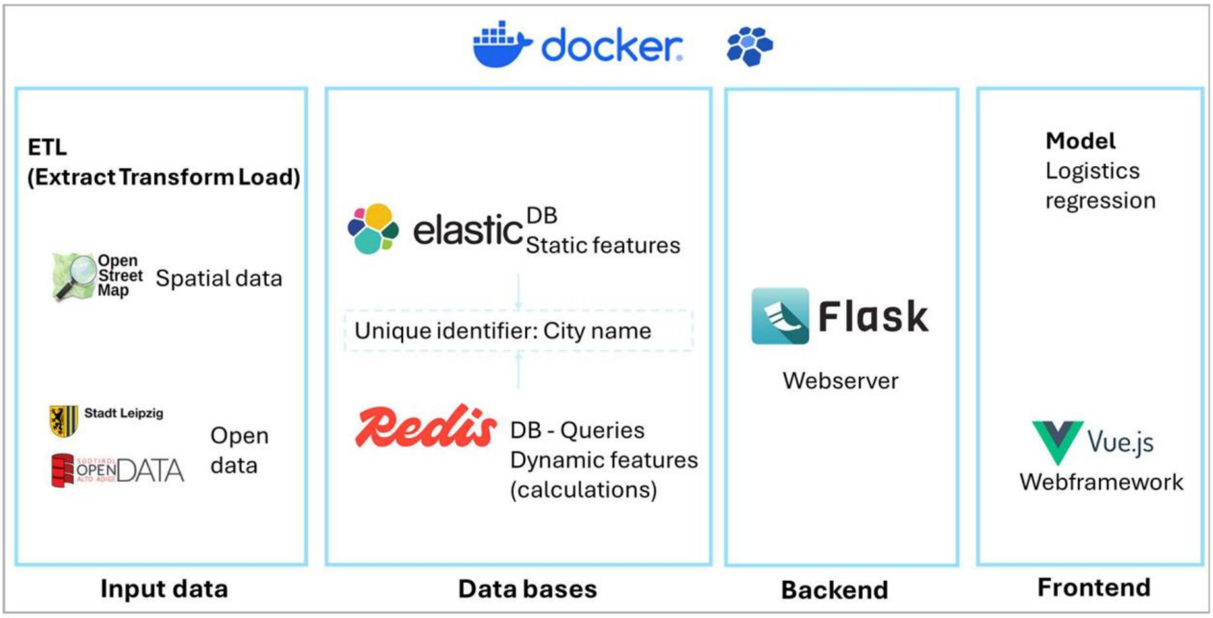


Figure 3 Simulation model framework

4. User interface of the "Pick-up station location finder"

The graphical user interface (GUI) of the simulation model, termed *"Pick-up station location finder"* is divided into two parts. On the left side is the control panel and on the right side is the map.

