D3.10 Budapest Value Case

Final demonstrator

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Acronyms

Acronyms	Explanation
ABM	Agent based model
API	Application Programming Interface
BAU	Business as usual
B2B	Business to business
BILK	Budapest Intermodal Logistics Centre
BKK	Budapesti Közlekedési Központ
CoP	Communities of Practice
COPERT	EU standard vehicle emissions calculator
DDDAS	Dynamic Data-Driven Application System
DT	Digital Twin
FUA	Functional Urban Area
GA	Grant Agreement
GHG Emissions	Greenhouse Gas Emissions
GitHUB	Web-based hosting service for software development projects
INLE	Inlecom (Project partner)
KPIs	Key performance indicators
LL	Living Lab
LL4	Living Lab 4 (Budapest)
LNG	Liquefied Natural Gas
LSP	Logistic Service Provider
MTM	Macroscopic Transport Model
MVP	Minimum Viable Product
PAN	Panasonic
ST	Sub Task
STAR	Sustainability Assessment of Mobility Projects

Acronyms	Explanation
SZE	Széchenyi István Egyetem
TENT-T	Trans-European Transport Network
UCC	Urban consolidation centre
UPM	Universidad Politécnica de Madrid – Madrid Polytechnic University (Project partner)
URL	Uniform Resource Locator (colloquially termed a web address)
VISUM	PTV VISUM software
WP	Work Package
WSZL	Waberer's-Szemerey Logisztika Kft.
ZLC	Zaragoza Logistic Centre (Project Partner)

Executive Summary

The Living Lab 4 (LL4) Budapest aims to improve urban freight transport efficiency and sustainability with clear benefits for all stakeholders in the Budapest inner city. Budapest faces two key problems in the baseline operational setup. On the one hand, the delivery times overlap with the daily rush hours, resulting in congestion and increasing number of conflicts in driving and parking traffic due to the limited capacity of the road and curb space. On the other hand, the location of the Urban Consolidation Centre (UCC) is outside the city perimeter, and the restrictions do not allow freight vehicles with more than 3.5 tons total weight to enter the inner-city area without an access permit into the restricted zones.

The purpose of this document is to provide an overview of how LL4 Budapest deploys Digital Twin (DT) and implements a new last-mile distribution model. The modelling activities as part of the development of the LL4 DT aim to prove the necessity of a UCC and a minihub and how the advanced simulation environment will help to explore the advantages and sustainability impacts (presented in D3.1) of using a UCC in combination with a minihub for serving the inner-city area of Budapest. This report includes a summary of the pilot actions that have been carried out during the physical implementation following the Minimum Viable Product (MVP) approach and it has been already reported in D3.9.

In case of Budapest pilot, several value case scenarios are examined, which contain the combination of different types of facilities, various types of vehicles and different lengths of operational time windows. In the AS IS scenario, the logistics service provider (WSZL) serves the stores with diesel-powered vehicles, while in the TO BE scenarios WSZL runs electric vans for the distribution (from the minihub to the stores), and Liquefied Natural Gas (LNG) truck or 16 tons electric vehicles for the supply of the minihub from the UCC. Based on the operational real data collecting from a control testing environment, the relevant KPIs for the AS IS and TO BE scenarios are calculated in order to test and validate new business models. Also, the collected operational data is used in the LEAD advanced simulation platform to compare the AS IS with the potential TO BE scenarios (“What if”).

This report gives an overview of the simulation environment, highlighting also the challenges of the development of the modelling environment LL4 had to face during the project, which served as learnings for the future.

The DT verification and validation through user acceptance are also described in the report. For these validations, LL4 organised several workshops with the CoP members and inviting different stakeholders. The workshops were essential to understand (physical pilot, Digital Twin simulations) and assess the user acceptance of the new business model and the digital twin. In the end, the lessons learned and recommendations are identified, which is concluded by a summary and outlook.

Last but not least, the results of the LL4 DT and pilot action helps Budapest to improve city logistics with receiving valuable experience for each LL4 project partners related to the testing of developed solutions. Moreover, all the knowledge and experiences gathered during the pilot can be incorporated into the Budapest Sustainable Urban Logistics Plan of which development is ongoing.

1 Introduction

1.1 Scope and objectives

This report provides an updated and final version of the activites and results presented in D3.9. The objective of this deliverable is to report the final release of the demonstration activities including user acceptance, recommendations and lesson learned. Thus the document presents the final models of the LL4 Digital Twin and a set of explanatory simulation scenarios demonstrating the efficiences achieved.

Table 1 contains the deliverable adherence to LEAD LL objectives covered during the final phase.

Table 1. Deliverable's adherence to LEAD objectives and Work Plan

LEAD GA Requirements	Section(s) of present deliverable addressing LEAD GA	Description
ST3.5.1 Preparation. MVP Specification and Modelling	Chapter 2. Budapest pilot	This chapter contains a detailed description of the pilot in Budapest following MVP approach, based on D3.9.
	Chapter 3. Simulation environment	This chapter describes how the Digital Twin modelling pipeline has been set up (concept, methods, data sources) and how it can be integrated with the LEAD Platform.
ST3.5.2. Digital Twin Verification.	Chapter 3., Section 3.1.6 Digital Twin Verification	These sections describe the verification process for validating the simulation scenarios and validating the KPIs measurements through user acceptance.
	Chapter 4. KPIs measurements	This chapter reports the results of the KPIs described in D3.9 for the baseline measurements and TO BE scenarios.
ST3.5.3. Real-life implementation.	Chapter 2.2. Physical pilot activities	This section summarizes the steps taken in D3.9 for the implementation of the physical pilot and the updates since the deliverable

LEAD GA Requirements	Section(s) of present deliverable addressing LEAD GA	Description
	Chapter 6 Chapter 7	These chapters describe the lessons learned from the physical implementation and the steps forward
ST3.6.4. Evaluation impact assessment	Chapter 5. Validation and user acceptance	These sections report the outcomes of the workshops, showing the results from the validation survey done during the workshops

1.2 How does this deliverable relate to other deliverables?

This report is the updated version of the D3.9 and contributes to the D3.2 and D3.15.

1.3 Structure of the document

In this section a description of the deliverable's structure is provided. This document is divided into seven main chapters:

- Chapter 1: provides the introduction and related information;
- Chapter 2: details the LL4 Budapest pilot by summarizing its minimum viable product and its four value case scenarios and updates the physical pilot activities;
- Chapter 3: describes the simulation environment by summarizing the scenarios modelling, the configuration of the DT, the data collection and anonymization and the definition of the modelling conditions. It is also detailed the "What if" scenarios and their simulation and results;
- Chapter 4: describes the final KPIs and compares it with the baseline and targets;
- Chapter 5: includes the physical pilot and DT validation through user acceptance;
- Chapter 6: includes the learnings and recommendations;
- Chapter 7: concludes through a summary and outlook.

2 Budapest pilot description

2.1 Minimum viable product

The city of Budapest, as an urban node, affected by the Orient East Med and Mediterranean TEN-T corridors, is an important logistics area with 20% of the country's population[1]. The target location for the pilot activities in LL4 Budapest focuses on the inner-city area, enclosed by the Grand Boulevard, where the density of retailers/ shops, the loading areas and the population are high.

The overall mission of Budapest Living Lab is to help improve urban logistics in the city for the sake of all citizens and stakeholders, and within the LEAD framework to perform LL4 pilot action to be able to test a Digital Twin as a tool to design distribution chains with multi-objective optimisation for all the actors involved. The aim is that the LL4 Digital Twin provides insights concerning the combination of the UCC and a minihub to find the best scenario for efficient last-mile operations.

For BKK, as the mobility manager of Budapest, the main goal is to improve its Macroscopic Transport Model (MTM) and update its freight transport layer. Furthermore, BKK has started to implement the Sustainable Urban Logistics Plan for Budapest, so during the project, BKK obtains useful information regarding city logistics which helps to create a more efficient city logistics system in Budapest.

For WSZL, the logistic service provider (LSP), the project gives a great opportunity to gain experience in the application of the minihub that can be utilized and applied in the supply chain in the long run, in real practice. And for Széchenyi István Egyetem (SZE) it gives a chance to develop its simulation competencies and to use the results of this project in other research (related to low/zero emission vehicle operations, city logistics).

2.2 Physical pilot activities

LL4 Budapest pilot action features a B2B (Business-to-business) distribution chain introducing a minihub with different operational time windows, and different low and zero emission vehicles for the completion of the last-mile delivery operations from the minihub in the investigation area of the city. The following figure summarizes the main elements of this 2-echelon distribution network, on which the interactions between the different stakeholders are also presented.

[1] *Budapest population 2022: [Budapest Population 2022 (Demographics, Maps, Graphs) (worldpopulationreview.com)]*

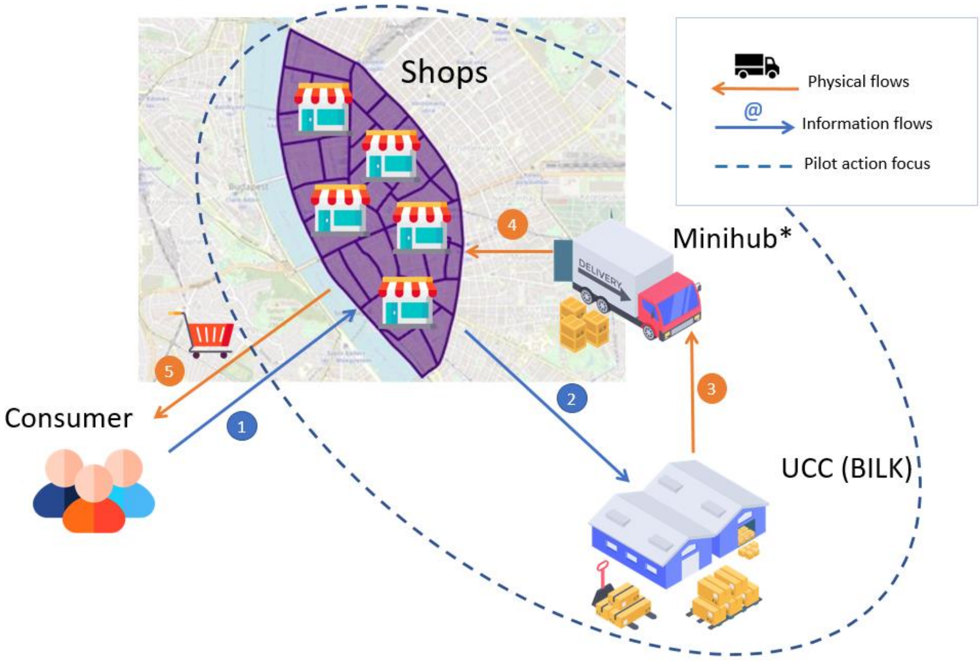

Figure 1. LL4 TO BE scenario and the interactions between the stakeholders (presented in D3.9)

During the physical pilot, LL4 examined 4 value case scenarios (presented also in D3.9) and compared them to the current operation of WSZL (AS IS scenario), which is the following: the target area is served from the UCC directly by 12 t diesel vehicles.

For the TO BE scenarios, firstly the 4 value case scenarios have been defined. These scenarios contain the combination of facilities, various types of vehicles and different lengths of operational time windows, as the following (variable parameters are marked with different colours):

Value case 1:

1) Two facilities:
   - UCC (Budapest Intermodal Logistics Centre - BILK)
   - permanent regional warehouse facility, operating 0-24
2) B2B
3) LNG truck and electric vans

Value case 2:

1) Two facilities:
   - UCC (Budapest Intermodal Logistics Centre - BILK)
   - permanent regional warehouse facility, operating 7-12
2) B2B
3) 16t electric vehicles and electric vans

Value case 3:

1) Two facilities:
   - UCC (Budapest Intermodal Logistics Centre - BILK)
   - (mobile) cross dock facility, operating 0-24
2) B2B
3) LNG truck and electric vans

Value case 4:

1) Two facilities:
   - UCC (Budapest Intermodal Logistics Centre - BILK)
   - (mobile) cross dock facility, operating 7-12
2) B2B
3) 16t electric vehicles and electric vans

Figure 2. Value case scenarios for the Budapest pilot

The value case scenarios have been presented in D3.9, but since then, there were changes in the used freight vehicles in every value case scenario. During the testing period, WSZL could not deliver with CNG truck and hydrogen fuel cell trucks, because electric vehicles and LNG vehicles were available in the WSZL's fleet. One of the reasons is that the charging/refuelling infrastructure for the used vehicles is located close to BILK (where WSZL has its logistics centre), unlike CNG stations. Regarding the hydrogen fuel cell trucks, contrary to WSZL's plans, it can be seen that the adaptation of hydrogen technology is a slower process in the market. Vehicle manufacturers have not had the necessary infrastructure and sufficient experience yet for mass production of hydrogen-powered vehicles. Additionally, hydrogen filling stations are currently limited to private use. Therefore, although hydrogen technology looks promising, it can be only become a reality at a later stage.

