E-Laas

Energy optimal urban Logistics As A Service

Milestone report

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Scope of this report	WUT contribution to M2
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1. Summary

This M2 report presents the decision on the adequacy of SULP measures analysed within WP2 of the E-Laas project. The assessment is based on survey research, macroscopic and microscopic modelling, KPI scaling, System Dynamics analysis, earlier WP0 and WP2 reports, project publications, and the WP2 dataset.

The results show that energy-efficient urban logistics cannot be achieved through a single technology or policy instrument. The SULP measures with the strongest support are those that improve the functioning of the whole delivery system: active management of loading and unloading spaces, digital reservation and monitoring of delivery space, data exchange, KPI-based assessment, route optimisation, order consolidation, and planned development of automated parcel machine (APM) and pick-up and drop-off (PUDO) networks. These measures can support different delivery channels and vehicle technologies.

Fleet electrification, cargo bikes, light electric vehicles, microhubs, access regulations, time windows and drones were assessed as conditionally adequate. Their effectiveness depends on local spatial structure, demand density, infrastructure availability, recipient behaviour, operational feasibility and the capacity of cities and operators to coordinate implementation. Further research and development are recommended for multi-level intermodal systems, mobile microhubs, advanced B2B and pharmaceutical delivery scenarios, autonomous delivery solutions, and stronger integration with the energy system.

The main inhibitors to achieving the E-Laas objectives are limited data availability, insufficient delivery space and delivery service infrastructure, investment and operational risks of fleet transformation, charging constraints, recipient behaviour, weak institutional coordination and spatial differences between urban areas.

The WP2 dataset supports transparency, replication and further development of the E-Laas methodology by providing survey data, the microsimulation model, input data, scenario parameters and result-processing procedures.

2. Introduction

Urban freight transport is becoming increasingly important due to the growth of e-commerce, home deliveries, out-of-home delivery channels, food delivery services and new forms of last-mile distribution. These processes increase pressure on urban space, transport networks, energy systems and the environment. At the same time, cities are expected to reduce emissions, improve quality of life and support more efficient use of infrastructure.

New technologies and delivery channels, such as electric vehicles, cargo bikes, automated parcel machines, PUDO points, microhubs and drones, create new possibilities for urban logistics. However, their actual impact depends on how they are implemented and combined with process organisation, infrastructure, data exchange and user behaviour. A delivery solution that is efficient from the operator’s perspective may lose part of its benefit if it generates additional trips by recipients or requires poorly located infrastructure.

For this reason, sustainable urban logistics should be analysed as a system involving many stakeholders: public authorities, logistics operators, couriers, residents, customers, infrastructure providers and energy suppliers. Effective SULP measures must therefore combine environmental objectives with operational feasibility, social acceptance, institutional capacity and local spatial conditions.

3. Purpose and scope of the report

The purpose of this report is to synthesise the results of WP2 and to assess the adequacy of SULP measures related to the solutions analysed in the E-Laas project. The report addresses the formal M2 milestone, which concerns the decision on the appropriateness of SULP measures emulated in WP2 and the selection of the most important inhibitors to achieving the E-Laas objectives.

The report focuses on conclusions relevant to urban logistics policy. It assesses which measures can be treated as adequate, which are adequate only under specific conditions, and which should be developed further in future research or pilot applications. It also identifies the key inhibitors that may limit the expected energy, environmental, operational or social benefits.

The report does not repeat the full methodological descriptions and detailed numerical results presented in D2.2 and D2.3. Detailed assumptions, survey results, modelling procedures and scenario outputs are provided in the earlier deliverables, scientific publications and the WP2 dataset. The role of this report is to integrate those results and translate them into recommendations for energy-efficient SULP development and for further use of the E-Laas methodology.

4. Methodological basis and evidence used for the M2 assessment

The assessment carried out within M2 is a synthesis of the results of work completed in WP0 and WP2, as well as research results documented in scientific publications prepared in connection with the E-Laas project. Its purpose is to translate the collected knowledge into an assessment of SULP measures, to indicate the conditions for their effective application, and to identify the most important factors affecting the achievement of the project objectives. M2 is based on reports D2.2 and D2.3, which are used as evidence for combining energy, operational, spatial, social and institutional perspectives. Detailed numerical results, model descriptions and research procedures are available in the source reports and publications, while this report focuses on conclusions relevant to the development of SULP.

4.1. Position of M2 in the project work structure

The E-Laas project is based on an energy-oriented view of the urban logistics system, covering the whole flow from a consolidation centre, hub or other dispatch point to the final recipient. The assessment is not limited to the energy used by the vehicle carrying out the last section of the delivery. It also considers the organisation of the flow, the infrastructure used, the modal structure, recipient behaviour, and the relations between operators, public authorities and service users. This approach follows from the four main objectives of the project:

- A1 - to represent urban logistics tasks as logistics flows,
- A2 - to define operational and complementary energy use in these flows,

- A3 - to analyse the spatial and temporal variation of energy use, including the sensitivity of the system to changing conditions,
- A4 - to develop energy awareness at the level of customers, service providers and public authorities.

Objectives A1–A4 define the logic of the assessment applied in M2. Energy serves as a common measure for comparing technologies, delivery channels and organisational solutions, while social and infrastructure aspects define the conditions for their real implementation. Outcomes O1–O3 refer respectively to supporting sustainable cities, developing resilient logistics methods and infrastructure, and creating urban logistics systems that respond to climate-related challenges.

M2 closes the sequence of connected research activities that started in WP0. Report D0.1 prepared the knowledge base concerning technical, organisational and regulatory solutions used in urban logistics. D0.2 defined the attribute structure describing reference cases and scenarios, while D0.3 translated this structure into a scenario catalogue for the RC1 reference case – the Górnośląsko-Zagłębiowska Metropolis (GZM). The data enabling their parameterisation were organised in the M0 repository [17], [18], [19], [20]. D0.3 also indicated how the scenarios are linked with later modelling, the selection of transport modes, the analysis of modal structure, delivery concentration points and assessment indicators.

In WP2, the scenarios and data structures were developed in three subsequent stages. D2.1 defined the assumptions for survey and simulation research, data sources, and the method of integrating micro- and macro-level analyses. D2.2 provided knowledge about the needs, behaviours and conditions related to recipients, couriers, logistics operators and local administration. D2.3 integrated the results of macroscopic modelling, microsimulation of last-mile processes, KPI scaling and analyses carried out using System Dynamics [21], [22], [23]. The modelling framework developed in D2.3 provides the basis for interpreting the results in M2 from the perspective of SULP, implementation conditions and development directions for urban logistics systems.

The links between the successive project outputs are shown in Fig. 1. The diagram shows that M2 integrates the knowledge obtained from scenario definition, stakeholder research and delivery system modelling.

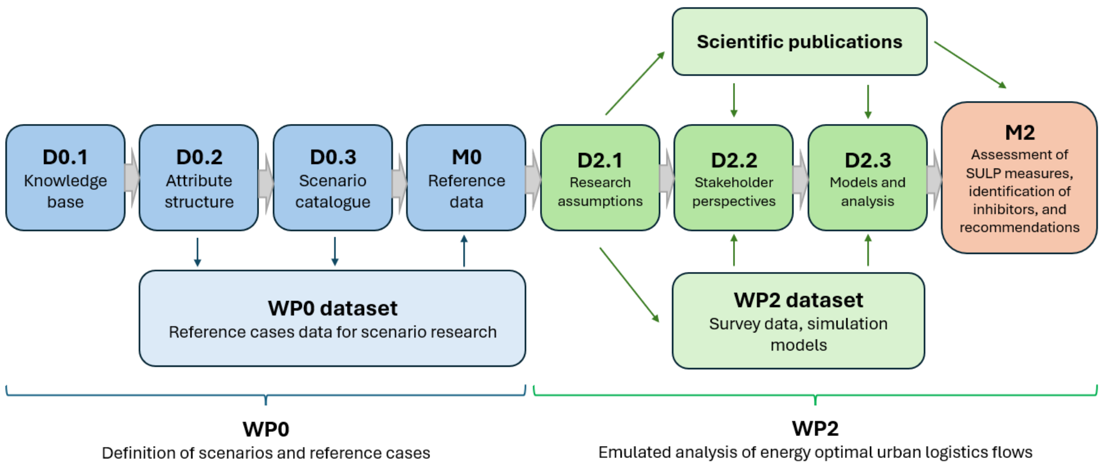

Fig. 1. Linkage of WP0 and WP2 results with the assessment of SULP measures in M2

4.2. Sources used in the assessment

The analyses in M2 were based on several complementary groups of materials. This made it possible to combine quantitative results with knowledge about user behaviour, the operating practices of logistics operators, and the conditions of urban transport policy. The scope and role of the individual sources are presented in Table 1.

Table 1. Material used in the M2 assessment

Material	Scope of information	Relevance for M2
Project proposal	Objectives A1–A4, expected outcomes, project targets and the scope of WP2	Defining the scope of the assessment and linking the conclusions with the E-Laas objectives
D0.1	State of knowledge, projects, urban practices and transport policy instruments	Identification of measures that may be included in SULP
D0.2, D0.3 and M0	Attributes, scenarios, transport relations, transport modes and reference data	Defining the scope of the analysed systems and variants of their organisation
D2.1	Assumptions for survey and simulation research, data sources and KPI structure	Ensuring methodological consistency of the analyses
D2.2	Needs, preferences, behaviours and conditions related to stakeholders	Assessment of feasibility, acceptance and implementation conditions of the measures
D2.3	Results of macro- and micro-level modelling, KPI scaling and System Dynamics	Assessment of energy, environmental, operational and spatial effects
Scientific publications	Detailed analyses of selected methods, technologies, scenarios and relationships	Documentation of detailed results and basis for formulating conclusions
Workshops and expert consultations	Experience of public administration, operators, researchers and practitioners	Complementing the interpretation of results with implementation context
WP2 dataset	Survey data, models, scenarios and experimental results	Ensuring transparency and enabling further use of the results

Project reports document the course and integration of work carried out in successive tasks, while scientific publications provide a more detailed discussion of selected methods, scenarios and results. They develop, among others, issues related to macroscopic assessment of emissions and energy consumption, microsimulation of last-mile deliveries, KPI scaling, parcel lockers, recipient behaviour, fleet electrification, cargo bikes, drones and SULP design.

The material used covers different levels of system description. Macroscopic modelling made it possible to assess the spatial distribution of flows, energy consumption and emissions at the metropolitan scale. Microsimulation enabled a detailed representation of service processes, routes, transport modes and the behaviour of delivery participants. KPI scaling methods linked the results of local experiments with a larger number of traffic analysis zones, while System

Dynamics made it possible to analyse long-term relationships between demand, infrastructure capacity, delivery channels and recipient mobility [23].

This evidence base makes it possible to assess the complete system, including the sender, operator, intermediate infrastructure, delivery channel and recipient behaviour, instead of limiting the analysis to a single transport mode. This is particularly important in the case of automated parcel machines (APM) and pick-up and drop-off points (PUDO). Parcel consolidation may improve the efficiency of courier operations, but the final balance also depends on the accessibility of points and on whether parcel collection generates an additional trip or is carried out as part of an existing user activity [11], [14].

4.3. Status of the evidence base

The range of solutions analysed in the project was diverse. For this reason, the material used in M2 was organised according to the way it was applied. Three complementary categories were adopted:

- results of direct analyses and experiments – relating to demand variants, fleet structure, modal structure, HOME, APM and PUDO channels, recipient behaviour, drone use, energy, emissions and infrastructure capacity;
- results supporting the interpretation of SULP measures – including survey research, spatial analyses, studies on access to infrastructure, parking, charging, process organisation and stakeholder cooperation;
- directions for further development and application of the methodology – including solutions that may be developed in future scenarios, urban applications or studies for specific operators.

The first category mainly includes the results of D2.3 and related publications. Macroscopic modelling analysed the impact of flow intensity and technological changes in the fleet on the spatial distribution of environmental impacts. Microscopic modelling represented the delivery processes of ready-made food, boxed meals and parcels, using different channels and transport modes. This approach covered traffic directly related to parcel delivery, as well as transfers, return trips and recipient travel [7], [23]. Within the research, PUDO is treated as an element of out-of-home delivery infrastructure and as a channel analysed from a system perspective. In the D0.3/M0 catalogue, it is not defined as a separate basic active scenario.

Scalability studies were also an important part of the direct analyses. The developed method for clustering traffic analysis zones and estimating KPIs makes it possible to transfer microsimulation results from selected reference zones to a larger area. This approach significantly reduces the number of required experiments, while still allowing energy, time and distance to be assessed for different parts of the city [15]. The results also indicated that the proper formulation of the scaling function may be more important for estimation quality than the choice of the zone-clustering algorithm itself.

The second category includes materials that support the interpretation of feasibility and social effects of the solutions. The D2.2 studies made it possible to link scenarios with recipient preferences, courier working conditions, operator capabilities and the competences of local government units. This material is used especially when assessing measures whose results depend on cooperation between several groups, the availability of urban space, the location of infrastructure or the acceptance of organisational changes [22].

The third category covers directions for further use of the developed methodology. D0.3 organised scenarios as core project scenarios, supporting scenarios and future research proposals. This makes it possible to treat the WP2 results as an open basis for further analyses, including more advanced consolidation systems, B2B and pharmaceutical deliveries, integration of urban passenger and freight transport, and further development of autonomous solutions [19].

This organisation of the material makes it possible to distinguish conclusions resulting directly from experiments from conclusions formulated on the basis of a combined interpretation of quantitative studies, surveys, literature and expert knowledge. At the same time, it allows the most promising directions for further development of the models and scenarios to be indicated.

4.4. Criteria for assessing the adequacy of SULP measures

The adequacy of SULP measures was assessed using the five criteria presented in Table 2. The criteria relate both to the project objectives and to the real operating conditions of urban delivery systems.

Table 2. Criteria for assessing the adequacy of SULP measures

Criterion	Scope of assessment
Energy and environmental effect	Impact on energy consumption, emissions, route length, number of operations and infrastructure use
Operational and economic feasibility	Possibility of integrating the measure into operators' processes while maintaining appropriate service quality and continuity
Social acceptance	Consistency of the solution with the needs of recipients, residents, couriers and other users of urban space
Institutional feasibility	Possibility for cities, operators and infrastructure managers to prepare, implement and monitor the measure
Resilience, adaptability and scalability	Ability of the solution to function under changes in demand, spatial conditions, infrastructure availability and user behaviour

The first criterion reflects the basic idea of E-Laas, according to which logistics solutions should be compared based on the energy used in the whole process. The assessment therefore covers the energy used by the vehicle, the number of routes, the level of consolidation, empty trips, recipient trips and the energy used by infrastructure. The microsimulation results confirmed that the final outcome depends on the organisation of the complete service chain, while the name of the delivery channel and the type of propulsion provide only partial information [7], [23].