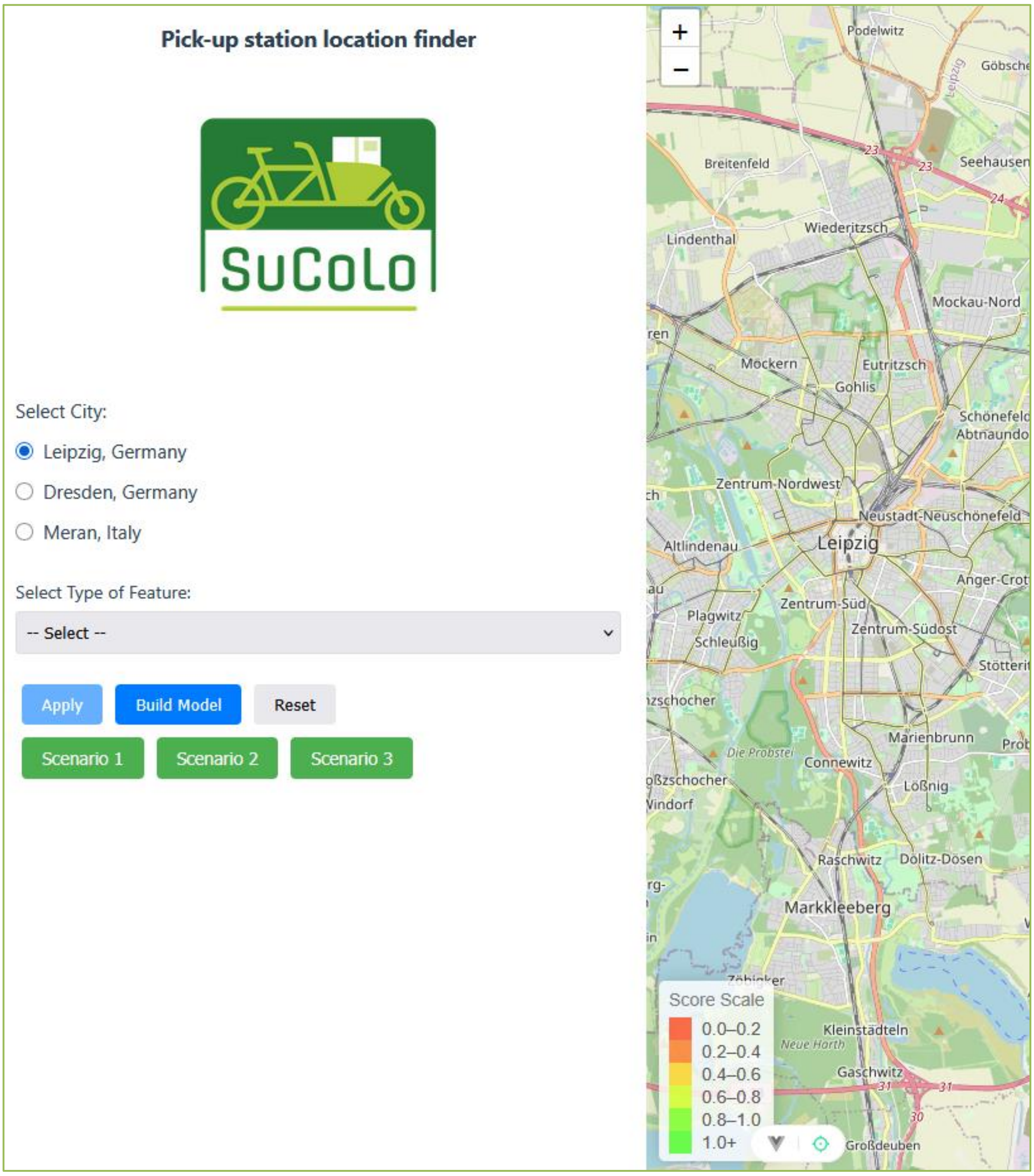


Figure 4 Screenshot of the app's start screen

The user can select features (e.g., proximity to a post office), assign distances and optional penalties, and adjust the weighting sliders from -10 to +10 based on importance given to the listed features. This which directly affects the model output.