Regarding the electric vehicles, WSZL encountered many obstacles, because the 3.5 t electric vehicles arrived later than expected. It has more reasons, on one hand, compared to recent years, the demand for vehicles with alternative powertrain has increased to a large extent, and on the other hand, due to the wartime crisis and COVID, the flow of raw materials for the manufacturing slowed down. Also, the vehicles already owned by WSZL were used by the business partners, so it was difficult to operate without them from the previous operation.

After the finalisation of the value case scenarios and providing the test vehicles for the deliveries, the physical pilot has started which main aims were to gather real life data by testing different types of vehicles in the investigation area, populate the Digital Twin models with them and calculate different impacts. During the pilot, WSZL tested different types of vehicles in the investigation area, simulating the use of the minihub near Nyugati railway stations as the location of the minihub.

LL4 was able to complete the pilot in which gained experiences with the test vehicles, as the followings:

In case of the LNG truck:

- Real vehicle tests with WSZL partners → from the retail, white goods and FMCG sectors
- Trucks in daily domestic operation they could achieve a maximum mileage of 400-800 km/day
- The vehicles are easily integrated into WSZL's FTL delivery processes
- The time required for refuelling can be compared to the diesel version, the process is easy to learn
- Average consumption: 20.75 kg LNG + 2.9 l diesel/100km → 20% CO_2 saving and 90% NOx emission reduction

In case of 16 t electric vehicle:

- Real vehicle tests with WSZL partners → from the retail, white goods and FMCG sectors
- Trucks operating in Budapest distribution. They could achieve approx. a mileage of 100-180 km/day
- The vehicle is easily integrated into the BILK-West Railway station route marked in the pilot. It was charged at BILK → it can be charged to 100% overnight
- Average consumption: 90-100 kWh → local emissions 0

In case of the 3.5 tons electric vehicle:

- Working in the operation of WSZL's key partners, with average 100 km per day
- Average transport of 200-500 kg
- Average consumption: 23-35 kWh → local emissions 0

Another result of the pilot is that the gathered operational data from the tests are used in the simulation environment to understand the impact of the different scenarios. However, due to the delays in the pilot, the data collection started later than it was initially planned causing delays also in the simulations.

3 Simulation environment

Deliverables (D3.9, 2022) and (D2.2, 2023) introduce a detailed description of the LL4 digital twin models developed and used from the LEAD models' library, the data structures, the anonymization process and the wrapper functions implemented to connect the user with the digital twin and the different models automatically.

The objectives of this section in this deliverable are threefold. First, to complement the previous deliverable D3.9 with an explanation of the final refinements needed to compare the sustainability performance of the pilot implementation after introducing the minihub in the city centre (near Nyugati Railway Station) vs. the BAU scenario ("BAU" vs. "minihub" scenarios). Second, to define the different "What if" scenarios that will be simulated with the digital twin. Finally, present the results of the scenarios simulated with the digital twin. They were presented to policymakers and logistics operators to validate the digital twin as an enhanced decision support system to improve the decision-making process (see Chapter 5).

3.1 LL4 Budapest real scenarios

In LL4 Budapest, the main goal is to produce evidence of the necessity of combining the UCC and the minihub in the city. To achieve this goal, the models developed in the LL4 explore the followings:

- the advantages and impacts of using the UCC and the minihub for serving a certain area using different time windows for loading and various vehicle sizes

- the use of Digital Twin as an advanced tool based on the freight transport layers and properties of the macroscopic transport model (existing freight regulation, freight through traffic, attraction and output of different zones) to assess the impacts of the implementation of the LEAD strategies (B2B, e-vehicles, LNG/CNG Truck, Digital Twin).

3.1.1 Description

For reproducing the logistics operations of the scenarios in the Digital Twin, LL4 has taken a unique data input request to WSZL, using a modelling approach that meets Budapest ambition and that integrates with the LEAD vision and could be easily extended to other cities.

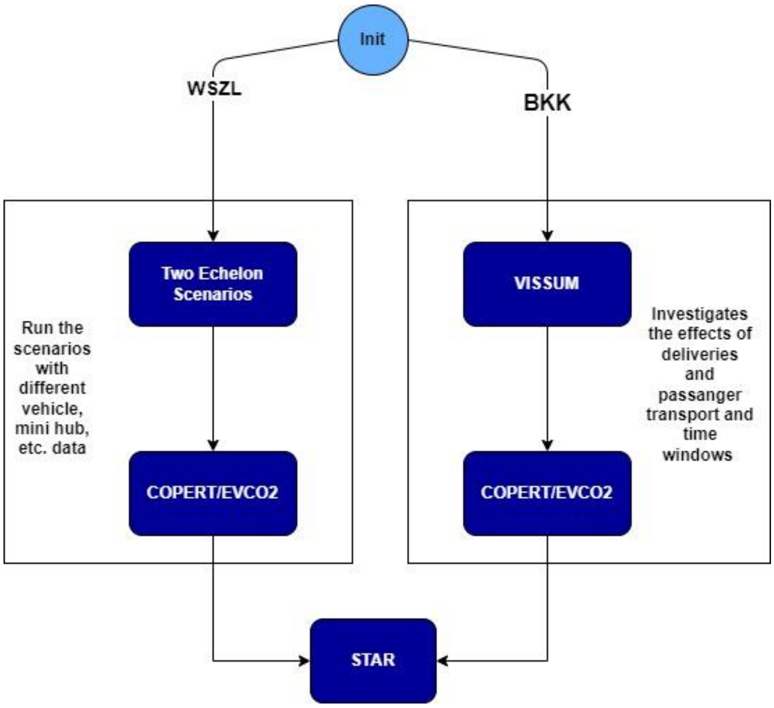

Figure 3. LL4 Budapest used models

The first step is a delivery resource planning with 2-Echelon model to evaluate the required resources in the different value case scenarios (presented in Chapter 2), followed by a vehicle emissions and energy consumption calculator of each scenario. The user will receive a comparison table from LEAD Dynamic Data-Driven Application System (DDDAS) for supporting the decision-making process to select the scenario. It is important to emphasize that Macroscopic Transport Model (MTM) does not use this comparison table as an input file. This modelling step only provides information on which scenario is worth implementing.

The second step is to examine the effects of different delivery methods in the service area of WSZL in connection with the passenger transport of the area with Macroscopic Transport Model in VISUM software. MTM is a transport model for the city of Budapest to investigate passenger and freight traffic as well. It calculates the required transportation related KPIs and feeds the vehicle emissions and energy consumption calculator to get more accurate results.

At the end of the simulation, the last step is to take the lists of 19 KPIs detailed in D3.1 of the scenarios (BAU vs minihub) and feed the UPM STAR Sustainability model. It allows comparing the sustainability assessment of the baseline scenario with the sustainability of the different value case scenarios.

Finally, the models were used to respond to different "What if" scenarios.

3.1.2 Generic Models and connections

The tables below contain an updated summary of the models and connections of the LL4 digital twin pipeline already explained in D3.9 (2022).

Table 2. Summary of the generic models integrated in the framework of LL4

Model	Description
2-Echelon model (ZLC)	This model allows estimating the resources needed (vehicles, drivers), total distance and delivery time per type of vehicle of 1-echelon network configuration or 2-Echelon network configuration. This model is useful when the user (LSP, shipper) aims to understand the impact of different scenarios with relatively low data granularity. The updated version and more detailed information are available in GitHub[2] and in the updated version of the (D2.2, 2022).
Macroscopic Transport Model in VISUM	PTV VISUM is a transport modelling software and is used as a tool to run the Macroscopic Transport Model (MTM). MTM is a strategic transport model with which the effects of major modifications in the transport network or in the territorial development structure can be investigated. In LEAD LL4 uses the model to examine the effects of different delivery methods using minihub in the city centre. More detailed information about the model can be found in (D2.2, 2022).
COPERT calculator	COPERT is the EU standard vehicle emissions and energy consumption calculator. LEAD uses COPERT in several LLs to estimate and compare the environmental impacts of implementing different scenarios. As an output, COPERT estimates: Energy consumption, GHG Emissions - CO2-equivalent and Air pollution - [PM; NOx; VoC]. More detailed information about the model can be found in (D2.2, 2022).
STAR Logistics Model (UPM)	The STAR Logistics model evaluates sustainability by performing a multicriteria analysis with multiple inputs to compare the baseline and new delivery scenarios. UPM updated this model within the scope of the LEAD project. STAR Logistics will serve as an evaluation tool for the final assessment of the sustainability of the project's logistics solutions. The following steps are taken to define the STAR framework: (i) Data gathering and sustainability criteria definition, (ii) Updating expert panel criteria and (iii) Methodology application and reporting. Additional information about the model is available in (D2.2, 2022).
GHG emission from EV	The methodology proposed for estimating the CO2eq emissions from electric vehicles is associated with the electrical mix used to produce electricity. The

[2] https://github.com/Horizon-LEAD/2echelon_v2

Model	Description
	proposed method estimates the electric vehicles CO2eq emissions based on mean kWh consumed by each vehicle and the carbon intensity for the electricity generation (g CO2eq /kWh). More detailed information about the model can be found in (D2.2, 2022).

Table 3. Summary of the LL4 model connectors

Model	Description
2Echelon_LEAD_to_from_COPERT	It is a Python to connect any model1 outputs with COPERT further detailed in LEAD GitHub repository. 2Echelon model uses this connector to calculate the energy consumption and environmental KPIs for the Internal Combustion Engine vehicles (CO2, PM2.5, VoC).
2Echelon_LEAD_to_from_EVCO2	It is a Python to connect any model1 or model 2 outputs with EVCO2 model, further detailed in LEAD GitHub repository. 2Echelon model and LMT engine use this connector to calculate the energy consumption and CO2 for electric vehicles.
VISUM_to_COPERT	It is a Python to connect MTM outputs with COPERT further detailed in LEAD GitHub repository. MTM uses this connector to calculate the energy consumption and environmental KPIs for the Internal Combustion Engine vehicles (CO2, PM2.5, VoC).
VISUM_to_EVCO2	It is a Python to connect the MTM outputs with EVCO2 model, further detailed in LEAD GitHub repository. VISUM MTM use this connector to calculate the energy consumption and CO2 for electric vehicles.

3.1.3 Configuration of the DT

The configuration of the Digital Twin was reported in D3.9 in detail, and the data structure and volumetric was also presented in D2.3. Since then, there were no changes in it LL4 uses four different types of data: 1) Store information, 2) Minihub information, 3) Fleet information, and 4) Orders information.

To simulate LL4 Budapest value case scenarios, the logistics service provider (WSZL) provided operational data in the form of Excel files with the required information about the stores, orders and the minihub. All available data are provided by WSZL. About the vehicles, the information is provided by WSZL as well. Chapter 2 and the next subchapter (3.1.4) include the description of the fleet of the vehicles which are used for the deliveries.

3.1.4 Data collection and anonymisation

The LL4 partners (BKK, SZE, WSZL) captured the necessary information of the physical activities to configure and developed the digital twin models (vehicles, facilities, services, operations). The technical partners used the following data required in the Budapest Digital Twin:

- traffic and territorial data
- vehicle characteristics
- facilities data
- services data
- other data

Traffic and territorial data

The traffic data was provided by BKK from the Macroscopic Transport Model of Budapest. BKK also provided territorial data and shapefiles with the polygon or boundaries of the investigation area and centroid of the delivery zone. Figure 4 shows a loaded network form the transport model (the pilot area is marked with green brick).