The second criterion covers the operating conditions of logistics operators. It includes, among others, delivery time and reliability, the availability of transport modes, their capacity and range, the need for transhipment, charging organisation, and the costs of technological and organisational changes. This makes it possible to distinguish measures that can be implemented relatively quickly from solutions that require gradual redesign of the distribution process.

The next criterion concerns the social dimension of the system. It is particularly important for solutions that change the way parcels are collected or shift part of the activity to the customer. For example, the benefits of using APMs are greatest when the points are easily accessible on foot or by bicycle, and when parcel collection can be combined with other daily activities [9], [11], [14].

The fourth criterion refers to governance conditions. It includes the competences of the city, the availability of cooperation mechanisms, monitoring, data exchange, financing, and the possibility of linking logistics measures with transport, spatial, climate and energy policy. The importance of this perspective is confirmed by research on SULP design, which highlights the need to combine strategic objectives, stakeholder perspectives, recommendations, barriers, innovations and a monitoring system within one coherent process [13].

The last criterion links the assessment with the project assumptions concerning disruptions, reconfiguration and scalability. It examines whether a solution can be gradually developed and adapted to demand growth, infrastructure overload, changes in modal structure and the diversity of different parts of the city.

Based on these criteria, three assessment categories were adopted:

- **adequate measures** – measures with clear support in the project results and a direct link to the E-Laas objectives,
- **conditionally adequate measures** – measures whose results depend on location, demand scale, infrastructure, recipient behaviour or the adopted organisational model,
- **measures recommended for further research and development** – promising solutions for which the developed models, data and scenarios may provide a basis for further analyses or local applications.

The purpose of the adopted classification is to indicate which measures can best support the achievement of the E-Laas objectives, under what conditions they should be applied, and which factors should be considered when preparing local logistics policies. The project results show that the effectiveness of SULP measures depends primarily on the proper alignment of technology, infrastructure, process organisation and user behaviour with the characteristics of a specific urban area.

5. SULP measures relevant to energy-efficient urban logistics

A SULP should be a coherent set of regulatory, infrastructure, organisational and technological measures aimed at improving the functioning of urban freight flows. From the E-Laas perspective, the key criterion is energy use across the whole delivery chain, from the consolidation or dispatch point to the final recipient. The assessment should therefore cover the entire process, including propulsion type, emissions generated in selected parts of the city, route length and structure, the level of consolidation, the number of stops, empty and return trips, intermediate infrastructure and recipient mobility.

The work carried out shows that effective urban logistics management requires coordination of measures at several levels. Access regulations should be linked with the availability of service locations and alternative distribution channels; electrification with route and charging planning; the location of APMs and PUDOs with residents' travel behaviour; and the use of cargo bikes with consolidation and the spatial distribution of demand. Digitalisation forms the integrating layer, as it enables monitoring, coordination and adaptation of measures to changing conditions [13], [22], [23].

The logic of this approach is shown in Fig. 2. The diagram integrates strategic objectives, stakeholder perspectives, recommendations, barriers, innovations, and implementation and monitoring mechanisms. It shows that infrastructure and technological measures should be embedded in a system of governance, cooperation and periodic assessment of results.

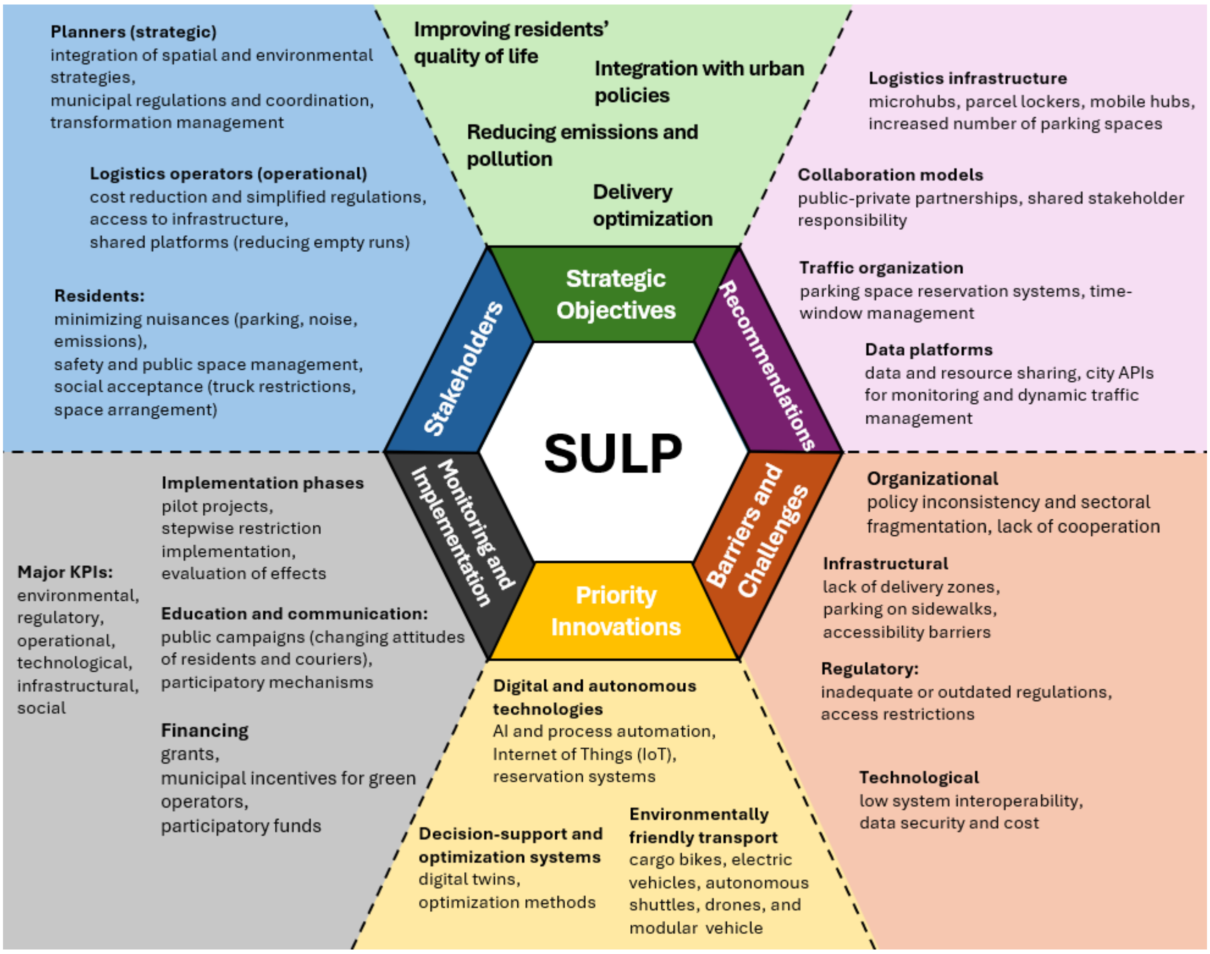

Fig. 2. SULP logic linking strategic objectives, stakeholders, recommendations, barriers, priority innovations, and monitoring and implementation
Source: [13].

As shown in Fig. 2, the main objectives of SULP include improving residents' quality of life, reducing emissions and pollution, optimising deliveries, and integrating logistics with other urban policies. Their implementation is supported by related measures in traffic and space management, logistics infrastructure development, low-emission transport modes, data sharing and public-private cooperation. In research on SULP design, particular importance was assigned to legal and accessible delivery service locations, microhubs, digitalisation of processes and data integration [13]. For the purposes of M2, SULP measures were organised into four main groups presented in Table 3.

Table 3. Main groups of SULP measures relevant to the achievement of E-Laas objectives

Measure group	Example instruments	Main impact mechanism
Access and delivery space management	access rules, time windows, loading and unloading zones, kerbside space management, space reservation	reducing unnecessary trips, time spent searching for a stopping place and traffic disruptions; improving service reliability
Consolidation and out-of-home delivery infrastructure	consolidation centres, microhubs, mobile hubs, APMs, PUDOs	concentrating flows, reducing the number of dispersed service points, enabling a change of transport mode
Low- and zero-emission transport modes and energy infrastructure	electric vehicles, light delivery vehicles, cargo bikes, e-bikes, drones, charging infrastructure, smart charging	reducing the use of fossil fuels, local emissions and noise; improving energy efficiency
Digitalisation, data exchange and monitoring	data platforms, route optimisation, digital reservation, KPI monitoring, models and digital twins	improving decision quality, coordination, resource use and response to changes in demand and traffic conditions

The four groups of measures form a complementary system: regulations and infrastructure define operational conditions, technologies reduce energy intensity, and data support coordination and assessment of effects. The greatest potential lies in packages of measures that combine regulations, infrastructure, properly selected technologies and an information system.

5.1. Access and delivery space management

Access management covers the rules defining where, when and under what conditions freight transport may take place. Instruments used in this area include, among others, entry restrictions for selected vehicle classes, clean transport zones, time windows, designated routes and priorities for low- and zero-emission vehicles. These measures may reduce the negative impacts of freight transport in particularly sensitive areas, but their effectiveness depends on providing operators with real possibilities to reorganise their processes.

Access restrictions should be designed to avoid shifting traffic to longer routes or increasing the number of smaller vehicles. From the energy perspective, the result for the whole system is important, including changes in transport work, the number of trips and fleet utilisation. For this reason, access rules should be linked with the location of consolidation points, the organisation of delivery zones, the availability of charging infrastructure and the possibility of using light transport modes.

The second key element is the organisation of space for short-term stopping, loading and unloading. If the number and location of such places do not match delivery demand, this leads to additional trips, manoeuvres, waiting time or vehicles stopping in ways that disrupt traffic. This increases vehicle operating time, energy consumption and reduces route reliability.

The impact of traffic conditions and service organisation on energy consumption is confirmed by studies of electric vehicles performing urban delivery tasks. The energy needed to complete a route depends on its length, vehicle mass, departure time, the number of service points and stops, congestion, road gradient and weather conditions. Better organisation of stopping and the reduction of unnecessary stops may therefore bring energy benefits even without changing vehicle technology [1].

Delivery service spaces should be planned with consideration of:
- the volume and structure of deliveries in a given area,
- the type of vehicles and the time needed for service,
- the distribution of main freight generators and recipients,
- the distance over which parcels must be carried from the vehicle to the recipient,
- variation in use during the day,
- the possibility of reservation, occupancy control and enforcement of rules.

Digital reservation may reduce uncertainty related to space availability, while data on the actual use of delivery zones may support periodic changes in their location, number and operating hours. In this approach, kerbside space becomes an actively managed resource of the urban logistics system.

The importance of the spatial differentiation of problems is also confirmed by work on macroscopic modelling. Linking a traffic model with emission assessment tools makes it possible to identify links and areas where the concentration of freight traffic causes the highest energy and environmental impacts. This information may be used to locate delivery service zones, design access rules and assess the effects of scenarios before their implementation [12], [23].

Regulatory instruments should be clear, possible to comply with and linked with available infrastructure. From the governance perspective, the stability of rules, consultations with operators and monitoring of real effects are particularly important. Environmental requirements should be integrated with social and operational objectives, because the organisation of deliveries affects emissions, courier working conditions, safety and the use of public space at the same time [8].

5.2. Consolidation and out-of-home delivery infrastructure

Consolidation means combining dispersed parcel flows and reducing the number of individual operations carried out in the most congested parts of the city. It may be implemented through urban consolidation centres, microhubs, mobile transhipment points, automated parcel machines and PUDO points.

A microhub introduces an additional level of the distribution network located closer to the service area. Larger batches of parcels are delivered to an intermediate point and then distributed using modes better adapted to urban conditions, such as cargo bikes, light electric vehicles or walking deliveries. Its effectiveness depends mainly on demand density, location, space availability, supply organisation and the quality of connection with the road and cycling network.

The multi-level nature of consolidation was developed in a study of a parcel distribution system using rail transport, BDF swap bodies, terminals and zero-emission last mile. The results indicate that the main environmental benefits result from reorganising the whole flow architecture, including consolidation at the national level, consolidated interregional transport, decentralisation of the last mile and the use of a zero-emission fleet in areas with high delivery density [2].

A BDF swap body may serve both as a loading unit and as a mobile microhub. After the interregional section is completed, it may be placed in a designated urban location and used as a supply point for cargo bikes or light electric vehicles. This makes it possible to limit the need for permanent warehouse infrastructure and to adapt the location of the microhub to changes in demand. However, this solution requires the synchronisation of transport operations, terminal handling, access to space and last-mile resources. For this reason, a mobile microhub should be designed as part of the whole network, not as a separate infrastructure object [2]. The principle of linking the successive levels of the system is shown in Fig. 3.

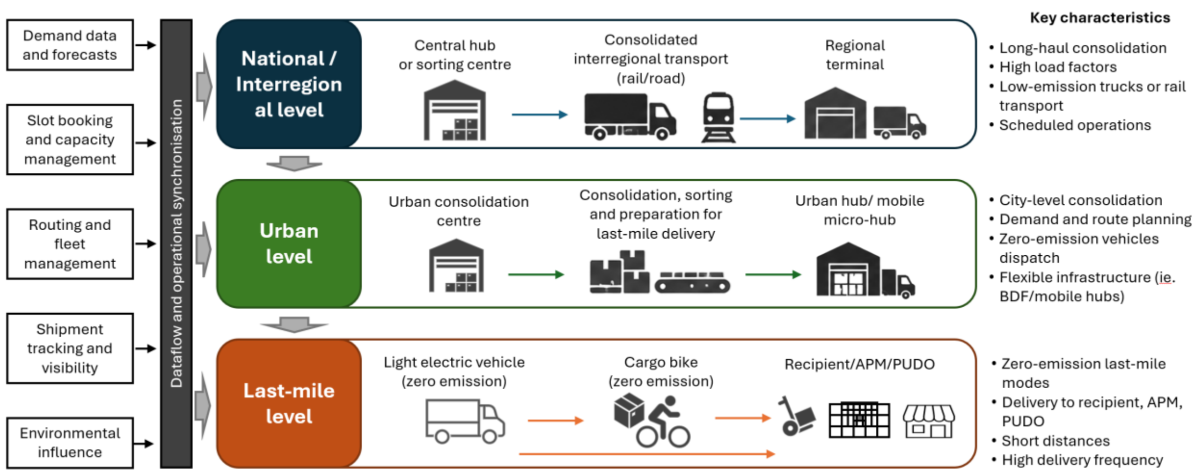

Fig. 3. Multi-level architecture of consolidation and zero-emission last-mile distribution

Figure 3 highlights that the efficiency of the last mile is also shaped by the organisation of earlier stages of the flow. A short and low-emission urban route will not provide the best system-level result if it requires energy-intensive, uncoordinated or poorly utilised preceding operations.