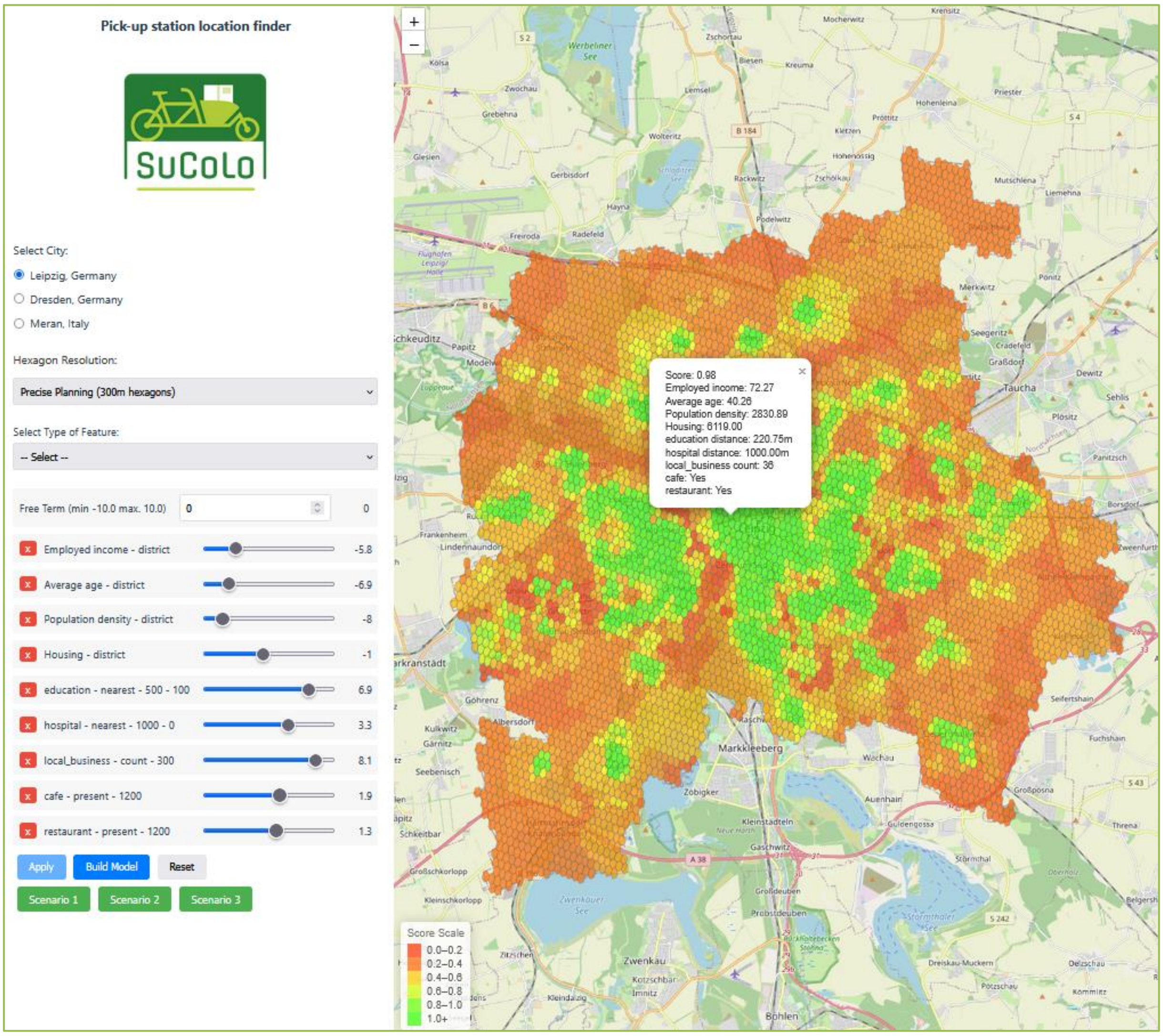
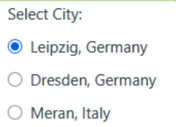
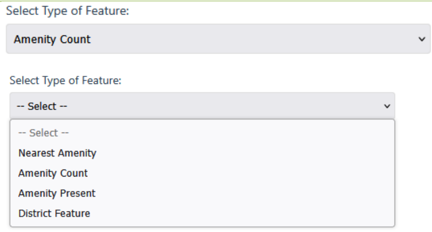
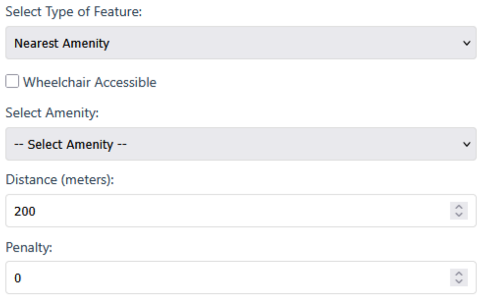
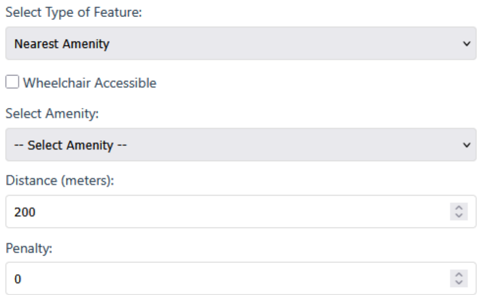
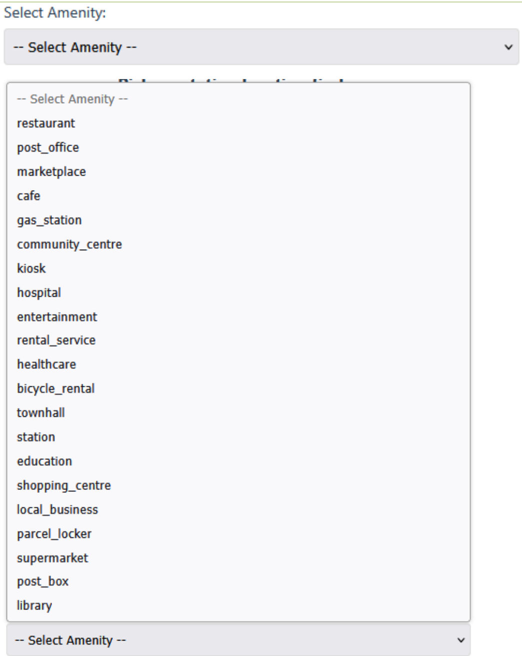