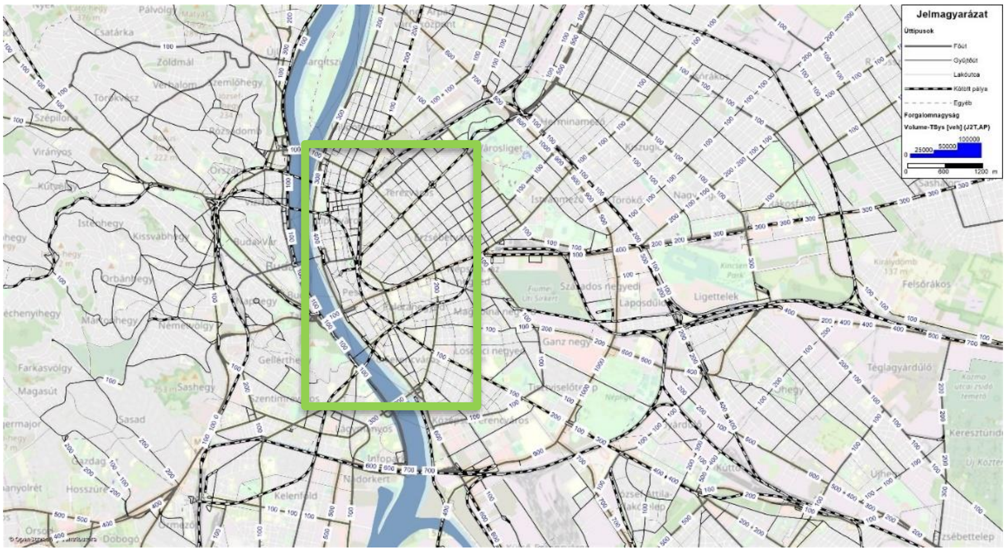

Figure 4. Loaded network with J2T category (freight vehicle 3.5 t – 7.5 t)

Vehicle characteristics

Table 4 shows the attributes of the characteristics of the vehicle used in the BAU scenario (D3.9, 2022) and 4 value case scenarios that are common to 2-Echelon and MTM model. The logistics service operator (WSZL) provided these data.

Table 4. LL4 Vehicles used in the BAU and value case scenarios

	BAU	*Value Case Scenarios*		
Attributes	*LL4 Budapest "BAU" scenario*	*LL4 Budapest 1st leg Value case 1,3*	*LL4 Budapest 1st leg Value case2,4*	*LL4 Budapest 2nd leg all scenarios*
VehicleTypeId	Heavy Duty Trucks, Diesel, Rigid 7.5-12 t, Euro VI A/B/C	Heavy Duty Truck, LNG, Rigid (Payload: 24t)	Electric vehicles, 16 t (Payload: 6-7 t)	Light Commercial Vehicles, Electric
Capacity	15 pallets	33 pallets	15 pallets	3 pallets
Velocity (km/h)	30	30	30	30
StartTime	06:00	06:00	06:00	06:00
EndTime	17:00	17:00	17:00	17:00

Facilities data

Table 5 shows the minimum characteristics of the UCC and the minihub required by the underlying models.

Table 5. LL4 Facility in the "AS IS" and "TO BE" scenarios

Attributes	LL4 Budapest "BAU" scenario	LL4 Budapest minihub
Name	BILK/UCC	Minihub
Id	1	2
Country	HU	HU
Address	Budapest Európa u. 5-7.	Váci u. 3.
Zipcode	1239	1062
Coordinates	47.379611,19.12289	47.51156, 19.05783

Services data

The set of daily deliveries carried out and provided by WSZL. Table 6 shows an example of one arbitrary service in LL4 Budapest, which is the input required by the 2-Echelon and MTM model.

Table 6. LL4 Services data sample

ID	Town	*Address*	*Postcode*	*LAT*	*LONG*	*Pallet*
A0000	Budapest	Európa utca 6.	1239	47.37682	19.11232	1
A0026	Budapest	Arany János utca 29	1051	47.50243	19.05327	1
A0050	Budapest	Nádor u. 18.	1051	47.50199	19.049	1
B0001	Budapest	Apáczai Csere János utca 1	1051	47.49832	19.04751	1
B0002	Budapest	Arany János utca 9.	1051	47.50193	19.04829	0.5
B0003	Budapest	Dorottya u.13.	1051	47.49847	19.04842	0.5
B0004	Budapest	Erzsébet tér 24447/2 hrsz	1051	47.49871	19.05346	1
B0005	Budapest	Hercegprímás utca 9.	1051	47.50122	19.05298	1
B0006	Budapest	Október 6. u. 22.	1051	47.50194	19.05071	0.5
B0011	Budapest	Sas u. 8.	1051	47.50043	19.05209	1
B0012	Budapest	Városház u. 14.	1051	47.49402	19.05461	0.5
B0013	Budapest	Apáczai Csere János u. 1	1052	47.494	19.05029	0.5
B0015	Budapest	Városház u. 7	1052	47.49426	19.05606	1

Other data

COPERT requires the monthly maximum and minimum temperatures, and the humidity of the city as well as the average peak and off-peak traffic speed and time share. This information is available in the (D3.9, 2022).

EVCO2 requires carbon intensity of each power source (gCO2e/kWh), the percentage of energy generated by every power source (%), number of electric vehicles used, the total energy consumption required by the vehicles (kWh) is usually reported in kWh. This information is provided by WSZL's energy expert, based on EU guidelines and expected emissions[3].

3.1.5 Definition of the modelling conditions

The modelling conditions have been already reported in D3.9 and further detailed in WP2. In this chapter, LL4 summarizes shortly the required assumptions for using the underlying models in LL4 Budapest scenarios.

2Echelon Model Assumptions and modelling conditions

For the 2-Echelon model, LL4 uses mainly fixed values (workshift, handling time, average time for delivering the goods). These values are based on some trials and practical experiences from the

[3] https://eur-lex.europa.eu/legal-content/HU/TXT/PDF/?uri=CELEX:32018R2066&from=ES

logistics service provider, in case of Budapest from WSZL. In Annex 1 the modelling conditions and assumptions for the 2-Echelon model can be found.

COPERT Assumptions and modelling conditions

As indicated before, for the calculation of the environmental impacts COPERT model requires input data related to meteorology and traffic conditions, as well as technical specifications of the used vehicles during the pilot. The specific vehicles data are chosen from the COPERT vehicles database. In case of LL4 Budapest, WSZL uses LNG truck, which is not include in the COPERT vehicle database, so another type of vehicle characteristic is used for the simulation.

Regarding the meteorological data (temperature and humidity), the values for Budapest are collected on the National Meteorological Service website[4]. There is possibility to obtain historical data for Budapest and other cities in Hungary. These meteorological data are constant during the simulations. These data can be found also in Annex 1.

For the calculation, the traffic circulation data (average speed and share along the activity) are also required in the input file of COPERT. These data are collected through the logistics provider partner (WSZL), and are also collected from TomTom website[5].

Macroscopic Transport Model Assumptions and modelling conditions

As mentioned above, LL4 Budapest uses MTM in VISUM in order to examine the effects of different delivery methods in the service area of WSZL in connection with the passenger transport of the area. It is important to highlight that for the modelling a road network was generated for the investigation area from MTM. Regarding the input data, on the one hand, BKK provides current traffic data (passenger traffic, freight traffic) from MTM as it was presented in the description of the models, on the other hand the model requires input data from WSZL.

The customer list of WSZL (name, address, coordinates) and the place of the minihub are required for the modelling. Based on the customer list, the model creates delivery routes on which the different scenarios are examined and the transportation related KPIs are calculated. The beginning and the end of the delivery route is always the minihub. The planning of these deliveries can be influenced by passenger transport and other freight traffic as well.

3.1.6 Verification

The results of the core models are used for the final verification of the LL4 Budapest simulation environment in order to validate if the LEAD innovative solution satisfies the objectives and meets the needs of the intended users. This process involved system testing and user acceptance tests. In the workshop the DT approach was also shown, together with the main results and after that, a survey was presented to the participants to validate the DT (reported in Chapter 5).

In order to verify the simulations, WSZL has operated its vehicles in the investigation area from which operational data has been gathered. The data have been compared to the simulations' results. The bases of the comparison are the number of vehicles, delivery distances, delivery time. In general, for

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[4] *Budapest éghajlati jellemzői.* https://met.hu/eghajlat/magyarorszag_eghajlata/varosok_jellemzoi/Budapest/
[5] *TomTom website:* Budapest traffic report | TomTom Traffic Index

the 2-Echelon model, there are some deviations for example between the simulated delivery distances and the real delivery distances or between the simulated delivery time of deliveries and the real delivery time. The reasons for this may be a) it is a rough estimation of the distance based on the delivery target area increasing the total distance; b) that unexpected traffic disruptions often occur due to irregular parking in the investigation are, which cannot be anticipated in advance increasing the time required for delivering in the real life. The other factor is that due to periodic road construction and maintenance work the traffic can slow down and this affects also deliveries, especially the time of deliveries mentioned before. Some internal studies made by WSZL also showed that in case of the diesel vehicles the energy consumption can be vary depending on the driver of the vehicles. That's why WSZL holds internal trainings for drivers in order to reduce consumption.

Table 7. Comparison data between the real life and the simulation

	Real life	Simulation (Echelon model)
Numbers of vehicles needed	5	5
Numbers of the partners/day	30	30
Delivery distance [km]	90 (average) km	139 km
Delivery time [h]	8	5.6

In case of Macroscopic Transport Model there are also some deviations between the simulated delivery distances and the real delivery distances, too. The main reason for this is that MTM is a strategic model, the map database sometimes does not contain the route used by the freight vehicles during the deliveries. Thus, in some cases, there were difficulties in geocoding the stores, on the one hand, there were points which have not had a road connection in the model (because there was no public transport near them), on the other hand, placing them on both sides of roads with separate traffic directions was difficult to solve. The Figure below shows an example for the delivery route in real life vs. in the simulation.

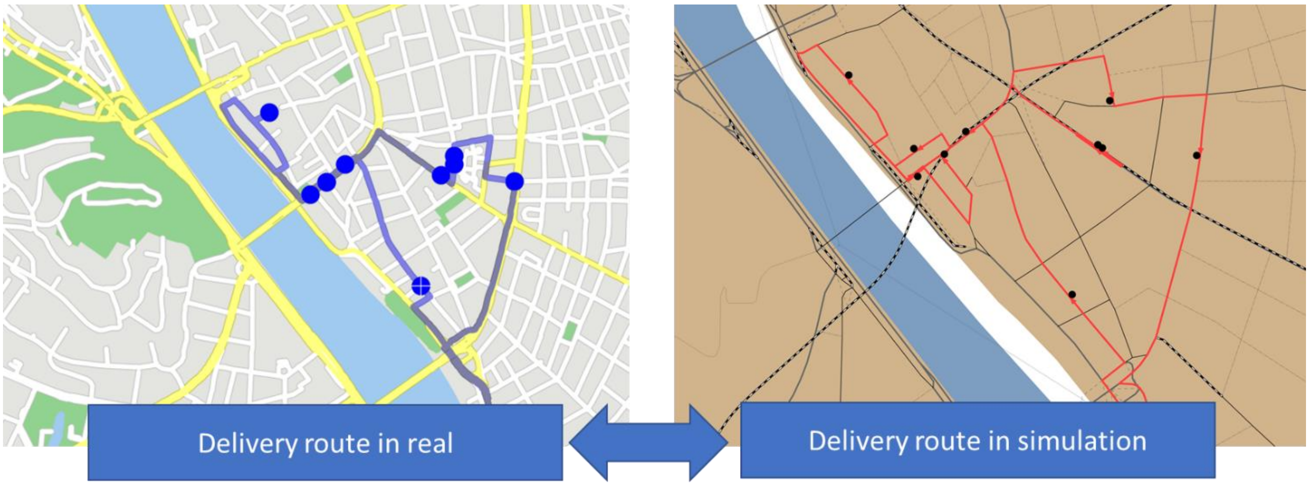


Figure 5. Delivery route in real life (HERE Maps) vs in simulation (VISUM)

3.2 LL4 Budapest "What if" scenarios definition

This section contains the definition of the different scenarios, the models, and the data used in each one of them. It connects to Section 2.2, where the different real scenarios are defined, and Section 3.1, where the models that are used within this deliverable are defined.

3.2.1 Real scenarios

In case of Budapest, the BAU scenario and all the 4 different value case scenarios (presented in Section 2) have been simulated with the models in order to validate them with the logistics service provider. For the simulations, LL4 used those operational data (vehicles, facilities, services) and other data which are described in Section 3.1.4.

3.2.2 "What if" scenario: changing the place of the minihub

Besides the real scenarios, LL4 examines other relevant "What if" scenarios as well, in order to support decision making processes. One of the "What if" scenarios is relocating the minihub. During the physical pilot, all the deliveries were made from Nyugati railways station. In order to explore the advantages of using minihub, and the optimal distance from endpoint, two other minihub locations have been selected, which can also be seen in the Figure below.