Another form of consolidation is provided by automated parcel machines and PUDO points. From the operator's perspective, they make it possible to deliver many parcels to one location, reducing the number of stops, service time and the risk of failed delivery. From the recipient's perspective, however, they require a trip to the collection point.

Customer preference studies indicate that the popularity of parcel lockers is driven mainly by convenience, flexibility, accessibility and the possibility of collection at a chosen time. Environmental factors are gaining importance, although convenience, flexibility and accessibility remain the main quality features of the service [9]. SULP should therefore support the location of infrastructure in a way that makes the sustainable solution also a convenient one.

The assessment of APM and PUDO should include courier operations, recipient mobility and the energy used by infrastructure. The consolidation benefit may be reduced when parcel collection generates a separate car trip. The most favourable locations are those accessible on foot, by bicycle or as part of daily trip chains, for example near places of residence, workplaces, services or public transport nodes [9], [11], [22].

The System Dynamics model developed in WP2 shows that the performance of an APM network also depends on its capacity, locker turnover, collection time, refill frequency and the possibility of redirecting parcels. Demand growth may improve unit efficiency due to stronger consolidation, but after service capacity is exceeded it leads to higher occupancy, delays and additional operations. In turn, a larger number of parcel lockers reduces the collection distance, but increases the fixed energy use of the infrastructure [14], [23].

The location and development of OOH infrastructure should therefore take into account:
- the spatial distribution of demand,
- accessibility on foot, by bicycle and by public transport,
- the possibility of combining parcel collection with other activities,
- capacity and expected turnover,
- service conditions for courier vehicles,
- impact on public space and the surrounding area,
- the possibility of integration with microhubs and other distribution channels.

5.3. Low- and zero-emission transport modes and energy infrastructure

Fleet transformation is one of the main directions for reducing the impact of urban logistics. It includes electric cars, light electric delivery vehicles, cargo bikes and e-bikes, electric scooters, as well as drones and other autonomous solutions. The choice of transport mode should result from the characteristics of the task, not from the assumption that one technology is optimal for all transport relations [24].

Microsimulation results confirm that, in selected configurations, fleet changes may reduce energy consumption and emissions by more than 20% compared with the base variant. At the same time, the result depends on route length, vehicle utilisation, the number of transfer and return movements, demand structure and the way vehicles are assigned to tasks [7], [23].

Electric vehicles are particularly useful in urban distribution systems where routes are repetitive and charging can be carried out at the depot or at planned points. However, their effective use requires forecasting energy consumption and taking operational conditions into account. Studies of predictive models have shown that energy demand is affected by, among others, section length, vehicle mass with load, route start time, the number of service points and stops, road gradient and wind [1].

This means that electrification policy should combine support for vehicle purchase with:
- matching vehicles to route and load types,
- forecasting energy demand,

- planning the time and location of charging,
- organising vehicle and energy reserves,
- integration with routing and fleet management systems.

The review of research on the Electric Vehicle Routing Problem confirms that planning electric fleet operations requires simultaneous decisions on routes, range, state of charge, charging points, energy replenishment technologies and the use of energy infrastructure. Further development directions also include integration with renewable energy sources, V2G and V2V technologies, and the inclusion of demand uncertainty and operational conditions [6], [10].

Cargo bikes and e-bikes have the greatest potential in areas with high building density, short distances, a large number of service points and difficult car parking conditions. The spatial analysis of food deliveries in GZM shows that their potential is highly differentiated. It is concentrated mainly in city centres and densely populated areas located close to food service points. Increasing the effective range of bicycles, for example through electric assistance, may significantly increase the share of deliveries carried out in this form.

Cargo bikes should be treated as part of a multi-level system. Their advantage is greatest when they do not have to start routes from a distant sorting centre, but are supplied from a microhub located close to the service area. This conclusion is confirmed by the model using BDF units as mobile microhubs: the benefit results from the coordinated combination of consolidated transport with zero-emission local distribution [2].

Drones may complement the delivery system in selected relations, especially where they make it possible to shorten the route or reduce dependence on congestion. However, their efficiency depends on parcel weight, range, flight profile, wind, take-off and landing points, and return flights. Analyses should cover the complete operational cycle, because transfer and return sections may account for a significant part of the total distance [4], [7]. Drones should therefore be treated as a specialised component of a mixed system, intended for selected tasks.

The development of an electric delivery fleet should be coordinated with energy infrastructure. The number and power of charging points are important, but so are their location, availability at the required time, reliability, use of connection capacity and energy cost. Infrastructure should be planned in relation to operator depots, microhubs, delivery zones and typical vehicle routes [10].

Research on pricing strategies for charging stations shows that tariffs reflecting daily variation in demand and energy cost may provide a better balance between economic performance and infrastructure use than a simple approach based on a fixed cost and margin. In the analysed variants, good results were achieved by the Time-of-Use strategy, which responds to daily changes in conditions [6]. In relation to logistics fleets, such mechanisms may support shifting charging outside peak periods and coordinating it with route schedules.

Energy infrastructure should also be analysed in the context of system continuity. Power supply disruptions may simultaneously affect vehicle charging, traffic signals and traffic control, digital platforms and pick-up point infrastructure. The development of electromobility should therefore be linked with energy reserve management, alternative charging points, fleet diversification and disruption response plans [3].

5.4. Digitalisation, data exchange and monitoring

Digitalisation is the layer that integrates all other SULP measures. It supports the diagnosis of flows, infrastructure planning, optimisation of operations, dynamic resource management and monitoring of achieved results. At the SULP preparation stage, data make it possible to identify:

- places and periods of delivery concentration,
- main freight generators and recipients,
- use of loading and unloading spaces,
- fleet and delivery channel structure,
- freight traffic intensity,
- spatial distribution of energy consumption and emissions,
- availability of pick-up points and charging infrastructure.

At the operational level, digital tools may support delivery zone reservation, route optimisation, charging planning, order consolidation and communication with recipients. At the strategic level, they provide the basis for assessing the effects of policies and updating them periodically.

The ability to combine city and operator data in a way that protects commercial information and recipient data is particularly important. A city does not need access to data on individual parcels to manage the system effectively. In many cases, information aggregated by traffic analysis zone, time interval, vehicle class and type of operation is sufficient.

The approach developed in WP2 for zone clustering and KPI scaling shows how detailed microsimulation results can be used to assess a larger area. Defining groups of similar zones, selecting reference zones and applying scaling functions make it possible to estimate time, distance and energy without preparing a separate detailed model for every part of the city. This may significantly reduce the workload of analyses and increase the number of variants assessed during SULP preparation [15].

Macroscopic traffic models may support the identification of areas with the highest impacts and the comparison of scenarios involving changes in demand and fleet structure. Combining traffic data with emission modules makes it possible to move from a general assessment of urban freight transport to the spatial identification of places where intervention may bring the greatest effects [12].

SULP monitoring should include indicators adapted to the management level. At the operational level, these may include energy and time per parcel, distance, vehicle utilisation, number of stops, empty trips and failed deliveries. At the district or city level, important indicators include energy consumption, emissions, transport work, infrastructure availability, the share of low-emission modes and the use of delivery space. At the strategic level, it is also necessary to monitor the achievement of climate objectives, social acceptance, stakeholder cooperation and the integration of logistics with other urban policies.

Research on SULP indicates the need to use both static and dynamic indicators. Static indicators make it possible to compare the current state with baseline values and adopted targets, while dynamic indicators show the direction of change and support earlier identification of negative trends. Indicators should also have a diagnostic function, for example by showing whether longer delivery times result from demand growth, infrastructure constraints, traffic organisation or inefficient route planning [13].

Data exchange requires clear rules on responsibility, access and the use of results. From the ESG and governance perspective, transparency, stable cooperation rules, and control and reporting systems link environmental goals with social goals. Governance therefore has an integrating function: it determines whether data, technologies and declared objectives are translated into real actions [8].

Digitalisation is not an independent objective of SULP. Its value comes from enabling better use of infrastructure, reducing unnecessary operations, coordinating stakeholders and adapting the system to changes in demand. Data platforms, models and optimisation tools should be linked with decision-making procedures and the cycle of monitoring and plan updates. As a result, SULP can function as a staged and adaptive tool that is updated in response to changes in technology, behaviour and urban conditions.

6. Stakeholder perspectives and implementation conditions

The assessment of the adequacy of sustainable urban logistics policies cannot be based only on technical or environmental criteria. The results of the survey research carried out within WP2 show that the energy efficiency of urban logistics depends on the interaction of many factors: recipient behaviour, courier working conditions, decisions made by logistics operators, availability of urban infrastructure, management of public space, and the approach of local government units to actively shaping delivery rules [22].

It is therefore important to identify solutions that may reduce emissions or energy consumption and to indicate which of them are technologically and organisationally feasible, socially acceptable, and consistent with the priorities and capacities of cities and municipalities. Research issues related to the optimisation of urban distribution systems are multi-criteria in nature, and achieving the expected effects requires taking into account different stakeholder perspectives, needs and expectations.

6.1. Local government units and public administration

Local government units are key stakeholders in urban last-mile delivery systems because they are responsible for shaping the conditions under which urban logistics operates. This applies in particular to:

- defining the rules for using street space,
- traffic organisation,
- shaping parking policy,
- locating logistics infrastructure.

For this reason, the role of public administration should not be limited only to reacting to problems generated by deliveries in cities. Local government units should be treated as active actors co-creating the conditions for energy-efficient, well-organised and socially acceptable urban logistics.

The perspective of local administration was identified on the basis of the survey research carried out within WP2. The study included 244 respondents representing cities and municipalities. This part of the research was qualitative in nature and included questions concerning, among others, observed problems related to deliveries and possible ways of solving them [22].

In the study, 52.5% of respondents did not indicate any problems related to freight deliveries in their cities or municipalities. This result should be interpreted with caution. It may reflect both the limited scale of problems in some units and the limited recognition of urban logistics as a separate policy area. From the M2 perspective, the key issue is the lack of systematic data and monitoring, which makes it difficult to distinguish between these two situations [22].

A similar picture emerges from the analysis of 46 SUMP documents. In 9 documents, no references to urban logistics were identified, while in 16 documents the issue was addressed only at the level of general declarations. Urban logistics is therefore present in some strategic documents, but often without specific measures, implementation instruments or management mechanisms [17].

In the survey, the most frequently indicated specific problem by local administration was the parking or stopping of delivery vehicles in prohibited places. This problem was indicated by 35.7% of respondents. This result shows that where local government units identify urban logistics problems, they mainly concern the management of public space, especially the organisation of loading and unloading spaces for delivery vehicles [22].

The problem of improper stopping of delivery vehicles is directly linked to delivery service time, road safety, blocking pavements, occupation of traffic lanes, and conflicts with pedestrians and other road users. Indirectly, all these elements also affect the energy efficiency of the urban logistics system. Longer time spent searching for a stopping place, the need to perform additional manoeuvres, and traffic disruptions lead to longer vehicle operating time, higher energy consumption and lower operational efficiency of the urban distribution system.

The results concerning proposed solutions confirm that, from the perspective of local government units, the most direct and practical instrument is the provision of dedicated parking or loading spaces. This solution was indicated as possible to introduce in 27% of responses. The second most frequently indicated category was access restrictions or changes in traffic organisation, indicated in nearly 14% of responses. This means that local government units most often see potential in instruments that are close to their core competences: managing street space, organising traffic and setting access rules for specific areas of the city [22].

At the same time, the results of report D2.2 reveal a significant gap between the declared possibility of implementing selected solutions and their actual use. This is most visible in the case of parking and loading spaces. They were indicated 66 times as a solution possible to introduce, but only 12 times as a solution already implemented or tested. This means that although cities and municipalities relatively often consider this instrument necessary and feasible, its practical use remains limited. The situation is different for traffic organisation and access restrictions, which appeared both as possible solutions and as solutions already implemented or tested. This may be interpreted as evidence that traditional traffic management tools are much better embedded in urban management practice than instruments dedicated directly to delivery logistics [22].

However, the scale of existing implementations remains limited. In the responses concerning solutions already introduced or tested, 72.5% of respondents indicated no implementations or tests. This means that in most local government units, urban logistics policy has not yet moved from the level of diagnosis or declaration to systematic implementation. Where measures are taken, they are usually local and remain within the traditional set of traffic management tools, such as signage, bans, changes in traffic organisation or the designation of individual spaces [22].

In the M2 assessment, the highest institutional feasibility is assigned to instruments that respond to the most frequently identified problems and fall within the basic competences of local government units: dedicated stopping, loading and unloading spaces, traffic organisation, access rules and time windows. Their effects may be represented through the availability of stopping spaces, time spent searching for a space, distance from the stopping place to the delivery point, service time, probability of improper stopping, route length and travel time.

Microhubs, urban consolidation centres, systematic management of APM and PUDO locations, and incentives for low-emission vehicles have greater transformation potential, but they require a higher level of coordination, financing, space availability and data on flows. For this reason, they are assessed in Chapter 8 as conditionally adequate measures.

From the perspective of local government units, the effectiveness of SULP depends on moving from local, isolated measures to systematic delivery management. Cities should diagnose conflict locations, monitor the use of delivery space, maintain regular dialogue with operators, and integrate urban logistics with parking policy, traffic organisation and spatial planning [13], [22].

The most important inhibitors on the side of local government units include limited data availability, limited experience in implementing instruments dedicated to urban logistics, competition for street space, the lack of stable cooperation mechanisms with operators, and investment constraints. For this reason, the most adequate measures are those that combine delivery space management with monitoring and cross-sector cooperation.

6.2. Logistics operators and service providers

Logistics operators and logistics service providers are key stakeholders in urban distribution systems because they directly organise delivery processes, manage fleets, plan routes, decide how recipients are served, and bear a large part of the costs of implementing changes. Unlike local government units, which shape regulatory and spatial conditions, operators are responsible for the actual performance of logistics services. Their decisions directly affect, among others, route length, the number of vehicles in traffic, and customer service quality.

For this reason, the assessment of the adequacy of urban logistics policies cannot ignore the operators' perspective. Solutions such as fleet electrification, the use of cargo bikes and microhubs, or the introduction of time windows can be effective only when they can be integrated into the operating models of logistics companies. For operators, implementing such solutions may involve additional costs, changes in work organisation or changes in fleet structure.