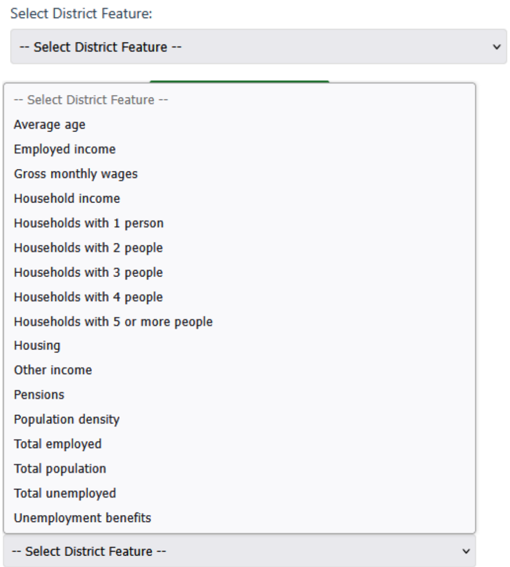
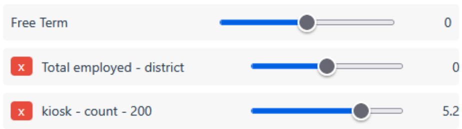
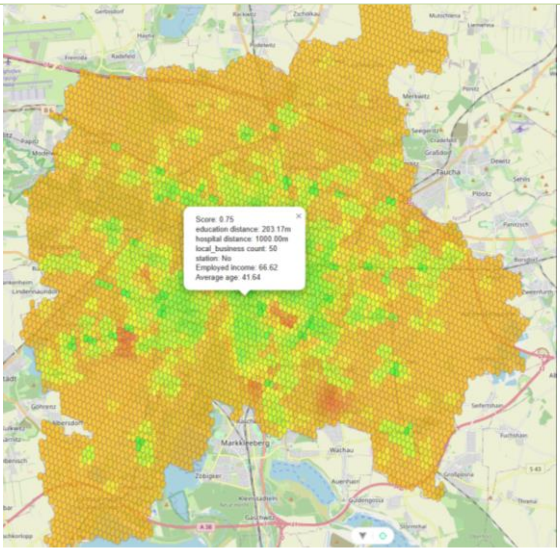
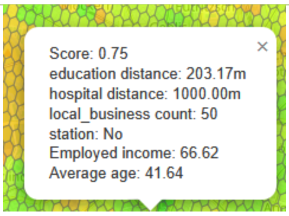
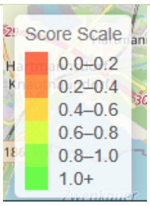