Table 8. "What if" scenario: New locations of the minihub

Attributes	Boráros square	Március 15 square
Name	Minihub	Minihub
Country	HU	HU
Address	Budapest Boráros tér	Budapest Március 15. tér
Zipcode	1093	1056
Coordinates	47.479691, 19.067673	47.491838, 19.052669

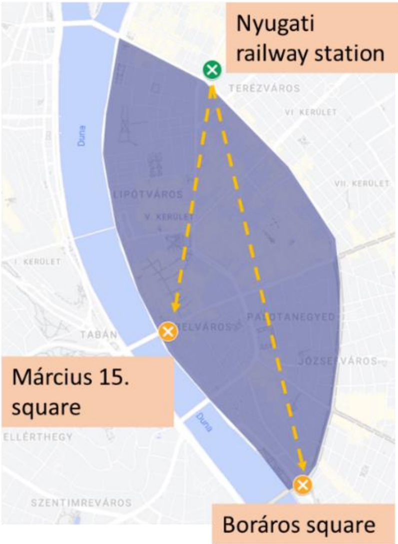


Figure 6. "What if" scenario: Changing the location of the minihub

For the simulations, LL4 used 3.5 t electric vehicles (with 5 pallets capacity) for the deliveries.

3.2.3 "What if" scenario: using e-vehicles and cargo-bikes

Another "What if" scenario that LL4 examined with the help of the Digital Twin is combining electric vehicles and cargo-bikes for the deliveries in the investigation area. The idea of using cargo-bikes also for the deliveries was suggested by service providers in the second workshop. In this case, the downtown area (in Figure in yellow) would be served by cargo-bikes from Március 15. square, while the other parts of the investigation area would be served from the other minihub, from Boráros square. This is also an interesting scenario, since in another R&D projects Március 15. square was also selected as a pilot from which the deliveries can be made.

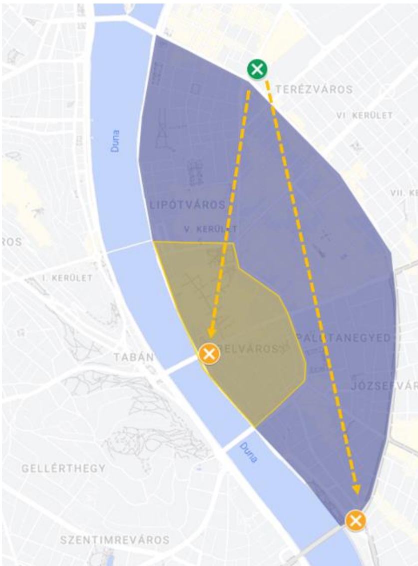


Figure 7. "What if" scenario: combining cargo-bikes and electric vehicles

3.3 Digital twin: "What if" scenarios simulation and results

As it was mentioned above, LL4 Budapest are modelling with Digital Twin to define the effects of each scenario of the environment, transportation and emission. This section contains the results of some different "What if" scenarios.

For the simulation, LL4 used 2-echelon model, Macroscopic Transport Model, COPERT model (for the simulation of diesel vehicles) and EVCO2 model for the simulation of the deliveries with electric freight vehicles in order to have the related KPIs calculated.

3.3.1 Real scenarios

The primary purpose of these scenarios is to examine the savings available for a two-echelon system. The required overall distance and the number of used vehicles is the primary basis for comparison. The Table below shows the results of the baseline and the 4 value case scenarios. For the baseline, according to the simulation, 5 heavy duty diesel trucks are sufficient to serve the stores by WSZL. It is estimated that vehicles travel a total of 167.7 km in a day, emitting 330.9 kg of CO_2.

For the TO BE scenarios, LL4 calculated the number of vehicles, delivery distance and GHG emission separately for the first and second leg. In case of the Scenario 1,3, where WSZL uses LNG truck for serving the minihub from the UCC and 3.5 t electric vehicles for the deliveries within the target location from the minihub, a total of 14 vehicles are needed. While in case of the Scenario 2,4 a total of 15 vehicles are needed for delivering the same amount of goods. According to the simulation, 13 electric vans are required for the distribution. In these cases, the calculation was done with 1 pallet/store for 65 delivery addresses, and the 5 pallets capacity limit gave this theoretical result. In practice, these deliveries could be made with less vehicles (approximately by a third), which means that about 4-5 vehicles would be enough to make the deliveries between the minihub and the stores, because one delivery route takes about 2 hours (handling time + delivery time).

Regarding the delivery distances, in all the TO BE scenarios there is a decrease: in Scenario 1,3 approximately by 51.47%, and in Scenario 2,4 approximately by 26.43%. In terms of the CO2 savings, it can be seen that significant savings can be achieved in each TO BE scenario: in Scenario 1,3 approximately 92.16%, in Scenario 2,4 approximately 99.98% CO_2 savings. However, the results from the simulation show less CO2 emissions than it was calculated with real data by WSZL. Regardless of this, the rate of CO_2 saving is obtained similar for both real and simulated scenarios.

Table 9. Simulation results for the BAU scenario and the 4 value case scenarios

	BAU scenario	Scenario 1,3	Scenario 2,4
Vehicle types	Heavy Duty Trucks, Diesel, Rigid 7.5-12 t, Euro VI A/B/C	1st leg: Heavy Duty Truck, LNG, Rigid 2nd leg: Light Commercial Vehicles, Electric	1st leg: Electric vehicles, 16 t 2nd leg: Light Commercial Vehicles, Electric
Numbers of vehicles	5	14 (LNG: 1; 3.5 t: 13)	15 (16 t: 2; 3.5 t: 13)

	BAU scenario	Scenario 1,3	Scenario 2,4
Delivery distance [km]	167.7	81.38 (LNG: 40; 3.5 t: 41.38)	123.38 (16 t: 82; 3.5 t: 41.38)
GHG emission [kg CO_2]	330.9	25.943 (LNG: 25.846; 3.5 t: 0.039)	0.07 (16 t: 0.031; 3.5 t: 0.039)

3.3.2 "What if" scenario: changing the place of the minihub

In this scenario, LL4 examined what happens if the location of the minihub changes, whether this causes any significant differences in the various environmental, economic and traffic impacts. Based on the simulation made by MTM model, it can be seen that this does not cause significant results in such a smaller area, there are very small differences in the KPI values.

In the case of this area, the biggest difference may be the change of the type and capacity of the used vehicles or expanding the area.

Table 10. Results of the "What if" scenario: changing the place of the minihub

Main output from MTM model	Nyugati railway station	Boráros square	Március 15. square
Numbers of vehicles	11	11	12
Average delivery distance/vehicle	7,89	9,7	7,65

This "What if" scenario was simulated with 2-Echelon model as well, which showed some differences. In case of Március 15. square, due to the method of estimation, much lower results were calculated even if the number of vehicles is still the same as in the other cases. The main reason for this is that the place of the minihub is the closest to the centre of the investigation area with a higher density of delivery addresses.

3.3.3 "What if" scenario: using e-vehicles and cargo-bikes

In this scenario, another business model has been tested, using e-vehicles and cargo-bikes for serving the stores in the investigation area. According to the simulation, the total delivery distance is about 100 km. The main reason for this is that the capacity of the cargo-bike is so small that more than two addresses cannot be served with one cargo-bike, and in total more delivery distances need to be done.

Regarding the distribution of the number of stores served, it can be established that 25% of the stores are in the downtown area, in this case it is 16 addresses. For these deliveries, 13 cargo-bikes are needed because of the small capacity. In total, these cargo-bikes cover 30 km. However, in case of deliveries by the electric vans from Boráros square, to serve the other remaining stores (49 addresses), which do not belong to the strictly considered downtown area, 9 vehicles are sufficient, covering a total of 70 km. Looking at the ratios, 60% of all vehicles are required to serve the downtown area, even though 75% of the addresses are outside this strictly considered area. Based on the results, the conclusion can be drawn that in case of WSZL's deliveries, cargo-bike service is not a great option, since the amount of goods to be delivered to each store is greater than what could ideally be delivered by cargo-bike. This type of delivery is worth investigating in the case of B2C.

The main conclusion of the simulations is that the effect can be measured well (in this case, with smaller pilot), it is valuable for the logistics service provider. However, in case of a larger investigation, it can be more valuable for public authorities and companies for experimenting and pre-piloting, such as in other city logistics related R&D project or introduction of new regulations.

3.4 LEAD Digital Twin for LL4

The LEAD Digital Twin (DT) Platform has been configured to support the Budapest LL models and to provide decision support through a single DT environment, combining the results offered by the independent digital modelling tools, as developed and utilised by specialized personnel in their local computing environments.

In more detail, Macroscopic Transport model in PTV's VISUM software has been the central modelling artifact based on which the integration took place, connecting to two other environmental impact assessment models, forming the following *DT Platform scenarios*:

1. Budapest DT Scenario 1: Focusing on the integration of VISUM simulation software with the EVCO2 model, in the case that the CO2 emissions from a delivery fleet comprising of electric delivery vehicles are required and,
2. Budapest DT Scenario 2: Focusing on integrating VISUM simulation software with the COPERT model, supporting the simulation case when environmental emissions from the delivery activity when conventional gas- and diesel-powered delivery vehicles are used.

To create these two *DT Platform scenarios*, two model connectors had to be developed: One connector from *VISUM-to-EVCO2* and a second from the *VISUM-to-COPERT* model. The model connectors are software packages available on the LEAD DT Platform, including connecting models' logic, that can handle the transformation of results data from one model, to input datasets for the next model in the model execution order (in each *DT Platform scenario)*.

The integration of models in the case of the Budapest LL has been further challenged by the fact that VISUM is a proprietary simulation software whose usage is only allowed in a computer environment for which a license exists. Therefore, it could not be run on the DT platform and its hosting server, and communication through an API with BKK's server had to be established (for which a license existed). An Application Programming Interface (API) to VISUM has been developed in collaboration with INLE, working as a server on BKK's local computing environment. From there, the DT Platform accessed the results from VISUM via the API, which were then provided to the model connectors and finally to EVCO2 and VISUM. The Budapest LL and its DT-specific configuration also used the API to COPERT software package, enabling usage of COPERT in the second *DT Platform scenario*. The API to

COPERT has also been used in the Madrid LL and Porto LL. Figures below give a high-level representation of the Budapest DT Scenario 2 (VISUM, COPERT) for the Budapest LL.