In report D2.2, the perspective of logistics operators was identified on the basis of 238 responses. The survey included questions concerning, among others, propulsion types used, potential technological changes, investment and infrastructure barriers, and flexibility under variable demand conditions. The results of this part of the study were particularly important for assessing which SULP policies can realistically be implemented by entities providing logistics services, and which require a deeper redesign of the operating model [22].

One of the most important results of the study was the fleet ownership structure. In the analysed group, the declared share of vehicles owned by the company was 100%; the sample did not include companies in which vehicles belonged to couriers or intermediaries. Full fleet ownership makes it easier to make central decisions on modernisation and the implementation of management systems, but at the same time it concentrates the costs and risks of transformation on the operator [22].

The second key result was the propulsion structure. In the analysed group, all reported vehicles had conventional propulsion, while no electric, hybrid or other alternative-propulsion vehicles were reported. Electrification would therefore mean the start of a significant technological transformation, including vehicle purchase, charging development, route adjustment, consideration of range and charging time, and changes in the way operations are planned [22].

The results of D2.2 also indicate that cargo bikes and other light transport modes are not currently a significant part of the fleet of the analysed group of operators. The results show that their use would require the purchase of new transport modes and a redesign of the operating model of companies. It would be necessary to create transhipment points, microhubs, route splits, and integration between supply chain elements performed by heavier vehicles and last-mile deliveries performed by “light” transport modes. Although such solutions are important for reducing emissions and improving service in dense urban areas, they should be considered more demanding to implement than a simple change in the parameters of the existing fleet [22].

The results make it possible to distinguish three levels of feasibility of changes on the operators’ side. Modifications of existing process parameters – fleet structure, route organisation, the share of HOME, APM and PUDO channels, and the use of concentration points – can be implemented relatively gradually and directly represented in models. Microhubs and systems combining heavier transport with light final distribution require a redesign of the operational network and cooperation with the city. Access regulations and rules for using delivery zones may support fleet modernisation, but if poorly designed they increase costs, lengthen routes and reduce operational flexibility [22], [23].

For operators, the key issues are reducing implementation risk, access to charging infrastructure and service space, regulatory predictability, and the ability to maintain service quality. Electrification, microhubs and light transport modes should be introduced gradually, using pilot projects and monitoring of operational parameters.

The most important barriers include the dominance of conventional propulsion, the concentration of investment costs on companies, uncertainty of access to charging, and the lack of light transport modes in current operating models. For this reason, technological measures need to be complemented by investment support, stable regulations and organisational solutions [22].

6.3. Couriers, drivers and delivery staff

Couriers and drivers are key stakeholders in urban distribution systems because they directly carry out last-mile deliveries. Their perspective makes it possible to identify constraints that are often not fully visible at the level of strategic documents, urban regulations or business decisions made by logistics operators. This applies mainly to the availability of loading and unloading spaces, recipient service time, the number of delivery points, route workload, failed deliveries and the impact of traffic conditions on delivery performance.

From the project perspective, the courier perspective is particularly important because the energy efficiency of the urban distribution system does not depend only on vehicle type or route length. A large part of time and energy losses is generated, for example, while searching for a stopping place, waiting, walking to the recipient, loading, unloading, handling failed deliveries or performing additional manoeuvres in dense urban areas. This means that SULP policies should be assessed in terms of emission reduction and their impact on the real work process of couriers.

In report D2.2, the perspective of drivers and couriers was identified on the basis of 1,082 responses assigned to seven delivery segments: ready-made food deliveries, boxed meal deliveries, grocery deliveries, parcels to individual customers, parcel lockers and pick-up points, B2B deliveries and pharmaceutical deliveries. The study focused on work organisation, transport modes used, service intensity, process completion time and the impact of weather conditions [22].

The results of D2.2 show that the key operational constraint from the courier perspective is access to a legal and functional stopping place. The average time spent searching for a stopping place is approximately 5.6 minutes. For a single delivery, this value may seem moderate, but with many service points per day, even a few additional minutes at each problematic stop significantly reduce route efficiency. In this sense, parking is both a spatial problem and a factor affecting the total cost of delivery operations and energy demand [22].

The importance of this problem is confirmed by responses concerning the frequency of difficulties in finding a stopping place during delivery. The answer “often” was indicated by 404 respondents, and “very often” by 6 respondents, which means that around 38% of the surveyed group experience problems with finding a stopping place. At the same time, D2.2 indicates a strong relationship between difficulties in finding a stopping place and stopping in a prohibited place or on an active traffic lane. In this case, the answer “often” was indicated by 314 respondents and “very often” by 13 respondents, while the correlation between the two variables was around 0.65. This means that stopping in prohibited places largely results from the lack of legal stopping space near delivery points, although individual driver decisions may also play a role [22].

The second important constraint concerns failed or problematic deliveries caused by the absence of the recipient. In the segment of parcels delivered to individual customers, the number of valid responses was 240. Respondents most often indicated that recipient absence concerns around 20% of deliveries; this answer was selected 115 times. Another 78 responses indicated 10%, and 47 responses indicated 30%. Respondents also indicated that when the recipient is absent, the parcel is most often left at the door (106 responses), not left at all (77 responses), or left with a neighbour (57 responses). These results show that door-to-door deliveries, unlike deliveries to pick-up points, generate significant operational uncertainty, which may lead to longer service time, repeated trips and, consequently, lower energy efficiency of the whole process [22].

The results of the research among drivers and couriers also indicate that the urban delivery system should not be analysed as a uniform process. Individual segments differ in terms of time pressure, the number of service points, cargo type, quality requirements and the possibility of changing the transport mode. Ready-made food and grocery deliveries are characterised by a large number of short loading and delivery cycles and high time sensitivity. Parcels to individual customers and deliveries to parcel lockers generate high mileages and a long working day. Pharmaceutical deliveries involve a high number of delivery addresses and specific quality requirements. This means that one universal delivery organisation model is not sufficient for all scenarios planned for analysis.

In the M2 assessment, the most direct relevance is assigned to instruments that affect the conditions of performing a single delivery, primarily the availability of stopping, loading and unloading zones and the reduction of time spent searching for a place. Their impact can be represented through the availability of parking spaces, the distance from the stopping place to the recipient, service time, the probability of improper stopping and the number of spatial conflicts [22].

The second group includes solutions that reduce failed deliveries and time uncertainty: more precise time windows, updated estimated arrival time, easy parcel redirection, efficient communication between the operator, courier and recipient, and integration of HOME, APM and PUDO channels. These solutions may reduce the number of delivery attempts, shorten service time and reduce repeated trips [22].

The effectiveness of these measures depends on their consistency with real working conditions. Delivery zones must be located close to recipients, available during service hours and protected against unauthorised occupation. Time windows should not cause excessive accumulation of orders, while microhubs and light transport modes should actually reduce the length and workload of final routes.

The main inhibitor remains the shortage of organised delivery service space, combined with uncertainty in the door-to-door process and the risk of designing regulations without considering real courier working conditions. From the perspective of this group, the most adequate measures are therefore those that improve the availability of stopping places, shorten service time and reduce the number of failed deliveries [22].

6.4. Customers, residents and social acceptance of solutions

Customers, residents and individual recipients represent the demand side of the urban distribution system. Their behaviour and preferences directly affect the number of deliveries, the choice of delivery channel, the location of delivery points, acceptable waiting time and willingness to use alternative service models. From the project perspective, this group is particularly important because solutions that are technically efficient and environmentally beneficial may not bring the expected effects if users perceive them as unattractive, less convenient, more expensive or less reliable.

The perspective of customers and residents therefore makes it possible to assess which logistics policies have the potential to gain social acceptance. This applies mainly to solutions such as parcel lockers, pick-up points, deliveries to concentration points, deliveries by low-emission vehicles, changes in the method of parcel collection, restrictions on door-to-door deliveries, or longer delivery time windows. For recipients, the key factors are price, convenience, predictability and control over the time of collection. This means that proposed solutions should be assessed in terms of energy used by the operator and their impact on the daily behaviour of residents.

In report D2.2, the user perspective was identified on the basis of 863 responses from individual recipients. The study covered, among others, the preferred parcel collection method, problems occurring in deliveries, the average number of parcels collected, walking time to a parcel locker, the way parcels are collected from a parcel locker or pick-up point, and the importance of low-emission vehicles. The results of this part of the study are important because they show under what conditions alternative delivery models may be socially acceptable and usable [22].

One of the most important results of D2.2 is that individual recipients still strongly prefer courier delivery to the place of residence. In the study, 62.1% of respondents indicated courier delivery as their preferred parcel collection method. This means that the door-to-door model remains the basic reference point for assessing alternative solutions. From the perspective of logistics policies, this is an important constraint: policies assuming a significant shift of deliveries from home to pick-up points must take into account that direct delivery remains the most desired form of service for a large share of users [9], [22].

At the same time, the results show that preferences are not uniform. Age clearly differentiates willingness to use parcel lockers. Among respondents under 18 years of age, 63.6% prefer parcel lockers, while in the 18–25 age group this share is 51.1%. In older groups, the importance of courier delivery increases: in the 26–35 age group, courier delivery is preferred by 58.9%, in the 36–50 group by 64.8%, and in the 51+ group by 68.6% of respondents. This means that acceptance of alternative collection models is segment-specific. Solutions based on parcel lockers and pick-up points may be particularly effective among younger users, while for older groups it remains crucial to maintain the possibility of home delivery [9], [22].

The second key factor is the spatial accessibility of pick-up points. The survey results show that a parcel locker competes effectively with home delivery mainly when it is located very close to the user or on the user’s daily route. Among people who have a parcel locker within 0–2 minutes, 63.4% prefer a parcel locker. With a walking time of 2–5 minutes, this share falls to

51.9%. After the threshold of 5 minutes is exceeded, preferences begin to shift towards courier delivery: with a walking time of 5–10 minutes, courier delivery is preferred by 67.1%, and with a walking time of more than 10 minutes by 71.7% of respondents. This result indicates that physical accessibility of pick-up points is one of the basic conditions for social acceptance of this delivery model [9], [22].

The importance of location is also confirmed by differences between types of residential areas. In rural areas, 64.3% of respondents declare a walking time to the nearest parcel locker of more than 10 minutes, and in suburban areas this share is 52.7%. By comparison, in housing estates close to the city centre this share is 17.3%, and in city centres 15.4%. This means that policies based on parcel lockers and pick-up points are much more natural for areas with good spatial coverage, while in peripheral and less urbanised areas they may generate additional user trips [9], [22].

However, it is important that collection from a parcel locker or pick-up point often does not constitute a separate trip. According to the survey results, 46.9% of respondents collect parcels on the way to or from work, and another 36.8% do so while carrying out other activities, such as shopping, walking or running errands. Only 16.2% of respondents declare that parcel collection requires a dedicated trip. This result is highly relevant for the energy assessment: parcel lockers can support the objectives of improving delivery energy efficiency only when parcel collection is integrated into existing user mobility patterns and does not generate additional trips [11], [22].

The results confirm the need to include the relationship between recipient behaviour and the energy efficiency of the system in SULP modelling and assessment. In the case of APM and PUDO, important factors include walking time, distance to the point, access mode, the share of walking, cycling, public transport and car trips, and the distinction between collection as part of an existing trip and a dedicated trip [11], [22].

The results also justify the assessment of measures that increase delivery predictability and flexibility, such as more precise time windows, information on the expected delivery time, the possibility of parcel redirection, integration of HOME and OOH channels, and solutions reducing the number of failed deliveries [9], [22].

The third group consists of policies related to limiting or modifying door-to-door deliveries. From the energy perspective, they may be beneficial because delivery to a collective point may reduce the number of stops, shorten courier routes and limit failed deliveries. From the user perspective, however, such solutions are acceptable only when they do not significantly reduce service convenience. This means that variants based on pick-up points should be spatially and demographically differentiated. A different level of acceptance may be assumed for younger users in well-served city centres, and a different one for older people, residents of peripheral areas or people with limited mobility.

The condition for social acceptance is maintaining a balance between system efficiency and user convenience. APMs and PUDOs should be accessible on foot and linked with residents' daily routes, while older people, residents of peripheral areas and people with limited mobility should retain the possibility of convenient home delivery.

The main risks include unequal spatial accessibility of points, additional car trips and the perception of new models as shifting the time cost from the operator to the recipient. The energy effect of OOH channels therefore depends equally on the infrastructure network and customer behaviour [9], [11], [22].

6.5. Conflicts and synergies between stakeholder objectives

Stakeholder objectives are partly aligned, but they result from different roles and responsibilities. Cities focus on the quality of space and reducing negative impacts, operators focus on costs and reliability, couriers focus on the feasibility of the process, and recipients focus on price, convenience and predictability. Conflicts occur mainly when the benefits of one group are achieved by shifting costs, constraints or effort to another group. The main synergies and conflicts are presented in Table 4 [13], [22].

Table 4. Conflicts and synergies between the objectives of the main stakeholder groups

Area	Stakeholders involved	Type of relationship
Dedicated loading and unloading spaces	All stakeholders of the urban delivery system	**Synergy.** Cities reduce illegal stopping and conflicts in street space, operators gain more predictable route conditions, couriers reduce the time spent searching for a stopping place, and customers may receive more punctual deliveries.
	Cities ↔ operators and couriers	**Conflict.** Cities may designate delivery spaces in locations that do not match the real needs of operators and couriers, for example too far from delivery points, in places with limited accessibility, or during hours that do not correspond to the actual rhythm of deliveries.
	Operators and couriers ↔ city residents	**Conflict.** Designating dedicated loading and unloading spaces usually means reducing the number of generally available parking spaces or introducing changes in traffic organisation. Such measures may face resistance from residents, especially if they are perceived as reducing parking availability near their homes.
Traffic restrictions and low-emission zones	Cities and their residents	**Synergy.** Cities aim to reduce emissions and noise, while residents may benefit from better quality of urban space and lower traffic nuisance.
	Cities ↔ operators and couriers	**Conflict.** Traffic restrictions may lengthen routes, increase delivery costs, reduce the operational flexibility of operators and increase time pressure on couriers.
	Cities ↔ customers	**Conflict.** If access restrictions introduced by cities make deliveries more difficult or extend service time, customers may experience lower service quality, for example longer waiting times or reduced availability of preferred delivery windows.