Figure 5 Demonstration of the simulation model results based on set preferences

Table 5 GUI functions

Screenshot	Function	Description
Pick-up station location finder	App Name	
	Logo	SuCoLo Logo; Leads to https://sucolo.eu/
	Radio Button City Selection	By selecting a city, the map jumps to the chosen city.
	Drop Down Menu Type of Feature	For selecting a Type of Feature, which can be Nearest Amenity, Amenity Count, Amenity Present and District Feature.
	Checkbox Wheelchair Accessible	Only shown after choosing the Type of Feature.
	Nearest Amenity Menu	Only shown after choosing the "Nearest Amenity". Choose Amenity. Options: select "Wheelchair Accessible" for barrier-free features, select a distance larger than 200 meters, and select a penalty for influencing the model.
	Amenity Count Menu	Only shown after choosing the "Amenity Count". Choose Amenity. Options: select "Wheelchair Accessible" for barrier-free features and select a distance larger than 200 meters.

	Amenity Present Menu	Only shown after choosing the "Amenity Present". Choose Amenity. Options: select "Wheelchair Accessible" for barrier-free features and select a distance larger than 200 meters.
	District Feature Menu	Only shown after choosing the "District Feature". Choose a feature.
	Drop Down Menu "Select Amenity" for Nearest Amenity, Amenity Count and Amenity Present	For adding one amenity to the model.
	Drop Down Menu "Select District Feature" for District Feature	For adding one district feature to the model.

Apply	Apply Button	By pressing the button, the Type of Feature, Amenity, Distance and Penalty can be chosen.
	Weight Slider; Delete the Selection	The menu opens after pressing the Apply button. Users assign weights to features, adjusting importance and influence dynamically.
Build Model	Build Model Button	By pressing the button, the calculations for the model will start.
	Model is shown on the map	The model is built.
	Popup by clicking on a Hexagon	Shows the calculated model scores.
Reset	Reset Button	Reload the page.
Scenario 1 Scenario 2 Scenario 3	Scenario Buttons	Reloads predefined Scenarios (Personas).
	Legend Score Scale	Shows Score Scale of the model. Position on the bottom of the page.

	Map Zoom in (+) or out (-)	Zoom function for the map, Position on top of the page.

4.1. Model Evaluation and further implementation

The model is assessed through a simulation case study and user persona-driven scenarios.

4.2. Case Study in Germany, Leipzig

The model was tested using open data from Leipzig, particularly the Lützschena-Stahmeln district. As stated earlier, citizen surveys were used to build user personas, incorporating their amenity preferences and demographic profiles.

Findings show that the model can adaptively suggest pick-up points in underserved suburban areas with both logistical and social benefits. Stations also serve as community hubs, encouraging interaction among residents and couriers.