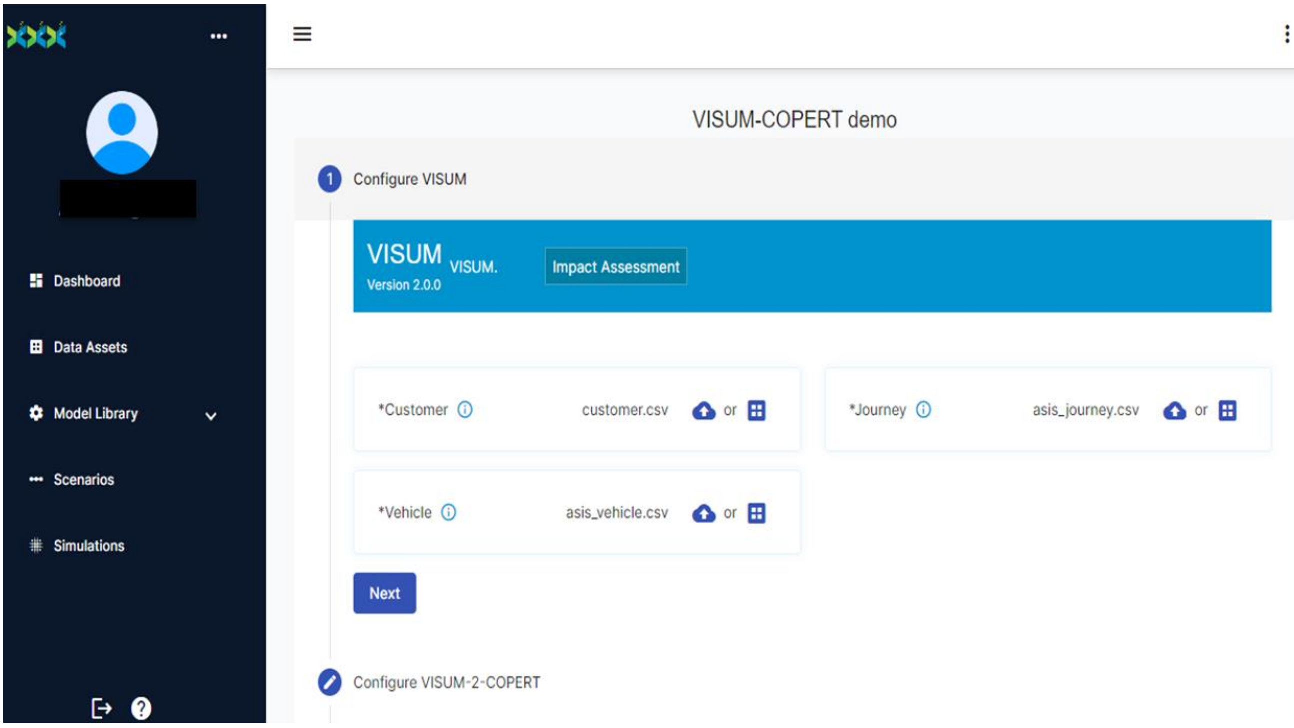


Figure 8. VISUM Configuration

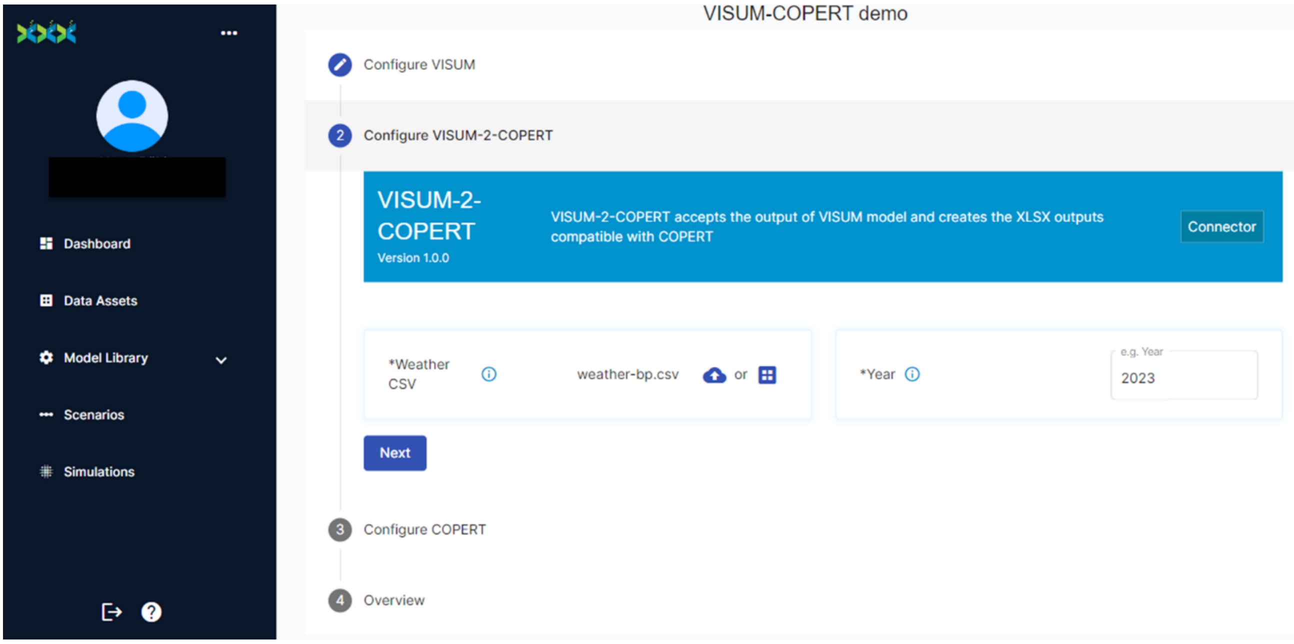


Figure 9. VISUM-2-COPERT Configuration

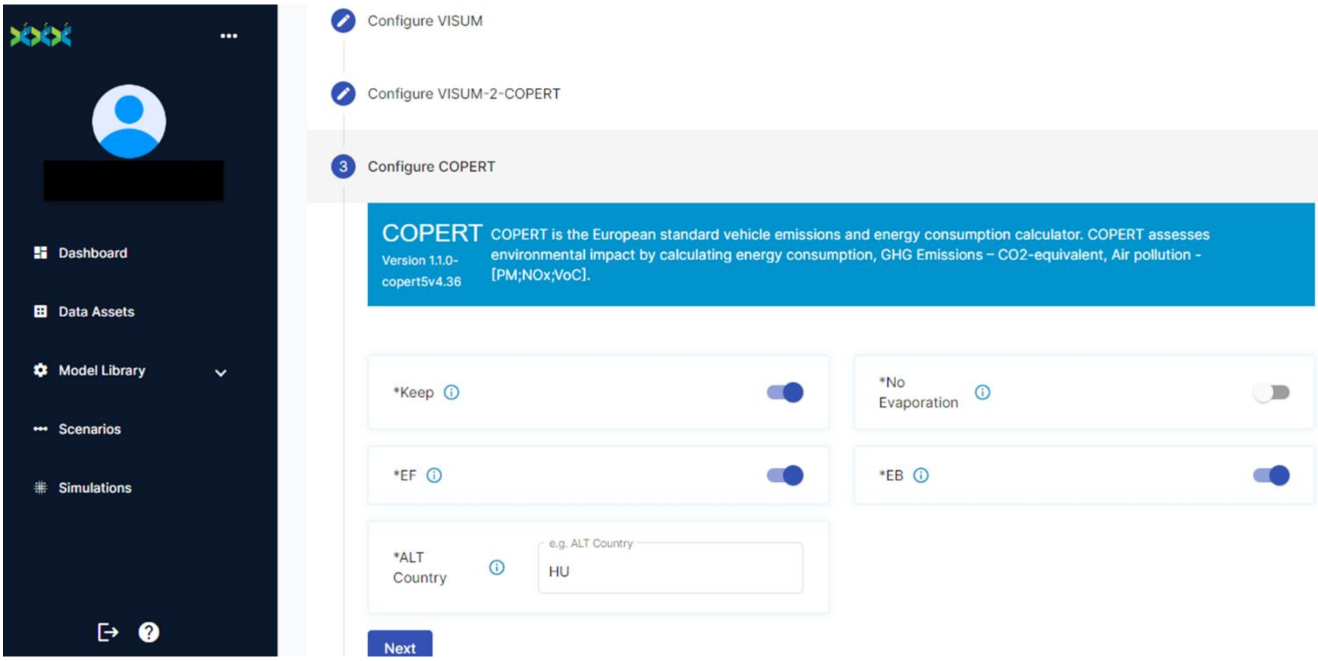


Figure 10. COPERT Configuration

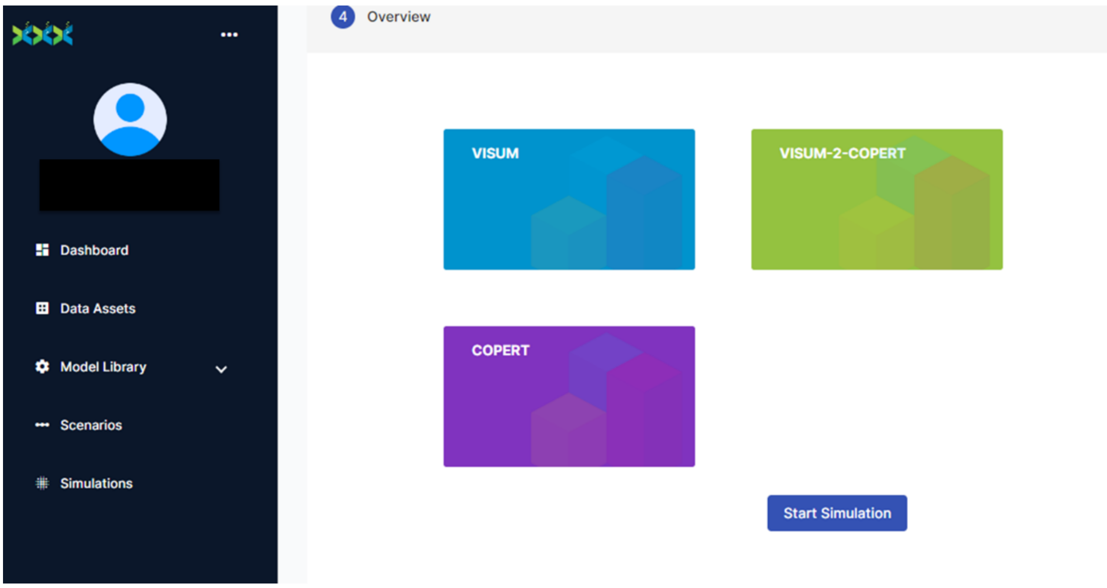


Figure 11. Overview of the Configuration

4 KPIs measurements

The relevant KPIs for LL4 Budapest have been presented in D3.1 with the related objectives and targets, and the baseline KPIs have been presented in D3.9. This section presents the (re)calculated values for the baseline and the TO BE scenario. The calculation method is included in Annex 2.

The data for calculating the KPIs come from the average distribution activities of WSZL within Budapest Grand Boulevard. The basis of the AS IS scenario calculation are the WSZL's partners located within the Budapest Grand Boulevard. In case of the baseline scenario, the investigation area is served from the BILK by 12 t vehicles. These vehicles have an average EURO5 engine. This area is served by an average of 5 vehicles, and WSZL meets the needs of an average of 6 partners in 8 hours a day per vehicle.

In case of the 4 value case scenarios, the investigation area and the average number of partners served per days are the same as it is in the baseline scenario. The more significant difference is that for the deliveries WSZL used different types of vehicles according to each scenario:

- in scenario 1 and 3: 40 t LNG vehicle and 3.5 t electric vehicles
- in scenario 2 and 4: 16 t electric vehicles and 3.5 t electric vehicles.

The tables below summarize the significant data for the KPIs calculation for the AS IS and for the TO BE scenarios.

Table 11. Significant data table of the Business As Usual (AS IS) of the Budapest Grand Boulevard (provided by WSZL)

Significant data for the AS IS calculation	
Number of partners served per day	6 partners
Daily working hours (within the investigation area)	8 hours
Daily delivery distances	90 km
KM fee (with toll fees)	1.4 EUR/km
Average consumption	15.4 litre/100 km
CO2 multiplier	0.0026 t CO2/litre
Average vehicle physical size	Length: 7.5 m, Width: 2.5 m

Table 12. Significant data table for the TO BE calculations (provided by WSZL)

Significant data for the TO BE calculation	
Number of partners served per day	6 partners
Daily working hours (within the investigation area)	8 hours
Daily delivery distances	40 t LNG or 16 t electric vehicles: 18 km 3.5 t electric vans: 21 km
KM fee (with toll fee)	1.8 EUR/km
Average consumption	LNG: 21 kg LNG/ 100 km, 2.6 litre diesel/100 km 16 t electric vehicle: 90 kWh/100 km 3.5 t electric vans: 35 kWh/100 km

Significant data for the TO BE calculation	
CO2 multiplier	0.0026 t CO2/litre
Average vehicle physical size	LNG: Length: 8.3 m, Width: 2.6 m 16 t electric vehicle: Length: 7.5 m, Width: 2.5 m 3.5 t electric vans: Length: 4.6 m, Width: 1.9 m

During the physical pilot, LL4 experimented with multiple solutions, and calculated the KPIs for all the scenarios. These calculated KPIs are included in Annex 2, but in the following tables only the baseline and the final value of the Scenario 3 are presented, because based on the experiments, the Scenario 3 is considered to be the most successful. This scenario performed significantly better in most examined scenarios, showing favourable emissions, which is one of the key factors when it comes to urban logistics. During the analysis of key performance indicators, only minor differences were observed between the Scenario 1 and Scenario 3. However, in Scenario 3, the occupied area for the last mile delivery in the city and the resulting traffic congestion were the lowest compared to the other scenarios and the current diesel operation, making this scenario the preferred choice as the best-case scenario. Moreover, based on the test experiences, the used vehicles, despite being more expensive due to high CAPEX costs, achieved significant emissions savings.

The operation in case of Scenario 3 was as the followings: The 40 t LNG vehicles departed from the BILK warehouse, then stopped at the designated area near Nyugati Railway Station. Here, the loading process into the 3.5 t electric vehicles was simulated with a 15 minutes waiting time. Afterward, the electric vehicles started delivering to the stores within the Grand Boulevard of Budapest.

In the following, the KPIs for LL4 Budapest are shown for the baseline scenario and for Scenario 3 (LNG truck, electric vans, 24h mobile depot). These tables have been also shown to the CoP members during the 2nd workshop.