Delivery time windows	Cities ↔ residents	**Synergy.** Time windows may reduce conflicts between deliveries and urban traffic, decrease delivery nuisance during the most congested periods of the day, and organise the use of public space.
	Cities ↔ operators and couriers	**Conflict.** Poorly designed time windows may cause the accumulation of deliveries, increase operational pressure, reduce route flexibility and make it difficult to maintain service punctuality.
	Cities ↔ customers	**Conflict.** Limiting available delivery hours may reduce customer convenience, especially when customers expect flexible home delivery or the possibility to choose a convenient collection time.
Parcel lockers and pick-up points	All stakeholders of the urban delivery system	**Synergy.** Operators may consolidate deliveries, couriers may reduce the number of dispersed deliveries, cities may reduce the number of delivery vehicle stops in urban areas, and customers gain greater control over the collection time.
	Customers ↔ operators	**Conflict.** If the pick-up point is located too far away or requires a dedicated trip, customers may perceive this solution as shifting the cost of time and effort from the operator to the recipient.
	Cities ↔ operators	**Conflict.** The expansion of parcel locker networks may create disputes over device locations, occupation of public space, the aesthetics of the surroundings, and additional pedestrian or car traffic near pick-up points.
Microhubs and consolidation centres	All stakeholders of the urban delivery system	**Synergy.** Microhubs and consolidation centres may reduce the number of delivery vehicles in dense urban areas, shorten final routes, support the use of light transport modes and reduce delivery nuisance for residents.
	Cities ↔ operators	**Conflict.** Disputes may concern location, financing rules, access rules and the organisation of hub operations.
	Operators ↔ couriers	**Conflict.** Consolidation may increase the number of transhipment operations, require precise coordination and change the organisation of couriers' work.
	Cities/operators ↔ residents	**Conflict.** Residents may oppose the location of logistics infrastructure near their homes if it is associated with noise, delivery traffic, occupation of space or a decline in the quality of the surroundings.
Fleet electrification	All stakeholders of the urban delivery system	**Synergy.** Fleet electrification supports the reduction of local emissions and noise, which is consistent with the environmental objectives of cities and residents' expectations regarding quality of life.

	Cities ↔ operators	**Conflict.** Cities may treat electrification as a tool for achieving environmental objectives, while for operators it means high investment costs, the need for access to charging infrastructure, and risks related to range and charging time.
Cargo bikes and light transport modes	Cities and residents	**Synergy.** Light transport modes may reduce delivery van traffic in city centres, reduce emissions and noise, and improve the quality of urban space.
	Operators ↔ couriers	**Conflict.** Couriers may be reluctant to use light transport modes if they reduce working comfort, increase physical effort, provide poorer protection against weather conditions or make it more difficult to complete deliveries within the required time.
	Operators ↔ customers	**Conflict.** Limited payload, weather impact, longer travel time or shorter range may make it difficult to maintain the level of service expected by customers.
Improved delivery predictability and communication with recipients	All stakeholders of the urban delivery system	**Synergy.** Customers gain greater control over collection, couriers reduce the number of failed deliveries, operators improve route efficiency, and cities may indirectly reduce unnecessary trips and stops.
	Operators and customers ↔ drivers	**Conflict.** Better communication may create additional pressure on couriers, because more precise delivery time declarations limit their flexibility in carrying out routes and increase the risk of delays under variable urban traffic conditions.
Management of parcel locker and pick-up point locations	All stakeholders of the urban delivery system	**Synergy.** Well-located pick-up points support delivery consolidation, reduce failed deliveries and fit into residents' daily routes, which may improve both operator efficiency and customer convenience.
	Cities ↔ operators	**Conflict.** Operators may prefer locations that are most efficient in terms of parcel volumes and service costs, while cities must also consider spatial order, pedestrian safety, aesthetics, accessibility and public space constraints.
	Customers ↔ operators	**Conflict.** If the network of pick-up points is unevenly distributed, some customers may have limited access to this form of delivery, which reduces social acceptance of the model.

7. Synthesis of WP2 modelling results and system analyses

The modelling work carried out in WP2 covered four complementary levels of analysis. Macroscopic modelling was used to determine the scale and spatial distribution of freight transport impacts in the metropolitan area. Microsimulation made it possible to represent the detailed course of last-mile processes, including routes, service operations, vehicle use and movements made by recipients. The developed KPI scaling method linked the results of detailed simulations with a larger urban area, while System Dynamics enabled the analysis of time-dependent relationships between demand, service capacity, infrastructure and the behaviour of system participants [23].

The roles of the individual levels are presented in Table 5. Their combined use made it possible to move from the assessment of a single delivery process to the interpretation of effects at the level of a zone, city and the whole logistics system.

Table 5. Modelling levels applied in WP2 and their relevance for SULP assessment

Level of analysis	Main issue	Main results	Relevance for SULP
Macroscopic modelling	Scale and spatial distribution of flows and their impacts	traffic volume, transport work, energy, emissions, external costs, areas of impact concentration	identification of areas and corridors requiring intervention and assessment of the effects of changes in demand and fleet structure
Microsimulation	Detailed course of last-mile processes	time, distance, number of routes, service and return movements, energy consumption and emissions by channel and transport mode	comparison of delivery organisation, technologies and service channels under specific operating conditions
Micro–macro integration	Transfer of results from reference zones to a larger area	groups of similar TAZs, scaling functions, estimated KPIs, accuracy measures	support for urban analyses without the need to develop a full microsimulation model for each zone
System Dynamics	Relationships and feedbacks developing over time	demand–capacity relations, infrastructure use, redirections, recipient behaviour, energy and service level	analysis of system resilience, overload thresholds and the effects of combined infrastructure, organisational and behavioural measures

The applied models perform different but complementary decision-support functions. The macroscopic model shows where the impacts of freight transport are concentrated, microsimulation explains which operations generate them, scaling makes it possible to extend the spatial assessment, and System Dynamics shows how the system may respond to demand growth, infrastructure development and changes in user behaviour. The combination of these perspectives provides the basis for further assessment of SULP measures [23].

7.1. Results of macroscopic modelling: flows, energy and emissions

Macroscopic modelling was carried out using the transport model of the Górnośląsko-Zagłębiowska Metropolis, developed in PTV Visum and linked with methods for assessing energy consumption and emissions based on COPERT and HBEFA. This made it possible to assign transport impacts to road network sections, road classes and traffic analysis zones, and then compare the base scenario with changes in freight traffic volume and fleet propulsion structure [12], [23].

The results confirmed clear spatial differentiation in transport impacts. For total traffic, the highest energy consumption and emissions were concentrated mainly in the main transport corridors. For freight transport, significant impacts also occurred on sections serving areas with intensive logistics, production, commercial and service activity. The distribution of impacts therefore depends both on the road hierarchy and on traffic volume and structure, traffic flow conditions, the share of delivery and heavy goods vehicles, and the land-use function of the served area [12], [23].

In relation to SULP, this means that measures should not be directed only at city centres. In metropolitan areas, the following may also be important:

- corridors connecting logistics and warehouse centres with urban areas,
- local roads serving the final sections of distribution,
- zones with a high number of freight generators and recipients,
- areas where freight traffic overlaps with high general congestion.

The demand growth scenario showed that increased delivery activity leads to higher energy consumption, emissions and external costs. However, the scale of change is not distributed evenly. Sections that already carry significant freight flows in the base state or have limited traffic flow conditions are affected more strongly. The development of e-commerce and seasonal demand peaks should therefore also be analysed in terms of the network's ability to absorb additional traffic, and not only as a proportional increase in the number of deliveries [12], [23].

The electrification scenario confirmed the potential to reduce local emissions from delivery vehicles. At the same time, electrification does not remove energy demand, but changes its structure and the location where impacts occur. The benefits of reducing exhaust emissions and noise in urban areas are linked with the need to provide electricity, adequate connection capacity and available charging infrastructure. In the case of demand growth, a change in propulsion alone also does not reduce the number of routes, stops or the use of street space [12], [23].

From the perspective of urban policy, electrification should therefore be combined with organisational measures aimed at reducing transport work, improving consolidation and assigning vehicles to tasks in a rational way. In this respect, the macroscopic model may support the selection of priority areas for the development of charging infrastructure, low-emission zones, consolidation points and freight traffic management [12], [23].

The modelling also showed the usefulness of existing urban transport models as a basis for assessing logistics policies. After the freight transport component is properly developed and linked with environmental methods, it is possible to compare scenarios at the scale of the whole city or metropolis. This approach supports the transition from general environmental declarations to spatially targeted SULP measures.

7.2. Results of microscopic modelling of last-mile processes

Microsimulation made it possible to represent processes that are shown only in an aggregated way at the macroscopic level. The model developed in FlexSim covered demand generation, assigning parcels to channels and transport modes, route planning, service at delivery points, transhipment, transfer and return movements, and the calculation of energy consumption and emissions. It was used to analyse ready-made food deliveries, boxed meal deliveries and parcel deliveries, including direct deliveries, deliveries to parcel lockers, customer pick-up trips and drone-based variants [7], [23].

The main conclusion is that the results strongly depend on the organisation of the whole process. Energy consumption depends on the distance between the sender and the recipient, as well as on the number and spatial distribution of service points, vehicle capacity, parcel grouping, service time, congestion, fleet structure, empty trips and returns [5], [7], [23].

In the analysed food delivery scenarios, changing the fleet structure to a variant with zero direct emissions made it possible to reduce energy consumption by more than 80% and CO_2 emissions by more than 60% compared with the base variant. This result shows the scale of potential improvement, but it refers to a specific configuration of demand, vehicles and processes. From the SULP perspective, the more important conclusion is that the greatest effects are achieved when a technological change is combined with proper vehicle use and route organisation [7], [23].

The analysis of parcel delivery channels showed that the name of the delivery channel does not determine its efficiency. Delivery to a parcel locker may reduce the courier route by consolidating many parcels at one point. However, its system-level result depends on how the recipient reaches the locker, the number of dedicated trips, the distance and the modal structure. In one of the analysed variants based on individual car pick-up, recipient trips accounted for more than 90% of the total energy consumption of the system. This means that benefits achieved on the operator side may be strongly reduced by additional customer mobility [7], [23].

An increase in the number of parcels may lead to two opposite effects. On the one hand, it increases total energy consumption and the load on resources. On the other hand, it may improve the unit result if it enables better use of vehicle capacity, a higher number of parcels per route and more effective consolidation. This effect was visible in some of the analysed scenarios, where energy per parcel decreased as volume increased. However, this does not mean that demand growth is neutral: improved unit efficiency may coexist with higher total transport work and greater infrastructure load [7], [23].

The results for drones confirmed their potential in selected configurations, especially in relations where the route can be shortened compared with the street network. At the same time, the analysis of the full operational cycle showed the importance of transfer and return flights. In the analysed variants, their share in the total distance was close to half, which means that an assessment limited only to the flight with the parcel would clearly underestimate energy consumption [4], [7], [23]. Drones are therefore particularly useful as a specialised element of a mixed system, intended for selected parcels and relations. Their use requires consideration of cargo weight, weather conditions, take-off and landing infrastructure, charging, and the organisation of return flights.

Microsimulation also confirmed the need to separate indicators for individual components of the process. In addition to aggregated values, indicators were calculated for service movements, transfer trips, changes in vehicle position and empty returns, among others. This makes it possible to identify whether an improvement results from a more efficient transport mode, better parcel grouping, a shorter route or the reduction of operations that do not directly add value for the recipient.

The last-mile results are complemented by an analysis of a multi-level distribution architecture using consolidation, rail transport, BDF swap bodies, mobile microhubs and a zero-emission fleet. In the analysed system variant, it was possible to reduce transport work by more than 30% compared with the direct road-based model. This result shows that energy improvement in the last mile may be further strengthened by reorganising earlier stages of the flow. As a consequence, SULP should consider the choice of the final delivery vehicle and its link with the regional and supra-regional distribution structure [2].

7.3. Micro–macro integration and scalability of results

Preparing detailed microsimulation for every traffic analysis zone of a large city or metropolis would require significant data, time and computational effort. For this reason, WP2 developed a procedure in which traffic analysis zones with similar characteristics are managed as groups, while detailed experiments are carried out for selected reference zones [15], [23], [25].

TAZs were described using demographic, spatial, network, traffic and functional characteristics. Different clustering methods were then applied, reference zones were selected, and B2C delivery microsimulation was carried out for them. The obtained KPIs, including delivery time, driving time, distance, fuel and energy consumption, were transferred to the remaining zones using scaling functions [15], [23].

The results showed that the spatial and functional similarity of zones can be used to reduce the number of required microsimulations by more than 90%, depending on the number of identified groups and the scope of validation. This enables the analysis of a larger number of organisational and policy variants without the need to build a full operational model for the whole city [15].

At the same time, the quality of the clustering itself did not determine the accuracy of KPI estimation. The form of the scaling function was the most important factor. The most stable results were obtained for functions inspired by the Beardwood–Halton–Hammersley relationship, linking transport work with demand volume and zone area. This means that spatial clustering is an organising step, but transferring results also requires a proper representation of the relationship between the number of serviced points, area and route length [15].

Local results should be extended to other areas after checking their similarity to the reference zone. The following factors are particularly important:

- population and building density,
- area and shape of the zone,

- number and distribution of delivery points,
- density and layout of the road network,
- traffic conditions,
- land-use functions,
- demand volume and vehicle capacity.

Indicators related to total values, such as distance or energy, may be transferred using different relationships than unit indicators, such as energy per parcel or the share of service time. Some KPIs are more strongly related to the scale of demand, while others are more sensitive to the local network structure, the spatial distribution of buildings and the way the process is organised.

The developed method has direct application in SULP preparation. It makes it possible to initially assess the effects of changes in fleet structure, development of pick-up points, access restrictions or delivery reorganisation for many types of areas. It also allows the identification of zones where detailed local analysis is needed and those for which results obtained in similar zones can be applied.

Scaling should be treated as an iterative procedure. As data from further implementations and simulations are collected, the number of reference zones can be increased, the functions can be updated and the accuracy of estimates can be improved. In this way, the model can develop in parallel with SULP implementation and support the assessment of further pilot projects.

7.4. System interpretation of delivery channels and infrastructure constraints

System Dynamics was used to analyse phenomena whose effects appear over time and result from feedbacks between demand, infrastructure, user behaviour and logistics operations. The model covered three parcel service channels: home delivery – HOME, delivery to a PUDO point, and delivery to an automated parcel machine – APM [14], [23].

The model consists of three connected subsystems. The first is responsible for the split of demand between the HOME, PUDO and APM channels. The second describes the operation of parcel locker infrastructure, including the number of machines and lockers, occupancy, free capacity, parcel dwell time, refilling, collections, redirections and overflow. The third covers energy consumption by courier vehicles, recipient trips and the APM infrastructure itself.