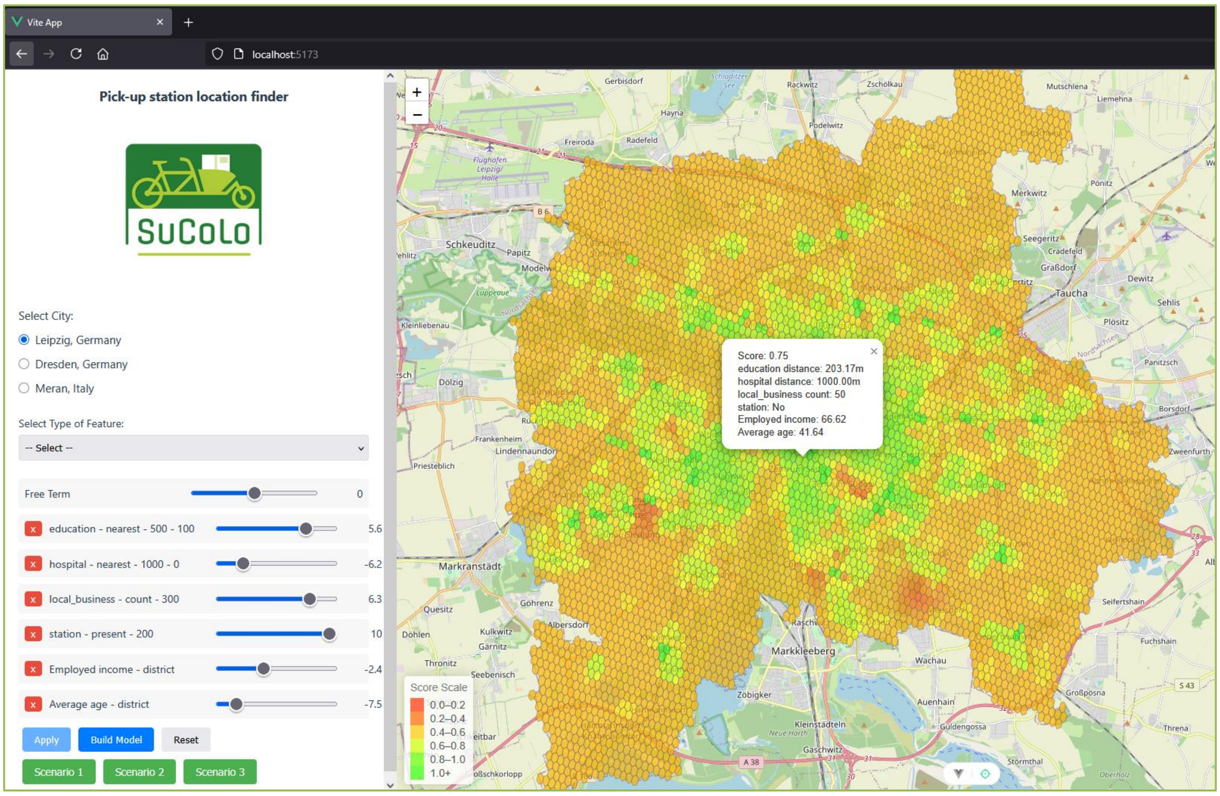


Figure 6 Screenshot of the app centred in Leipzig

5. Discussion and further work

The simulation model developed for the optimal placement of micro-hub and cargo bike pick-up stations on urban outskirts demonstrates the potential of combining data-driven logistics with community-focused urban planning. By integrating open spatial data, demographic profiles, and delivery analytics, the model offers a dynamic and adaptable solution fitting to the unique characteristics of less densely populated areas.

The case study in Leipzig illustrates how such a model can be effectively applied in real-world settings. Incorporating user personas derived from citizen surveys enables the system to align logistical priorities with local social preferences, ensuring that proposed locations are not only operationally efficient but also socially inclusive. This dual focus enhances the model's relevance for stakeholders aiming to balance economic goals with community engagement.

One of the model’s uniqueness is its interactivity and flexibility. Users can adjust weights and parameters to simulate various scenarios and business objectives. The ability to connect real-time data sources and user feedback ensures that the model remains responsive to changes in urban dynamics, such as population shifts or evolving delivery patterns.

However, some challenges remain. The quality and granularity of open data sources can affect model accuracy. As said, available open data sources published in the LIS from 2021to 2024 were used. There are some gaps in the historical data, which have been filled in with supplementary data. Further data availability, such as cycle paths, population figures in smaller units, etc., would significantly enrich the model. Moreover, it has been found that social aspects are harder to quantify and integrate systematically. Future development could incorporate additional machine learning techniques for more advanced prediction, deeper integration of behavioral data, and broader testing across different cities to enhance generalizability.

Future developments to the simulation model will be outlined in D4.3 *Reports on the research pilots’ design, implementation and results*. More potential features will be possibly added to the app in the future, including:

- Integrating other cities (Merano, Italy and Dresden, Germany)
- Predictive modeling for future delivery demand on the outskirts
- Automated ETL pipeline implementation with real-time data
- Allow users to visualize suggested locations on a city map and use it for model calculation
- Integrate co-creation features, such as user feedback on location suggestions, integrating occasional community events, etc.
- Highlight locations with potential for social interaction (e.g., parks, cafés, local markets)

In summary, this model provides a new tool for modern urban logistics planning, especially in the context of growing demand for sustainable last-mile delivery solutions. By combining technical precision with social awareness, it sets a promising direction for the future of mobility and urban service infrastructure. In the end, the simulation model will be able to be found open access under the following link:

https://github.com/Logistics-Living-Lab

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