Table 5. LEAD Environmental final KPIs: LL4 Budapest "AS IS" vs "TO BE" scenarios

KPI	Baseline value (AS IS)	Final Value (TO BE)	Target	Δ (AS IS – TO BE)
Energy consumption (litre/delivery)	69.3	8.5	-20%	-87.5%
GHG emission (tCO_2/delivery)	1.1	0.022	-20%	-97.92%
Air quality (gPM/delivery)	8.3	0.224	-10%	-89.9%
Air quality (gNO/delivery)	581.1	5.9	-10%	-98.89%

KPI	Baseline value (AS IS)	Final Value (TO BE)	Target	Δ (AS IS – TO BE)
Noise impact (dBA)	400	0 (local noise)	-10%	-100%

During the pilot, LL4 achieved significant reductions and savings in the environmental impact compared to the preliminary objectives by using alternate energy delivery vehicles (electric vehicles, LNG truck).

Table 6. LEAD Social final KPIs: LL4 Budapest "AS IS" vs "TO BE" scenarios

KPI	Baseline value (AS IS)	Final Value (TO BE)	Target	Δ (AS IS – TO BE)
Jobs created (employees)	13	18	+5%	+28%
Quality of the jobs	1	4	Average score >= 3.5	achieved
Neighborhoods quality of life	1	4.5	Average score >= 3.5	achieved
Users sustainable behaviour	1	4.5	Average score >= 3.5	achieved
Cooperative solutions & incentive measures	Not applied			

In case of the social KPIs, most of the initial targets have been achieved. According to the drivers of the vehicles, using these types of vehicles is easier and even can be quicker to serve the logistics partners at WSZL. During the pilot phase, LL4 held several workshops, in which the different stakeholders could share their experiences and promote other sustainable solutions, for example using cargo-bikes for the deliveries in the inner city. This suggestion has been considered and examined also as a "What if" scenario (see in Section 3.3). The main aim was to have an open discussion with the different stakeholders about city logistics related solutions, incentive measures which can be integrated into the Budapest Sustainable Urban Logistics Plan, and provide useful input for the pilot projects such in case of LEAD project. It was more optimal for the project to share ideas with stakeholders instead of conducting a survey, potentially discussing the drawbacks and obstacles of the next steps (actual implementation), and possibly expressing a need towards the relevant stakeholders to address and resolve these issues.

Table 7. LEAD Economic final KPIs: LL4 Budapest "AS IS" vs "TO BE" scenarios

KPI	Baseline value (AS IS)	Final Value (TO BE)	Target	Δ (AS IS – TO BE)
Average delivery cost of the business model (EUR)	630	718.68	-10%	**+13.6%**
Congestion 1 (Congested Shipments)	Not applied			
Congestion 2 (Congestion from vehicles)	863.2 m^2	322.8 m^2	-10%	-62.6%
Urban storage and parking space	742.5 m^2	113 m^2	-5%	-84.77%
Financial internal rate of return of the investment conducted	Not applied			
Shop/retail benefits (shippers)	Not applied			
Delivery time (minutes/delivery)	2400	1728	-5%	-28%
Delivery reliability within the time window	90%	90%	+10%	**0%**

Regarding the economic KPIs, there were a slightly increase in the delivery costs, mainly due to the higher cost of using these electric vehicles. In case of the delivery reliability, there was no change, the service level of WSZL is already at a good value. There were some KPIs, that were not measured finally. Instead of Congestion 1, LL4 measured Congestion 2, because data was available for this type of KPI. Regarding the financial internal rate of return of the investment conducted, this was not taken into account for the baseline scenario either, as no actual costs were incurred. This KPI will be calculated at a later stage, during this pilot LL4 examined the technical conditions and how this type of freight transport can be integrated into the current distribution chain. Regarding the shop/retail benefits, LL4 didn't calculate this value, because for them this testing period was only good feedback that WSZL operation can work with this type of vehicles, but other than this, it has not yet brought any other benefits.

In general, the pilot has delivered most of the KPIs as expected. Considering the results of the pilot, it is worth extending the pilot area and examining a larger part of the distribution chain in order to achieve truly significant results.

5 Validation and user acceptance

LL4 Budapest (BKK, WSZL and SZE as organizers) conducted 3 stakeholder workshops since the completion of D3.9 Budapest Value Case (v1) with the involvement of the Communities of Practice (CoP) and additional, scope-specific stakeholders. All three workshops were related to the strategic planning of sustainable urban logistics (SULP) in Budapest, but only two of these were dedicated specifically to the LEAD project LL4 activities and the final validation of the Budapest Value Case scenarios. The first two workshops were organized in 2022 and the third one in early 2023. The three workshops have been built up on each other, accordingly, for the better understanding of the relation between them, all the three are mentioned here, but, with regards of the LEAD project activities, only the results of the first (Workshop 1) and the third (referred hereby as Workshop 2) are specifically relevant, while the second workshop was entirely dedicated to the reviewing of Budapest SULP actions.

The objective (in the first step) was to introduce the setting of the pilot activities to the stakeholders involved in the LL4 Communities of Practice (CoP) and to build in their additional observations before starting to perform the physical actions. They were also invited to share their suggestions for the possible future use of the DT, or other existing modelling tools, and their thoughts about other future scenario compositions that should be considered. The objective was (in the second step – after completing the pilot activities) to validate the pilot as a new business model and its results and to evaluate the DT process and DT as a tool by the potential future users. During the validation, user acceptance assessment was also focused to compile insight for enhancing the adoption and overcome the identified barriers and challenges. As a side-objective, LL4 Budapest, by extending of the scope of these workshops, requested the participants (the same circle of stakeholders) to give feedback on the draft SULP actions, in order to channel their feedback together with the LL4 Budapest pilot results into the Budapest SULP.

All the workshops used different interactive tools and working in groups for the effective involvement of the participants and for the better processing of their inputs provided.

5.1 Workshop 1: LEAD Budapest Living Lab workshop

Workshop 1 was organized on 2nd June 2022, in parallel with the setting up of the physical pilot actions. The actual status of the Digital Twin, the location of the actions (defining the B2B target locations with iterative steps), the LL4 scenarios combining the chosen LEAD strategies, the description of the 2-echelon supply process and the expected impacts (measured by KPIs, as listed in Chapter 4) of LL4 activities were introduced to the invited CoP stakeholders: 30 participants coming from various fields of urban freight transportation and city logistics (as listed in Annex 3). The overall session focused on validating the LEAD project's process, and simultaneously, also inviting the participants to be involved in the ongoing Sustainable Urban Logistics Planning (SULP) of Budapest.

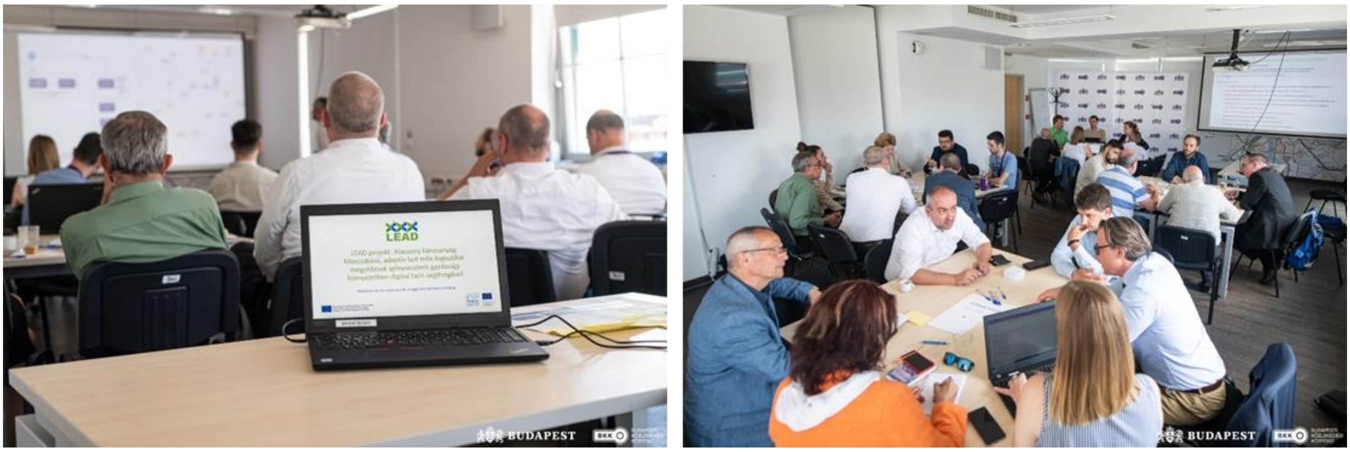


Figure 12. View of the local workshop DT presentation and group activity (2nd June, 2022)

The workshop highlighted LEAD strategies and tools that are most relevant for LL4 stakeholders and the combination of those methodologies that were to be tested through the pilot activities. CoP participants were familiarized with the methods – including simulations with the Digital Twin and their validation through the live pilot actions – providing the existing Macroscopic Transport Model of Budapest with an improved freight transportation layer.

Presentations on current LEAD project activities and SULP planning were also followed by some interactive sessions where the participants were divided into groups to identify the actual main problems and challenges affecting city logistics and last-mile delivery flow in Budapest and to discuss the priorities of different solutions on the short and on the long-run. Regarding the implementation of the different measures, the groups preferred, in general, the ones that support a more reliable and predictable service operation, with better cooperation between the different actors.

The group session and the workshop also encouraged the CoP participants for openness and cooperation, for being more transparent to achieve the shared goals. Each participant was interested in the future exploitation of LEAD results and tools and in assisting the sustainable urban logistics planning for the city.

Workshop agenda and list of attendees are shown in Annex 3.

The workshop was published on the LEAD project website, under news items, available here.

5.2 Workshop 2: Validation of the Budapest pilot actions and the Digital Twin modelling

Workshop 2, as the final local workshop in LL4 Budapest was organized on 30 April 2023, and was performed by incorporating the UPMs methodology on validation of the pilot activities and the evaluation of the Digital Twin with the help of two different surveys, which are shown in Annex 3 (D3.15, 2023). The answering of the surveys by the CoP participants were conducted during the workshop via online Mentimeter[6] tool and the detailed results are shown in Annex 3.

[6] *https://www.mentimeter.com/*

With the help of the CoP stakeholders, the workshop aimed to evaluate the user acceptance of the Budapest pilot actions, the outcomes of the Digital Twin modelling, and the Budapest Value Case scenarios. Participants from different sectors, including urban logistics, freight transportation, package delivery, traffic modelling research activities, and rulemaking for public space distribution attended the workshop.

Figure 13. View of the local workshop LL4 pilot validation survey and group activity (April 30th, 2023)

In the introduction, a summary of LEAD project's activities and outcomes was given to the participants. Following that, participants were asked to provide feedback on the Budapest Pilot actions and Digital Twin modelling, as well as their thoughts and recommendations on how to enhance data-based planning for a sustainable city logistics ecosystem.

The pilot validation survey results (referred to in Annex 3) show that CoP members consider the LL4 pilot actions to be very feasible on a larger scale in the city (e.g., involving all logistics operators and other districts, etc.). They also agree on that the larger scale implementation would have a positive impact on the quality of life of the city's inhabitants and also on the business performance of logistics operator. In general, CoP members strongly agreed on the medium- long-term impacts of the presented LEAD strategies on last-mile logistics.

During the workshop, the modelling possibilities related to city logistics were an important topic. The Digital Twin validation survey results (referred to in Annex 3) show that CoP members consider LL4 DT modelling quite valuable for the logistics service providers, and right now moderately valuable for the policy maker level. The participants discussed, that modelling the movement of goods is possibly similar to the modelling of the movement of people, with the gravity model, but proper segmentation is very important. The biggest problem is not the lack of methodology for modelling, but the lack of data. While in public transportation, the data owner is the local public transport authority/public transport operator/municipality, the data is available for modelling, however, the city logistics and related tasks are done by the private sector, the data is not available for the transport authorities.

The participating private logistics companies confirmed, that they are collecting and analysing a lot of data (including the necessary data for modelling), but a legal framework for data transfer to the city is missing. If it would be compulsory, for all the logistics companies to transfer data, it would be a good solution, but on a voluntary basis, companies will not likely share the data, as it could lead to a competitive handicap. In case of the LL4 pilot, the data provided by WSZL is a good starting point to be able to run tests on a pilot level, however at the city level, it is not enough just to upscale the data from WSZL.

CoP's suggestions, related to both pilot actions and DT modelling evaluation, showed increased demand for an integrated and coordinated data collection and sharing. For that purpose, by concentrating on the mapping of accessible data sources and potential collaboration with operators to construct new pilot cases based on LEAD project results, LL4 partners extended the workshop's focus. Participants were also encouraged to engage in a more in-depth discussion regarding the possibility for data-sharing cooperation between industrial actors, academic institutions, and the city's integrated transport manager.