The most important relationships adopted in the analysis are presented in Fig. 4. The diagram shows that demand growth increases the use of fleet and infrastructure, but may also improve the level of consolidation. The expansion of the APM network reduces collection distance and may limit car use, but at the same time increases the fixed energy consumption of the machines. Too long parcel dwell time in lockers reduces turnover, while high occupancy leads to redirections to other parcel lockers or PUDO points.

The results of the base scenario showed that total energy consumption increases with the number of parcels, while the value per successfully served parcel remains relatively stable. For the adopted GZM configuration, the APM channel was characterised by unit energy consumption more than ten times lower than HOME delivery. The assessment of the APM channel included courier operations, recipient trips, the operation of the machines and the courier's trip to the parcel locker [14], [23].

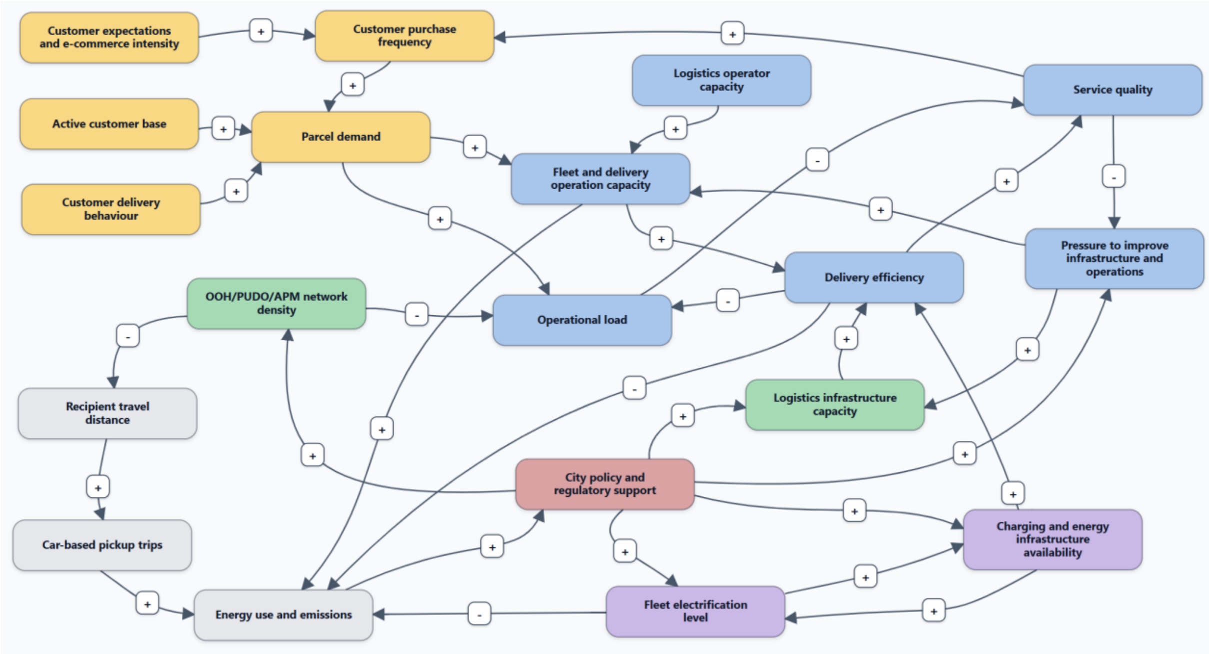

Fig. 4. Main cause-and-effect relationships in the HOME–PUDO–APM delivery system
Source: [23].

This result confirms the significant potential of consolidation, but also indicates the conditions needed to maintain this potential. A high share of trips combined with other activities reduces additional energy use on the recipient side. An increase in the share of dedicated car trips worsens the APM balance, especially in areas with long distances to collection points. The location of parcel lockers should therefore reduce both the recipient's distance and the need for additional trips.

Increasing the number of APMs improves accessibility and reduces the average collection distance. At the same time, each additional machine increases the fixed component of energy consumption and requires courier service. Therefore, the most favourable solution is a properly adjusted density of infrastructure, based on the spatial distribution of demand, machine capacity and recipient behaviour.

Parcel dwell time in lockers is one of the key parameters of effective capacity. Shorter collection time increases turnover without the immediate need to expand the number of machines. This may be supported by appropriate information, reminders, pricing solutions or the possibility of easily choosing an alternative point.

When locker use approaches available capacity, a redirection mechanism is activated. Some parcels may be redirected to another parcel locker and, after available capacity is exceeded, to a PUDO point. This mechanism increases system resilience and helps maintain the service level during periodic demand peaks. At the same time, redirections may lengthen both the operator's routes and the recipient's trip, so they should be coordinated on the basis of current information about capacity and spatial accessibility.

The SD model shows that demand growth does not automatically lead to lower efficiency. When capacity is available, it may increase consolidation and reduce unit energy consumption. However, after a high level of infrastructure use is reached, the probability of redirections, delays and lower service quality increases. SULP should therefore support the target size of infrastructure and mechanisms for its flexible use during demand peaks.

System resilience may be developed through:
- maintaining several complementary delivery channels,
- redirecting parcels between APM and PUDO based on available capacity,
- providing recipients with current information about alternative points,
- monitoring parcel dwell time and occupancy levels,
- flexibly adjusting service frequency,
- developing infrastructure in stages, based on observed utilisation thresholds.

7.5. Cross-cutting conclusions for SULP assessment

The synthesis of the results from the four modelling levels leads to the following findings relevant to the assessment of SULP measures:

1) The energy efficiency of a solution depends on the context. The same transport mode or delivery channel may achieve different results depending on demand density, network structure, route organisation, capacity use and recipient behaviour. Technology should be assessed in relation to the complete process, not a single section.
2) Urban space differentiates the effects of policies. Freight transport impacts are concentrated both in main corridors and in areas of intensive economic activity, as well as on local last-mile sections. Solutions should be selected according to the characteristics of specific zones and corridors.
3) APM and PUDO may significantly reduce unit energy consumption if consolidation on the operator side is not offset by additional recipient trips. The key factors are walking accessibility, trip chaining, appropriate capacity, locker turnover and the possibility of parcel redirection.
4) Electrification is an effective tool for reducing local emissions, but it should be linked with route organisation, vehicle assignment and charging infrastructure. A change in propulsion without reducing transport intensity does not reduce the number of vehicles, space occupation or congestion.
5) Light transport modes achieve the greatest potential in dense areas with short routes and many service points. Their use is particularly justified when combined with microhubs and consolidated transport in earlier stages of the flow.
6) Demand growth may improve unit efficiency through consolidation, but at the same time it increases the total load on the fleet, network and infrastructure. Policies should take into account capacity thresholds, seasonal peaks and the possibility of flexible flow redirection.
7) Transferring local results to a larger area requires consideration of spatial and functional similarity. The developed KPI scaling approach makes it possible to significantly reduce

the number of microsimulations, but estimation functions should reflect demand, zone area and local structure.

8) Data and monitoring are necessary for adaptive management. Information on demand, routes, delivery zone use, APM occupancy, recipient trips, energy consumption and service level makes it possible to assess measures, identify approaching overload thresholds and update SULP.

The WP2 results therefore indicate the need to use packages of measures instead of single instruments. The greatest potential lies in solutions where technological change is linked with consolidation, properly located infrastructure, space management, user information and systematic monitoring of effects. This interpretation provides the basis for the decision on the adequacy of SULP measures presented in Chapter 8.

8. Decision on the adequacy of SULP measures analysed in WP2

The assessment carried out within M2 indicates that the SULP measures considered in the project can support the achievement of the E-Laas objectives, but their effectiveness depends on how technology, infrastructure, process organisation and the behaviour of system participants are combined. The modelling results do not justify selecting one universal solution for all types of deliveries and urban areas. Instead, they confirm the need to use integrated packages of measures adapted to spatial structure, demand level, available resources and local priorities.

Assessing a measure as adequate means that it is consistent with the WP2 results and with the identified implementation conditions. It does not always mean that a complete urban policy instrument was directly emulated. The decision on adequacy was based on the results of macroscopic analyses, microsimulation, KPI scaling and System Dynamics modelling, as well as on the stakeholder findings presented in Chapter 6. The following aspects were considered in particular:

- the impact of the measure on energy consumption, emissions and transport work,
- operational and economic feasibility,
- social acceptance,
- the ability of the city and operators to implement and monitor the measure,
- the resilience of the solution to changes in demand, infrastructure constraints and disruptions,
- the possibility of scaling and adapting the measure to different types of areas.

The assessment did not identify any analysed measure that should be considered generally inadequate regardless of context. Some instruments have strong support and may be recommended as basic elements of SULP. Others show significant potential, but require adaptation to local conditions, phased implementation or further development in detailed applications. This approach is consistent with the logic of SULP as a document developed in a continuous improvement cycle, in which solutions are piloted, monitored and adjusted to changing conditions [13].

8.1. Integrated assessment matrix of measures

Table 6 presents the measures relevant to the achievement of the E-Laas objectives. The status of the evidence indicates whether the decision was based on direct modelling experiments, a combined interpretation of modelling results and stakeholder research, or supporting analyses and development scenarios. Three decision categories were used in the matrix:

- **adequate** – measures with strong support in the WP2 results and suitable for inclusion as basic elements of SULP;
- **conditionally adequate** – measures with confirmed potential, whose results depend more strongly on location, demand scale, infrastructure, process organisation or user behaviour;
- **recommended for further research and development** – promising solutions for which the project results provide a basis for further scenarios, pilot projects or applications in specific sectors.

Table 6. Integrated matrix assessing the adequacy of SULP measures

SULP measure	Evidence status	Main conclusion from WP2	Decision	Conditions for effectiveness	Main inhibitor
Designation and active management of loading and unloading spaces	Stakeholder research, policy analyses and indirect representation of operational effects	Availability of stopping space affects travel and service time, additional manoeuvres, reliability and energy consumption	**Adequate**	location consistent with demand, control of use, appropriate operating hours, enforcement of rules	competition for street space and limited control of occupancy
Digital reservation of delivery zones and kerbside space management	Stakeholder research, SULP analysis and analysis of digital tools	Information on space availability may reduce search time, improve predictability and provide data for further planning	**Adequate**	integration with traffic organisation, operator access, current information and control of use	system interoperability and availability of up-to-date data
Data platforms, KPI monitoring and periodic SULP updating	Results from all modelling levels, KPI scaling and stakeholder research	Without monitoring, it is not possible to identify the real energy effect, overload thresholds and spatial differentiation	**Adequate**	common KPI definitions, data aggregation, access rules, responsibility for analysis and response	fragmented data, limited trust and dispersed responsibility
Route optimisation, order consolidation and reduction of empty mileage	Direct micro- and macroscopic modelling	The energy result depends on the organisation of the full delivery cycle, including transfers, returns and capacity use	**Adequate**	access to operational data, proper representation of demand, dynamic route updating and resource coordination	demand variability, limited availability of operator data
Planning the location and capacity of APMs and PUDOs	Direct microsimulation, System Dynamics and recipient research	Consolidation may significantly reduce unit energy consumption if points are accessible and collection does not generate too many dedicated car trips	**Adequate**	walking and cycling accessibility, integration with daily trips, appropriate capacity, turnover and service frequency	poor location, additional recipient trips and locker overload
Information and organisational incentives supporting collection as part of existing trips	Recipient research and modelling of APM user mobility	Trip chaining reduces additional transport work and improves the system balance of out-of-home deliveries	**Adequate**	clear information, possibility to choose the point, location near generators of daily trips	dominance of convenience and time over declared environmental motivations

Access restrictions, time windows and low-emission zones	Policy analyses, stakeholder research and indirect representation in models	Regulations may reduce nuisance in selected areas, but may also cause detours, additional trips or changes in vehicle structure	**Conditionally adequate**	provision of alternative routes, consolidation points, service spaces and exemptions for appropriate vehicle groups	regulatory fragmentation, longer routes and mismatch with logistics operations
Electrification of the urban delivery fleet	Direct scenario experiments and studies of energy consumption and EVRP	Electrification may significantly reduce energy consumption and local emissions, but it does not automatically reduce the number of trips or space occupation	**Conditionally adequate**	matching vehicles to routes, charging planning, access to infrastructure and consideration of the actual energy mix	investment costs, range, charging time and power availability
Smart charging management and energy tariffs	Modelling of pricing strategies and analysis of energy infrastructure	Tariffs reflecting daily variability may improve infrastructure use and charging coordination	**Conditionally adequate**	possibility to plan charging, integration of energy data and route schedules, fleet flexibility	energy price variability, grid constraints and demand unpredictability
Cargo bikes, e-bikes and light electric vehicles	Spatial analyses, modal scenarios and microsimulation	The greatest potential occurs in dense areas, with short relations, many service points and parking constraints	**Conditionally adequate**	appropriate demand density, cycling infrastructure, microhub, matching of parcels and range	capacity, range, weather conditions and the need for transhipment
Microhubs and urban consolidation centres	Policy analyses, multi-level modelling and results concerning light transport modes	A microhub may reduce the number of vehicles serving dispersed points and enable a zero-emission last mile	**Conditionally adequate**	proper location, regular and sufficiently high demand, access to space, operator coordination	costs, space availability and limited cooperation between operators
Drones in selected last-mile processes	Direct microsimulation and technological analyses	Drones may shorten selected relations, but the result depends on the full cycle, including transfer and return flights	**Conditionally adequate**	appropriate parcel mass and type, short cycle, take-off and landing infrastructure, and favourable weather conditions	range, payload, regulations, weather conditions and energy used for returns
Multi-level consolidation using rail, BDF units and mobile microhubs	Complementary scenario analysis covering the national and urban levels	Benefits may result from reorganising the whole flow architecture and linking consolidated transport with a zero-emission last mile	**Recommended for further research and development**	regular and sufficiently large flows, reliable connections, efficient terminals and synchronisation of network levels	punctuality requirements, operator coordination and access to terminals and urban space
Developed B2B and pharmaceutical delivery scenarios	D0.3 scenario catalogue and stakeholder research results	The developed attribute and model structure enables further analyses for flows with different service requirements	**Recommended for further research and development**	separate parameterisation of demand, time, cargo, quality requirements and recipient structure	process diversity and specific service requirements
Extended autonomous systems, V2G/V2V and integration with local energy sources	Technological reviews and methodological extensions	These solutions may increase energy and operational flexibility, especially in strongly electrified systems	**Recommended for further research and development**	standardisation, technological maturity, interoperability and integration with urban systems	cost, technical complexity, safety and regulations

The most universal measures are organisational, informational and infrastructure-related, because they improve the conditions for different types of deliveries regardless of the transport mode used. They include delivery space management, system monitoring, process optimisation and deliberate planning of pick-up points.

Technological solutions also show significant potential, but their effects are more dependent on the conditions of application. The WP2 results indicate that an electric vehicle, cargo bike, drone or microhub alone does not guarantee improvement. The effect appears only when the technology is matched with space, demand and process organisation. D2.3 emphasises that energy consumption and emissions depend simultaneously on vehicle technology, demand density, spatial structure, delivery channel, infrastructure, recipient behaviour and operators' decisions [23].

8.2. Measures assessed as adequate

Measures assessed as adequate include solutions that respond to problems identified by several stakeholder groups, have a confirmed link with energy or operational parameters, and can be implemented gradually without the need to completely redesign the existing system.

- **Delivery service space management**

The designation and active management of loading and unloading spaces should be one of the basic elements of SULP. This measure responds to the problem of illegal or difficult stopping indicated by administration, operators and couriers. Its importance goes beyond spatial order. Reducing the time spent searching for a place, the number of additional manoeuvres and the distance over which parcels must be carried affects working time, energy use, service quality and vehicle utilisation.

The appropriate direction is to move from designating individual, static spaces to managing delivery space as a resource that changes over time. This includes the possibility of differentiating the function of a space depending on the time of day, providing digital information on occupancy, and periodically adjusting the number of zones to actual demand. The convergence of stakeholder views on the need to develop legal and accessible delivery service infrastructure was confirmed in stakeholder research and in the SULP analysis [13], [22].

- **Data platforms and KPI monitoring**

The implementation of platforms enabling data aggregation and monitoring of SULP results was assessed as adequate. The models developed in WP2 show that energy assessment requires combining data on demand, routes, vehicles, infrastructure and recipient behaviour. A single indicator, such as the number of electric vehicles, is not sufficient to assess the whole system. Monitoring should include both total and unit values, including:

- energy and emissions per parcel,
- delivery distance and time,
- number and share of empty trips,
- level of vehicle and infrastructure utilisation,
- availability of loading zones,

- APM occupancy and number of redirections,
- share of collections generating an additional trip,
- reliability and service level.

Indicators should be analysed spatially, because the same result aggregated for the city may hide areas with high levels of overload or inefficiency. The approach based on zones and diagnostic KPIs is consistent with the results of SULP research, which indicated the need to use static and dynamic indicators and to treat the plan as an improvement cycle [13], [15], [23].

➢ **Route optimisation and reduction of non-productive operations**

The direct results of microsimulation justify recognising process optimisation as a basic measure. Energy is consumed while driving with a parcel, travelling to the service area, repositioning vehicles, waiting and returning. For some modes, especially drones and individual recipient trips, return movements may account for a very significant share of total distance. SULP should support solutions that enable:

- better grouping of orders,
- reduction of failed delivery attempts,
- sharing of selected infrastructure,
- coordination of routes with the availability of zones and charging,
- reduction of empty trips,
- adjustment of service frequency to actual demand.

Although optimisation is directly implemented by operators, the city can create conditions for it by providing information on traffic, regulations, delivery zones and infrastructure.

➢ **Planning APM and PUDO as an urban network**

Active inclusion of APM and PUDO in urban planning was also assessed as adequate. This decision concerns planning the distribution, capacity and service of APM and PUDO as a coherent network, with the number of machines adjusted to demand, capacity and accessibility. The modelling results confirmed that the out-of-home delivery channel may achieve a favourable energy result due to parcel consolidation. At the same time, recipient research and the System Dynamics model showed the importance of location, recipient mobility, parcel dwell time and available capacity. D2.2 indicates that the attractiveness of a parcel locker depends on actual walking time, spatial accessibility and connection with residents' daily mobility [11], [14], [22], [23]. Urban policy should therefore support locations that are:

- accessible on foot and by bicycle,
- located near generators of daily trips,
- possible to service safely by a courier vehicle,
- equipped with capacity matching local demand,
- able to support parcel redirection to an alternative point,
- not generating excessive spatial conflicts.

Combined with informing users about the possibility of collecting parcels as part of trips they already make, this solution also supports objective A4 related to energy awareness.

8.3. Measures assessed as conditionally adequate

This group includes solutions with significant energy or environmental potential, whose effects depend on a larger number of interrelated conditions. Their implementation should be preceded by spatial analysis, scenario analysis or a pilot project.

➢ **Access regulations and time windows**

Access restrictions, low-emission zones and time windows may improve conditions in sensitive areas, but if poorly designed they may lead to longer routes, a higher number of vehicles or the concentration of deliveries in short time intervals. Regulations should be assessed at a scale larger than the zone itself in order to identify their impact on the whole course of routes. The conditions for adequacy are:

- provision of alternative routes or consolidation points,
- stability and clarity of rules,
- possibility of serving entities providing essential services,
- coordination with neighbouring territorial units,
- periodic assessment of effects on traffic and delivery efficiency,
- linking restrictions with positive incentives for low-emission modes.

Access regulations should therefore be treated as one element of a package of measures, and not as an independent answer to all urban logistics problems.

➢ **Fleet electrification and charging management**

Electrification was assessed as conditionally adequate because its energy and environmental potential was confirmed, but achieving the expected effect requires matching the vehicle to the task. In microsimulation, selected zero-emission fleet variants made it possible to reduce energy consumption and emissions by more than 20% compared with the base scenario. At the same time, the EVRP review indicates that range, variability in energy consumption and charging availability create an additional layer of routing and infrastructure decisions [7], [10], [23]. The most justified approach is the gradual assignment of electric vehicles to tasks:

- with predictable routes and mileages,
- starting or ending at a depot with access to charging,
- carried out in areas where local emissions and noise are important,
- enabling charging outside the peak operating period,
- ensuring an appropriate level of vehicle utilisation.

Infrastructure development should be coordinated with the route plan and fleet schedule. The results of pricing strategy modelling also indicate that dynamic tariffs reflecting the time of day and energy cost may balance infrastructure use and economic performance better than simple fixed tariffs [6].

➢ **Cargo bikes and light vehicles**

Cargo bikes and e-bikes show the greatest potential in areas where spatial characteristics make it possible to use their advantage over cars. The GZM analysis showed that their potential is concentrated in zones with high population density, a high number of food service points and short delivery relations. The conditions for effectiveness include:

- short distribution range,
- appropriate type and weight of parcels,
- dense structure of service points,
- safe cycling infrastructure,
- possibility of transhipment at a microhub,
- work organisation that takes seasonality and weather into account.

In dispersed areas, a bicycle does not necessarily have to be an appropriate substitute for a car. However, it may be part of a mixed system, serving only those zones and relations where it provides an operational advantage.

➢ **Microhubs and urban consolidation**

Microhubs were assessed as conditionally adequate [2], [13]. They may reduce the number of conventional vehicles making many stops and create conditions for cargo bikes or a light electric fleet. However, their result depends on reaching an appropriate scale of flows. A microhub should be treated as part of a broader distribution network, linked with terminals, sorting centres and operator resources. Its effectiveness depends mainly on location, space availability, demand density, connection quality and supply organisation. The greatest potential occurs in the case of:

- dense urban areas,
- regular and consolidated flows,
- limited access or difficult parking conditions,
- availability of a fleet dedicated to serving the final section,
- the possibility of sharing the point or coordinating between participants.

A microhub used with low and irregular volume may increase the number of transhipment operations without sufficiently reducing routes. For this reason, pilot implementation is recommended, preceded by an analysis of location and the break-even threshold.

➢ **Drones**

The microsimulation results indicate that drones may be adequate in specialised processes, but they should not be treated as a universal substitute for road transport. Their potential occurs especially in short, direct relations, for lightweight parcels or in areas where the road network causes a significant extension of the route [4], [7], [23]. The assessment should always cover the full cycle, because transfer and return flights may account for a significant share of total distance and energy. In addition, their use depends on weather, spatial conditions, regulations, availability of take-off and landing sites, and social acceptance of noise and autonomous devices.

8.4. Measures recommended for further research and development

The project results also made it possible to indicate solutions that may extend the application of the E-Laas methodology to further levels of the transport system and other types of flows. These directions remain consistent with the developed scenario structure and may use the prepared data, indicators and models as a basis for further analyses.

- **Multi-level intermodal systems and mobile microhubs**

The analysis of a system using a central hub, rail transport, BDF units and a zero-emission last mile indicates the possibility of assessing deliveries as one flow covering the national, interregional and urban levels. The benefits result mainly from consolidation, the use of efficient modes on the main sections, and the decentralisation of the last mile [2]. BDF units may provide a link between levels: they can be used as units in interregional transport and then as mobile microhubs. In this model, traditional dispersed delivery van traffic is partly replaced by consolidated transport of units and zero-emission local distribution. Further applications should focus on schedule synchronisation, terminal handling, the reliability required by courier operators, capacity utilisation and the selection of mobile microhub locations.

- **B2B and pharmaceutical deliveries**

B2B and pharmaceutical scenarios were included in the D0.3 catalogue as important directions for further research. The developed attribute structure makes it possible to describe them in a way that is consistent with B2C scenarios, but they require different parameters to be considered [19], [23]. In B2B deliveries, important aspects will include batch size, frequency, recipient structure, time windows, vehicle type and consolidation potential. In pharmaceutical deliveries, quality requirements, temperature, safety and reliability are also important. The micro-, macro- and system-level methods developed in WP2 may be used to compare variants of these processes after appropriate parameter adjustment.

- **Advanced autonomous systems and energy integration**

Another direction is the development of models covering autonomous vehicles, delivery robots, V2G and V2V cooperation, and integration of the logistics fleet with local renewable energy sources and energy storage. The EVRP review indicates the growing importance of issues related to charging technologies, energy exchange and renewable sources in route planning [10]. These solutions may increase system flexibility, but they require the integration of logistics decisions with energy management, digital infrastructure and safety. The developed models provide a basis for building scenarios in which a logistics vehicle is simultaneously an energy consumer, storage unit and potential energy supplier. To summarise the M2 decision, delivery space management, the use of data and KPIs, optimisation of the full process, and deliberate planning of APM and PUDO infrastructure should be considered basic and adequate measures. Electrification, light transport modes, microhubs, access regulations and drones are conditionally adequate, provided that specific spatial, infrastructure and operational requirements are met. Multi-level intermodal systems, developed sectoral scenarios and advanced integration of autonomous transport modes with energy infrastructure are justified directions for further development of the E-Laas methodology.

9. Key inhibitors to achieving the E-Laas objectives

The WP2 results indicate that achieving energy and environmental benefits does not depend only on the availability of a specific technology or urban policy instrument. Equally important are data quality, the organisational capacity of system participants, the availability of space and infrastructure, recipient behaviour, and the possibility of adapting a solution to local conditions.

In this report, inhibitors are understood as factors that may limit the scale of the expected improvement, delay the implementation of a SULP measure, or lead to side effects that reduce the achieved benefits. For example, fleet electrification may significantly reduce local emissions, but its operational result depends on charging availability and proper route planning. Delivery to APM may improve consolidation on the operator side, but the system-level effect may be reduced by additional car trips made by recipients. Similarly, access restrictions may reduce traffic volume in a specific zone, but if poorly designed they may lengthen routes or increase the number of trips. For this reason, inhibitors were considered as elements of an interconnected system. The identification of inhibitors defines the conditions that must be taken into account so that the measures assessed in Chapter 8 actually support the achievement of the E-Laas objectives.

9.1. Method for identifying and prioritising inhibitors

The inhibitors were selected on the basis of a combined interpretation of stakeholder research, macroscopic and microscopic modelling, KPI scaling, the System Dynamics model, and publications related to urban policies, electromobility, infrastructure and user behaviour. The requirements resulting from objectives A1–A4 and outcomes O1–O3 of the project were also taken into account. Prioritisation was based on five premises:

- **recurrence** of a given problem in results concerning different stakeholder groups,
- **impact on model results**, especially energy consumption, emissions, transport work, service level and system resilience,
- **relevance for achieving objectives A1–A4,**
- **relevance for the practical feasibility of SULP measures,**
- **possibility of limiting or neutralising the energy and environmental benefits** resulting from the application of a given solution.

Factors affecting several levels of the system at the same time were considered particularly important. For example, limited data availability affects the representation of flows, energy calculation, spatial analysis, infrastructure planning and monitoring of results. Similarly, limited institutional cooperation hinders data exchange, space management, charging coordination, microhub implementation and joint pilot projects. Two priority levels were used in the assessment:

- **critical priority** – the inhibitor has a cross-cutting impact on most SULP measures and may fundamentally limit the possibility of preparing, implementing or assessing them,
- **high priority** – the inhibitor has a strong impact on selected groups of measures and may significantly reduce the expected effects, but its importance depends more on the specific solution and local conditions.

No detailed point-based hierarchy was applied. The diversity of cities, operators and delivery systems means that the order of importance of individual factors may change depending on the type of flow, spatial structure and level of infrastructure development. The adopted priority levels therefore refer to their general importance for the implementation of E-Laas.

Objectives A1–A4 and outcomes O1–O3 used in the further assessment cover, respectively: representing urban logistics tasks as flows, identifying operational and complementary energy use, spatial and temporal analysis of energy and sensitivity, development of energy awareness, support for sustainable cities, resilient methods and infrastructure, and urban logistics systems responding to climate-related challenges.

The relationships between the identified inhibitors are presented in Fig. 5. The diagram shows that data- and governance-related factors form the basis for infrastructure and operational decisions. These, in turn, affect the possibilities of fleet transformation, recipient behaviour and the achieved energy effects. Scalability determines the possibility of transferring the developed solutions to further zones and cities.