The workshop was published on the LEAD project website, under news items, available here.

5.3 Conclusion

In general, user acceptance, based on the workshop results and CoP feedback, showed very good results, highlighting the data-based deployment of a minihub and the use of alternate energy delivery vehicles (as this is shown by the pilot validation survey, wordcloud answers to question No. 8 of Annex 3). The LEAD pilot actions produced findings and added information for further investigating the practical effects of combining LEAD strategies. The session demonstrated that there is still a lot of room for improvement in data-sharing collaboration between business stakeholders, academic institutions, and the city's integrated transport manager. Building cooperation and attaining beneficial outcomes also benefited from the lessons learned from the Budapest Sustainable Urban Logistics Plan underway simultaneously with the LEAD project.

The LL4 Digital Twin, according to its built-up structure, is valuable for the logistics service providers to assess future value cases with the combination of LEAD strategies. Eventually, the tested scenarios showed similar results as it was expected (based on preliminary CoP evaluation), scenario No. 3 was the one that combined the LEAD strategies in the most efficient way (based on the measured KPIs).

6 Learnings and recommendations

LL4 has experienced several challenges during the implementation.

Research projects require different people with experience in different domains to work together. One of the most important lessons is that the only way to achieve LLs goals is to find and connect people with the right competencies during the course of the project.

In collaborative research projects, the stakeholder engagement is also vital, since the different stakeholders represent very different interests and this area is owned mostly by private sector. Strong coordination and willingness from the CoP participants to collaborate and work together is essential. Moreover, this is really important in the simulation phase, where LLs need to work closely with technical partners to develop well-functioning digital twin models.

During the project, the integration of the MTM model was more challenging than it was expected due to technical complexities. A server program had to be created, which enabled the connection between the modelling machine and the platform. This also raised questions regarding the IT security, which had to be handled. In such a situation, proper communication and cooperation with the supporting and technical team proved crucial, and facilitated the LL team to carry out the necessary tasks in the most efficient way.

In connection with the simulation one of the main lessons learned is that LLs need to find a solution for the data collection. Here, it is worth mentioning that the main conclusions of the workshops and the discussions with logistics companies were that data collection remains a challenge. To accelerate the transition to data-driven decision making with an advanced tool, a legal framework should be established. DTs are data-driven decision support tools and can compile data in real time to provide insights dynamically. Thus, data availability should be a priority and the data must be thoroughly mapped (how accurate, how well it can be used, from where can be gathered, etc).

Regarding the real-life implementation, the proportions of the used and available types of vehicles in the last-mile distribution service providers have been changing rapidly during the last years given not only the pandemic situation and the increased number of home deliveries but also due to the willingness of the freight delivery sector to contribute to reach the climate goals. Besides this, there were some challenges related to the fleet availability. If the actual vehicles that are to be deployed for running the physical tests, are also allocated for other delivery operations of the service provider, their operation schedule need to be considered more carefully when planning the dates for the testing. It is suggested to also pre-book some additional alternative dates for the test runs that are coordinated between the project team and the service provider in case the first dates would not work out for some not foreseeable reason, as the availability of these vehicles, involved in actual operations, would be less flexible.

7 Summary and outlook

In conclusion, regardless the challenges experienced during the pilot, LL4 was able to assess different scenarios combining the real testing-controlled environment (vehicles operational data) and simulate “What if” scenarios by using LEAD models. LL4 gathered experiences from using transhipment points in the distribution chain of WSZL (different types of vehicles, delivery costs, delivery time, etc.). Based on the pilot results, the DT developed in the project can be used well at the pilot level for examining a smaller area in case of Budapest, but it still needs to be developed in order to be used at the city level of Budapest.

In case of Macroscopic Transport Model, the project gave a good starting point for the development of the freight traffic layer, but in order to be further developed and extended to the city level, a lot of data is still needed from other stakeholders. BKK also need to have a well-detailed development plan using the experiences from LEAD project and to develop a legal framework for data transfer (in Chapter 5 more detailed information can be found).

Regarding the physical pilot, the project partners gained a lot of experience and knowledge, especially regarding the used vehicles during the pilot. These results and knowledge can be used in other R&D projects such as in LIFE HungAIRy project in which micro consolidation centres will be implemented in order to help supplying the inner-city area of Budapest.

Last but not least, LEAD project provided useful inputs, tools for the development of the SULP in Budapest and helped to lay the foundation for further collaborations with stakeholders beyond the project.

References

LEAD Deliverable D2.3 Decision Support System & APIs (v1)

Royo, B., Ciprés, C., Lekkakos, S. (2021). LEAD D1.4 Innovation Agenda - Value case scenarios and validation KPIs, LEAD Project

Royo, B., Ciprés, C., Lekkakos, S. (2021). LEAD D3.1 Living Labs planning, setup and management, LEAD Project

LEAD Deliverable D3.9 Budapest Value Case (v1)

Annex 1: Digital twin details

Table 13. 2-Echelon Model: modelling conditions and assumptions for the AS IS scenario

Parameter	Value	Explanation
k	0.58	Arbitriary value. Some trials reflect this was the best value
workshift	8	WSZL workshift time
branchHandlingTime	1	Average time for preparing orders in the facility of Budapest (WSZL)
UCCHandlingTime	0.5	Average time for preparing and crossdocking orders in the UCC (WSZL)
stopTimeFirstEchelon	0	Average time for deliverying the orders from UCC to the minihub. In the AS IS scenario the averagetime is zero, because this step does not exist.
stopTimeSecondEchelon	0.1	Average time for deliverying the goods to the stores
distanceType	2	After different trials, the haversine distance provided closer values to the real distance.

Table 14. Meteorological data input of Budapest for COPERT

Month	Minimum Temperature (ºC)	Maximum temperature (ºC)	Humidity (%)
January	-4.0	6.0	82.0%
February	-3.0	7.0	75.0%
March	2.0	11.0	67.0%
April	9.0	16.0	60.0%
May	13.0	20.0	62.0%
June	17.0	24.0	63.0%
July	20.0	25.0	60.0%
August	19.0	27.0	62.0%
September	13.0	20.0	68.0%
October	9.0	15.0	73.0%
November	1.0	9.0	81.0%
December	-3.0	5.0	83.0%

Annex 2: KPIs calculation methodologies (Budapest pilot)

Table 15. LEAD Environmental KPIs: LL4 Budapest calculation method (AS IS scenario)

KPI	Calculation Method	Measurement units
Energy consumption	For a baseline scenario, based on the vehicle specific data provided by WSZL, LL4 calculates the environmental KPIs.	Average energy consumption per delivery (litre/delivery)
GHG emission		Average CO_2 per delivery (tCO_2/delivery)
Air quality		Average PM2.5 per delivery (gPM2.5/delivery)
		Average NO_2 per delivery (gNO_2/delivery)
		Average VOC per delivery (gVOC/delivery)
Noise impact		Average dBA per delivery (dBA)

Table 16. LEAD Social KPIs: LL4 Budapest calculation method

KPI	Calculation Method	Measurement units
Jobs created	Data from operator	Number of employees
Quality of the jobs	Quality of the jobs (local survey involving the CoP)	Average score >= 3.5
Neighborhoods quality of life	Neighborhoods quality of life (local survey involving the CoP)	Average score >= 3.5
Users sustainable behaviour	Users sustainable behaviour (local survey involving the CoP)	Average score >= 3.5
Cooperative solutions & incentive measures	Cooperative solutions & incentive measures (number of solutions implemented during the pilot development)	Not applied

Table 17. LEAD Economic KPIs: LL4 Budapest calculation method ("AS IS" and "TO BE" scenarios)

KPI	Calculation Method	Baseline scenario value
Average delivery cost of the business model	Data from operator	Annual average cost per delivery (€/delivery)
Congestion 1 (Congested Shipments)	Data from operator	Not applied
Congestion 2 (Congestion from vehicles)	Data from operator	Daily average time spent by vehicles on the road multiplied by the area occupied by vehicles (m^2*/day)
Urban storage and parking space	Data from operator	Urban storage and parking area required depending on the type and ownership of the area (m^2)
Financial internal rate of return of the investment conducted	Data from operator	Not applied
Shop/retail benefits (shippers)	Local survey involving Shops/Retails	
Delivery time	Data from operator	Average time required to make a delivery (minutes/delivery)
Delivery reliability within the time window	Data from operator	Daily average percentage of deliveries made on time within the time window and in good conditions (%)

Table 18. LEAD Environmental KPIs for the baseline and for the 4 value case scenarios

KPI	Baseline value (AS IS)	Final Value Scenario 1	Final Value Scenario 2	Final Value Scenario 3	Final Value Scenario 4
Energy consumption (litre/delivery)	69.3	8.5	0	8.5	0
GHG emission (tCO_2/delivery)	1.1	0.0224	0	0.0224	0
Air quality (gPM/delivery)	8.3	0.8	0.00001	0.224	0.00001
Air quality (gNO/delivery)	581.1	5.9	0	5.9	0

KPI	Baseline value (AS IS)	Final Value Scenario 1	Final Value Scenario 2	Final Value Scenario 3	Final Value Scenario 4
Noise impact (dBA)	400	0	0	0 (local noise)	0

Table 19. LEAD Social KPIs for the baseline and for the 4 value case scenarios

KPI	Baseline value (AS IS)	Final Value Scenario 1	Final Value Scenario 2	Final Value Scenario 3	Final Value Scenario 4
Jobs created (employees)	13	18	15	18	15
Quality of the jobs	4	4.5	5	4.5	5
Neighborhoods quality of life	3	3.5	4	3.5	4

Table 20. LEAD Economic KPIs for the baseline and for the 4 value case scenarios

KPI	Baseline value (AS IS)	Final Value Scenario 1	Final Value Scenario 2	Final Value Scenario 3	Final Value Scenario 4
Average delivery cost of the business model (EUR)	630	331.5	397.8	331.5	397.8
Congestion 1 (Congested Shipments)	Not applied				
Congestion 2 (Congestion from vehicles) [m²]	863.2	322.8	354.7	322.8	354.7
Urban storage and parking space [m²]	742.5	209.1	240.9	113.1	144.9
Financial internal rate of return of the	Not applied				

KPI	Baseline value (AS IS)	Final Value Scenario 1	Final Value Scenario 2	Final Value Scenario 3	Final Value Scenario 4
investment conducted					
Shop/retail benefits (shippers)	Not applied				
Delivery time (minutes/delivery)	2400	1728	1728	1728	1728
Delivery reliability within the time window	90%	90%	90%	90%	90%

Annex 3: Workshops' details

Table 21. Attendees' organizations/ companies of LL4 Workshop 1-2

Organization	Description
BKK Centre for Budapest Transport, project partner	Budapest LL coordinator, local mobility manager, decision support for the municipality, responsible for SUMP
BME / Technical University of Budapest, Department of Material Handling and Logistics Systems	academics in disciplines of urban mobility, logistics, data science, computer science
Budapest Public Roads	public road operator
Clean Air Action Group	environmental NGO
DPD Hungary	courier service
Foxpost Zrt.	parcel locker and delivery service
GLS General Logistics Systems Hungary Kft.	delivery service and logistics
Green Brother	professional network for green technology, energy efficiency, circular economy, smart cities and mobility
Hajtás Pajtás	courier service
Hungarian Association of Logistics, Purchasing and Inventory Management (MLBKT)	association for logistics, inventory management
KTI Institute for Transport Sciences Non-profit Ltd.	R&D, disciplines of urban mobility, logistics, data science for sustainable transport systems
Magyar Posta Zrt.	Hungarian Post Office Ltd
MKFE	Hungarian Road Transport Association
Mobilisssimus Kft.	professional consultancy, conceptual and strategic planning
Municipality of Budapest	regulator and general decision maker, providing input and support
SAP Hungary Kft.,	systems, applications, and products in data processing
Széchenyi István University (SZE), project partner	academics in disciplines of urban mobility, logistics, data science, computer science
Trenecon Kft.	professional consultancy, engineering, conceptual and strategic planning
ViddL Kft.	courier service
Waberer's-Szemerey Logisztika Kft. (WSZLK), project partner	service provider (warehousing, consolidation centres)

Table 22. Agenda of LL4 Workshop 1

LEAD Budapest Living Lab workshop

Starting of the Budapest pilot actions and the Digital Twin modelling

Date: 2 June 2022, 09:00-12:00

Location: BKK Centre for Budapest Transport

AGENDA		
09:00	**Introduction**	BKK
09:10	**Budapest sustainable urban logistics planning (SULP) process**	BKK
09:20	**LEAD project activities and discussion of their relation with the SULP process**	BKK
09:30	**Workshop activity: Challenges of urban logistics**	Everyone
10:20	*Coffee break*	
10:30	**LEAD methodology and assessment of the value case scenarios**	BKK
10:45	**Group activity:** • **Scenarios, comparing the types of measures** to be introduced in city logistics for short and long run (util 2030) • **Vision and objectives** (comprehensive and operational objectives for short and long run)	Everyone
11:45	**Group activity conclusions and feedback to the Living Lab coordination team**	Everyone
12:00	**Closing**	BKK

Table 23. Agenda of LL4 Workshop 2

LEAD Budapest Living Lab workshop

Validation of the Budapest pilot actions and the Digital Twin modelling

Date: 30 March 2023, 09:00-12:00

Location: BKK Centre for Budapest Transport

AGENDA		
09:00	• **Introduction**	BKK
09:10	• **LEAD general overview and project status**	BKK
09:20	• **Pilot actions**	WSZL
09:30	• **Digital Twin modelling**	SZE
09:40	• **Project results**	WSZL, SZE
09:50	• **Completing survey on Pilot action and DT validation**	Everyone
10:00	*Coffee break*	
10:15	• **Short presentations on…** – Traffic data, Macroscopic Transport Model – Overview of Budapest SULP planning – Pilot activities related to urban logistics	BKK
10:45	• **Group activity:** Data based planning of urban logistics processes in Budapest, mapping of data sources, collection of data, analysing data and modelling	Everyone
11:45	• **Group activity conclusions and feedback on LEAD results**	Everyone
12:00	• **Closing**	BKK

Budapest pilot validation survey (provided by UPM)

BUDAPEST PILOT VALIDATION SURVEY

Dear participant, thank you very much for attending the workshop.

For the validation and acceptance of the solutions proposed in the Budapest Living Lab aimed at achieving more sustainable and efficient last mile logistics operations, we need you to answer the following questions.

Please indicate the stakeholder you represent:

Public administration	
Shipper	
Logistic Operator	
Consultancy firm	
Research / University	
Lawyer	
Independent professional	
Citizens / Neighbour	
Other (NGO, etc.)	

Based on the results shown in the workshop and your personal expertise, rate the following items:

Perceived implementation and impacts of the pilot

1. Please rate how successful has been the **implementation** of pilot in the Budapest Living Lab.

Poor	Fair	Good	Very Good	Excellent	NR/DK

2. According to your opinion, the **business model** presented to implement the pilot in the Budapest Living Lab is…

Not at all feasible	Slightly feasible	Moderately feasible	Very feasible	Extremely feasible	NR/DK

3. Please rate the degree of **performance** of the pilot KPIs **impact results compared to the KPIs objectives set** at the beginning of the LEAD project.

Poor performance	Fair performance	Good Performance	Very Good performance	Excellent performance	NR/DK

4. Please indicate whether you agree or disagree with the **medium- long-term impacts of last-mile logistics LEAD strategies presented?**

Strongly disagree	Disagree	Neutral	Agree	Strongly agree	NR/DK

Perceived scalability of the pilot

5. Do you consider that applying the pilot launched in the Budapest Living Lab **on a larger scale** in the city (e.g. all logistics operators, other districts, etc.) is?

Not at all feasible	Slightly feasible	Moderately feasible	Very feasible	Extremely feasible	NR/DK

6. If the pilot presented in the Budapest Living Lab were **applied on a larger scale** (e.g. other logistics operators, other districts, etc.), do you think it would have **positive impact on the quality of life city's inhabitants**?

Totally disagree	Disagree	Neutral	Agree	Totally agree	NR/DK

7. If the pilot presented in the Budapest Living Lab were **applied on a larger scale** (e.g. all logistics operators, other districts, etc.), do you think it would have a **positive impact on the business performance of logistics operators**?

Totally disagree	Disagree	Neutral	Agree	Totally agree	NR/ DK

Other questions

8. What aspect/s do you consider outstanding regarding the LEAD strategies presented at the Living Lab?

9. What aspect/s would you improve of the LEAD strategies presented at the Living Lab?

Budapest Digital Twin validation survey (provided by UPM)

BUDAPEST DIGITAL TWIN VALIDATION SURVEY

Dear participant, thank you very much for attending the workshop.

For the validation of the DIGITAL TWIN of urban logistics solutions in Budapest Living Lab aimed at supporting experimentation and decision making with on-demand logistics operations, we need you to answer the following questions.

Please indicate the stakeholder you represent:

Public administration	
Shipper	
Logistic Operator	
Consultancy firm	
Research / University	
Lawyer	
Independent professional	
Citizens / Neighbours	
Other (NGO, etc.)	

Based on the presentation of the DIGITAL TWIN (DT) in Budapest Living Lab,

1. From a non-technical perspective, is the objective of the digital twin sound and understandable?

Totally disagree	Disagree	Neutral	Agree	Totally agree

2. Is the output provided by the DT clear an easy to the understand by non-technical people?

Totally disagree	**Disagree**	**Neutral**	**Agree**	**Totally agree**

3. In your opinion, does the DT replicate the logistic operations with enough accuracy?

Totally disagree	Disagree	Neutral	Agree	Totally agree

4. Does the DT include most of the information needed by planners and policy makers?

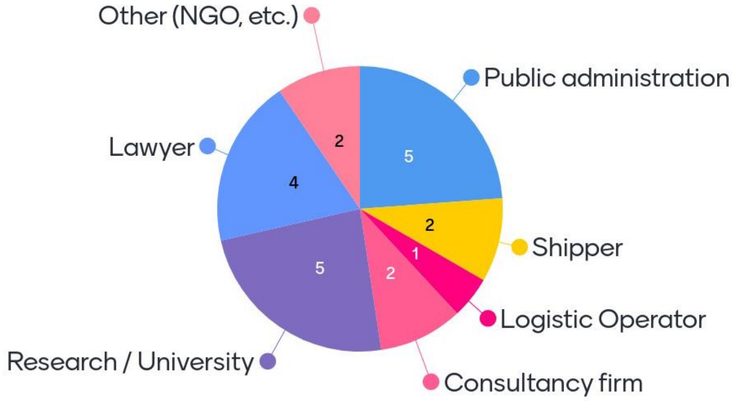
Totally disagree	**Disagree**	**Neutral**	**Agree**	**Totally agree**

5. Will the DT be useful for planners and logistic companies to achieve their objectives?

Totally disagree	**Disagree**	**Neutral**	**Agree**	**Totally agree**

6. Point out what specific topics/aspects do you miss within the DT:

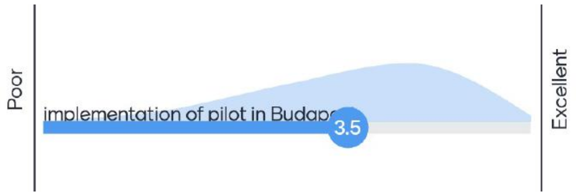
Table 24. Stakeholders by type – participating in the surveys based on UPM methodology for the validation of value case scenarios and evaluation of Digital Twin modelling



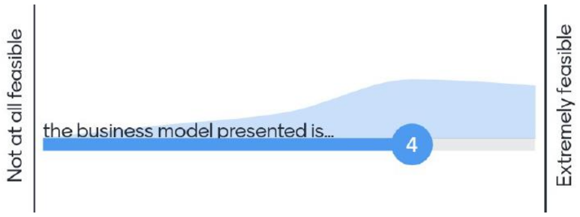
Results of Budapest pilot validation survey – aggregated values and word cloud

Perceived implementation and impacts of the pilot

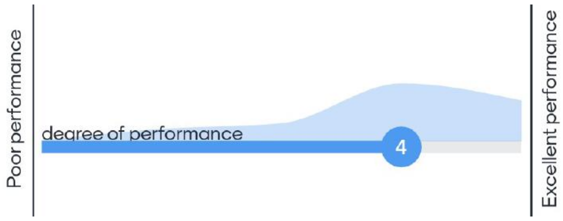
1. Please rate how successful has been the **implementation** of pilot in the Budapest Living Lab.



2. According to your opinion, the **business model** presented to implement the pilot in the Budapest Living Lab is…



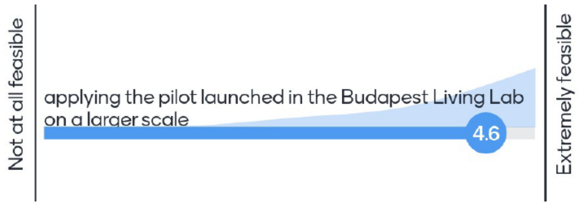
3. Please rate the degree of **performance** of the pilot KPIs **impact results compared to the KPIs objectives set** at the beginning of the LEAD project.



4. Please indicate whether you agree or disagree with the **medium- long-term impacts of last-mile logistics LEAD strategies presented?**

Perceived scalability of the pilot

5. Do you consider that applying the pilot launched in the Budapest Living Lab **on a larger scale** in the city (e.g. all logistics operators, other districts, etc.) is?



6. If the pilot presented in the Budapest Living Lab were **applied on a larger scale** (e.g. other logistics operators, other districts, etc.), do you think it would have **positive impact on the quality of life city's inhabitants**?

7. If the pilot presented in the Budapest Living Lab were **applied on a larger scale** (e.g. all logistics operators, other districts, etc.), do you think it would have a **positive impact on the business performance of logistics operators**?

Other questions

8. What aspect/s do you consider outstanding regarding the LEAD strategies presented at the Living Lab? *(Original answers were given in a word cloud)*

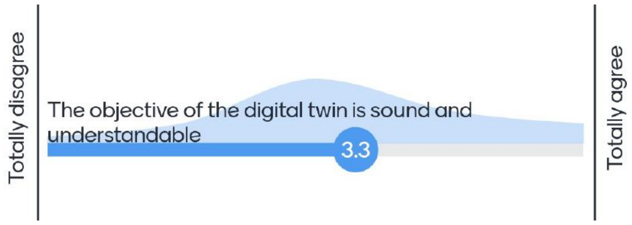
Data based, LNG, Minihub, Alternative energy vehicles, Electric, Low emission, Lower traffic, Local emission, Innovative, Environment friendly, Agile, Sustainability, Effectiveness, Agile urban supply, Innovative business models

9. What aspect/s would you improve of the LEAD strategies presented at the Living Lab? *(Original answers were given in a word cloud)*

Business model, Data, Cargo bike, Minihub optimalisation, Locations in the city, Costs, Environment impacts, Use of electric vehicles, Business efficiency, Resident benefits, Pay-off calculation, Loading bays, Intelligent, Level of service, Minihub other location, Cost effectiveness, Regulations, Cooperation between operators, LNG, Involvement of more logistics service providers, Business models, Motivation, Data communities, Sharing of capacities

Results of Budapest Digital Twin validation survey – aggregated values and word cloud

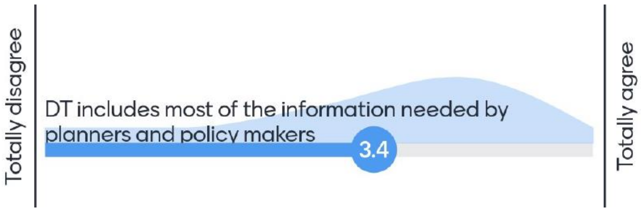
1. From a non-technical perspective, is the objective of the digital twin sound and understandable?



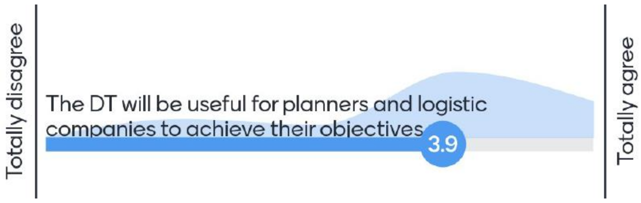
2. Is the output provided by the DT clear an easy to the understand by non-technical people?

3. In your opinion, does the DT replicate the logistic operations with enough accuracy?

4. Does the DT include most of the information needed by planners and policy makers?



5. Will the DT be useful for planners and logistic companies to achieve their objectives?



6. Point out what specific topics/aspects do you miss within the DT? *(Original answers were given in a word cloud)*

Small parcel, Market aspects, Costs, Benefits, Loading bay, Deliveries coming in from outside of the city limit, More detailed costs, Cargo bike, Parcel locker, Observation of life cycle, Storage, Mobility modes, Intermodality, Environment impacts, Customers, Visualisation, Ad-hoc demands, Transparency, Time windows, More stakeholders, Resource allocation, Dynamic function allocation