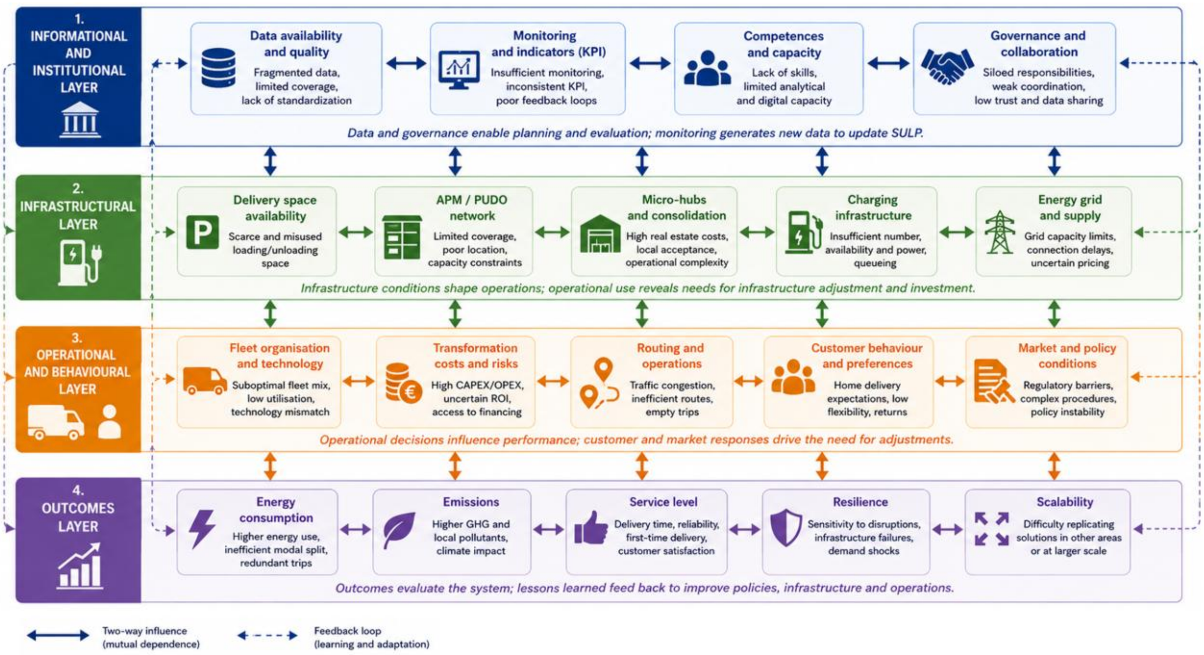

Fig. 5. Systemic links between the main inhibitors to achieving the E-Laas objectives

9.2. Priority inhibitors

Based on the synthesis carried out, seven inhibitors were selected as the most important for achieving the E-Laas objectives.

➢ **Limited availability, consistency and exchange of freight flow data**

The data needed for a full assessment of the system are dispersed between logistics operators, public administration, infrastructure managers, digital service providers and public sources. Individual datasets differ in scope, spatial scale, update frequency and method of aggregation. The assessment of energy use and the effects of SULP requires, among others, information on:

– the number and distribution of deliveries,
– the locations of senders, recipients and intermediate points,
– vehicles used,
– routes and travel times,
– stopping, loading and unloading times,
– the number of failed deliveries,
– recipient behaviour,

- availability of charging and delivery infrastructure,
- energy consumption and emissions.

D2.1 organised these information needs and linked them with modelling, operational optimisation, energy assessment, social aspects and urban policy. It also indicated the need to combine basic, spatial, operational, energy-related and survey data [21].

Limited data availability directly affects the quality of representing flows required by A1, calculating energy according to A2, and carrying out the spatial and temporal analysis and sensitivity assessment required by A3. It also makes it more difficult to monitor the effectiveness of SULP after implementation. As a result, decisions may be based on values that are averaged, outdated or insufficiently differentiated in spatial terms.

Access to operator data is particularly important. For system management, a city can rely on data aggregated by zones, periods, vehicle classes and delivery types, without using information on individual customers or parcels. This inhibitor should be reduced through aggregation standards, clear rules on ownership and access, protection of commercial information, and the creation of shared monitoring platforms.

➢ **Limited availability of space and mismatch of delivery service infrastructure**

The second inhibitor concerns competition for limited urban space and the mismatch between infrastructure and the actual intensity and nature of deliveries. This concerns loading and unloading spaces, short-term stopping, locations of microhubs, parcel lockers, PUDO points and infrastructure enabling a change of transport mode.

The lack of available stopping space leads to searching for free space, additional manoeuvres, stopping in prohibited places or increasing the distance over which parcels must be carried. These effects influence several aspects at the same time:

- delivery time,
- energy consumption,
- route reliability,
- safety,
- use of public space,
- traffic conditions for other users.

This problem is cross-cutting, because it was indicated in the studies of administration, operators and couriers. The results of D2.2 showed that loading and unloading spaces are considered a practical solution, but their use requires proper location, control and linkage with traffic organisation. Infrastructure should be treated as a system managed over time, with locations, functions and rules adjusted to actual demand [22].

The location of APMs and PUDOs is similarly important. A pick-up point may reduce the number of courier stops, but if it is located outside residents' daily routes, it may generate additional car trips. A microhub may enable the use of cargo bikes, but it requires appropriate space, network access and a regular parcel flow [11], [14], [22].

Limited space may therefore reduce the effectiveness of several measures at the same time: consolidation, electrification, the development of light transport modes and access management. For this reason, this inhibitor was assessed as critical.

➢ **Investment costs and operational risk of fleet transformation**

Fleet transformation involves investment costs and risk resulting from changes in transport modes and the organisation of operators' work. This transformation may include the purchase of electric vehicles, cargo bikes, light delivery vehicles, charging devices and fleet management systems, as well as the development of transhipment points. Purchase cost is only one part of the challenge. The operator must also ensure:

- appropriate vehicle range,
- the ability to complete the required number of routes,
- matching capacity to parcel structure,
- charging without reducing fleet availability,
- service continuity in the event of failures and demand growth,
- staff training,
- integration of new modes with existing processes.

In the analysed group of operators, combustion vehicles dominated, and light transport modes were not a basic element of operations. This means that implementing EVs or cargo bikes may require vehicle replacement, route redesign, changes in depot locations, work schedules and consolidation methods [22].

Operational risk may be a stronger inhibitor than the investment cost itself. Operators must maintain punctuality, flexibility and service quality. A solution that reduces emissions but increases the probability of delays or route failure will be difficult to integrate permanently into operations.

Fleet transformation therefore requires a phased approach, pilot projects, total cost of ownership analysis, matching vehicles to specific route types and stable regulatory conditions. Financial instruments and mechanisms for sharing risk between operators, cities and infrastructure providers are also important.

➢ **Availability of charging infrastructure and dependence on the energy system**

As the share of electric vehicles increases, the location, power, availability, reliability and integration of chargers with fleet schedules become as important as their number.

Charging infrastructure must match the real operational profile. A charging point available in urban space cannot always be used by a delivery vehicle because of its dimensions, stopping time or the need to return quickly to the route. Similarly, high technical power does not ensure usefulness if the station is unavailable during peak periods or requires an additional trip. The main mechanisms limiting transformation include:

- mismatch between charger locations and depots or routes,
- queues and uncertainty of access time,

– limited connection capacity,
– variability of energy costs,
– difficulty in synchronising charging with order service,
– vulnerability to failures and power outages.

Research results on the resilience of logistics systems and electric fleet planning indicate that charging constraints and power supply disruptions affect the possibility of route reconfiguration, fleet use and service continuity. Charging infrastructure, the energy network and the organisation of service locations should therefore be analysed as interdependent elements of the system [3], [10].

The importance of this inhibitor goes beyond the fleet itself. Power outages may also affect traffic lights, traffic management, digital platforms, terminals and parcel lockers. Growing electrification therefore increases the need to develop alternative charging locations, energy reserves, flexible schedules and business continuity plans.

➢ **Recipient behaviour and the possibility of generating additional trips**

The choice between home delivery, APM and PUDO, the way of reaching the pick-up point, parcel storage time and willingness to accept changes in delivery organisation are particularly important [11], [22], [23].

The benefit of consolidating deliveries to APM may be reduced when recipients make separate car trips. In the WP2 models, customer mobility was a separate component of energy consumption. The system-level result depended on:
– the share of dedicated trips,
– the share of collections combined with another activity,
– modal structure,
– distance to the point,
– possibility to choose the location,
– availability of the point at the required time.

The System Dynamics model also indicates that recipient behaviour affects infrastructure capacity. Long parcel dwell time in a locker reduces turnover and may lead to redirections, even if the number of machines remains unchanged [14], [23].

This inhibitor is particularly important for objective A4. User energy awareness includes the ability to make decisions that actually reduce energy use in the whole system, beyond declared support for environmental protection. Convenient and nearby infrastructure may be a more effective incentive than an information campaign alone. Policy should therefore combine education, information about the effects of choices, and service design in which the energy-efficient option is also easy to use.

➢ **Limited cooperation and institutional maturity of urban logistics management**

The dispersion of competences and the limited ability to conduct a coordinated policy for urban deliveries is also an important challenge. Urban logistics is located at the intersection of traffic management, parking, spatial planning, climate policy, energy infrastructure, municipal services and private business activity. Effective SULP implementation requires cooperation between:

- city authorities and organisational units,
- road and public space managers,
- logistics operators,
- energy and charging infrastructure providers,
- property owners,
- managers of APMs, PUDOs and microhubs,
- residents and service users.

The results of the local administration study indicate that urban logistics is often not yet managed as an independent, system-level policy area. Measures focus mainly on traditional traffic organisation instruments, while more advanced solutions requiring data exchange, shared infrastructure or public-private partnership are implemented less often [13], [17], [22].

Limited cooperation affects all other inhibitors. It makes access to data, location of delivery spaces, creation of microhubs, charging planning and preparation of coherent regulations more difficult. It may also lead to a situation in which individual measures are rational from the perspective of one participant, but do not bring the expected improvement at the level of the whole system. Institutional maturity in this case means the ability to:

- diagnose problems on the basis of data,
- maintain regular dialogue with operators,
- prepare pilot projects,
- define responsibilities and sources of financing,
- monitor effects,
- modify measures after implementation.

Because of its cross-cutting impact on all groups of policies, this inhibitor was assessed as critical.

- **Spatial differentiation and conditions for scaling solutions**

Another difficulty is the risk of directly transferring results between areas with different spatial and functional structures. Delivery efficiency depends on population density, building density, the road network, demand, infrastructure availability, the locations of senders and recipients, and residents' behaviour.

A solution suitable for a compact city centre does not necessarily achieve a similar effect in a suburban area. This applies in particular to:

- cargo bikes,
- microhubs,
- walking accessibility of APMs,
- access restrictions,
- scaling the number of delivery spaces,
- demand for charging infrastructure.

The KPI clustering and scaling method developed in WP2 makes it possible to reduce the number of required microsimulations, but the results showed that high-quality zone clustering alone does not guarantee accurate estimation. The choice of the scaling function is important, including its ability to reflect demand, area size and the spatial characteristics of the zone [15], [23]. D2.1 also indicates that scaling should be carried out by process segment. Food deliveries, boxed meal deliveries, home parcel deliveries and deliveries to APM have different time and operational characteristics. Results from one process should therefore not be automatically applied to all types of flows [21].

This inhibitor does not limit the usefulness of the methodology. It defines the need for local parameterisation, selection of appropriate reference zones and gradual expansion of the results base. Scaling should be an iterative process developed together with further analyses and pilot projects.

9.3. Link between inhibitors and the E-Laas objectives

Table 7 presents the link between the inhibitors and objectives A1–A4. The symbol ● indicates a direct and strong impact, while ○ indicates an indirect or supporting impact.

Table 7. Link between the main inhibitors and the E-Laas objectives

Inhibitor	Main impact mechanism	A1	A2	A3	A4	Priority
Limited availability, consistency and exchange of data	Makes it difficult to represent flows, calculate energy, carry out spatial analysis, monitor effects and compare scenarios	●	●	●	○	**Critical**
Limited space and mismatch of delivery service infrastructure	Increases time, distance, number of manoeuvres and spatial conflicts; limits consolidation and change of transport mode	●	●	●	○	**Critical**
Investment costs and operational risk of fleet transformation	Limits the pace of implementing EVs and light transport modes and may affect reliability and service level	○	●	●	○	**High**
Charging availability and dependence on the energy system	Affects the possibility of completing routes, work schedules, energy cost and resilience of the electrified system	○	●	●	○	**High**
Recipient behaviour and additional trips	May reduce consolidation benefits, increase collection energy and affect APM/PUDO capacity and service level	●	●	●	●	**High**
Limited cooperation and institutional maturity	Makes it difficult to coordinate policies, exchange data, finance measures, monitor effects and implement packages of actions	○	○	○	●	**Critical**
Spatial differentiation and scaling conditions	Limits direct transferability of results and requires segmentation and local parameter adjustment	○	●	●	○	**High**

The most cross-cutting factors are data access, spatial infrastructure and institutional capacity to coordinate measures. These factors form the basis for other actions. Without appropriate information and cooperation, it is difficult to properly locate infrastructure, select areas for electrification, monitor recipient behaviour and assess the effectiveness of implemented policies.

The inhibitors do not occur independently. They may form mutually reinforcing sequences. Limited data availability makes it difficult to determine the need for delivery zones and chargers. Poorly located infrastructure increases operator costs and may generate additional recipient trips. Lack of cooperation limits data exchange and joint financing, while difficulties in scaling may lead to transferring solutions without considering local conditions.

The key conclusion for SULP is therefore the need to reduce several inhibitors at the same time through packages of related measures. The development of an electric fleet should be linked with charging and route planning, the development of APM with walking accessibility and capacity monitoring, and the management of delivery zones with a data platform and enforcement of rules. Recommendations addressing these relationships are presented in Chapter 10.

10. Recommendations for energy-efficient SULP and the implementation of the E-Laas objectives

The WP2 results indicate that improving the energy efficiency of urban logistics should be achieved by combining infrastructure, organisational, technological and behavioural measures. A single instrument may bring only a limited effect if it is not linked with the conditions of its use. The designation of a delivery space requires control of its occupancy, the development of parcel lockers should take recipient mobility into account, and fleet electrification must be coordinated with routes, schedules and charging infrastructure [13], [23].

The recommendations were therefore formulated as integrated packages of measures. This approach is consistent with the logic of SULP, in which strategic objectives, stakeholder needs, infrastructure, regulations, data and monitoring mechanisms form one management system. The review of urban practices identified examples of the combined use of dedicated delivery spaces, digital parking control, low-emission regulations, microhubs and cargo bikes. Research on SULP design also confirms that the plan should combine strategic, operational and social measures and function as a continuous improvement cycle [13], [23].

10.1. Integrated packages of measures

Based on the decision presented in Chapter 8 and the inhibitors identified in Chapter 9, five basic packages of measures are recommended. Their scope is presented in Table 8.

Table 8. Integrated packages of measures recommended for SULP

Package of measures	Main elements	Expected impact mechanism	Basic monitoring indicators
Delivery space management	loading and unloading zones, digital reservation, occupancy information, control and enforcement, time-varying use of space	reducing search for space, additional manoeuvres, illegal stopping and delays	search time for a stopping place, zone occupancy, stopping time, number of violations, delivery energy and time
Out-of-home deliveries integrated	APM, PUDO, walking and cycling accessibility, location	parcel consolidation without generating an	energy per parcel, share of dedicated trips, collection distance, locker

with residents' mobility	near daily activities, capacity and redirection management	excessive number of additional recipient trips	occupancy, redirections, service level
Electrification linked with energy management	matching EVs to tasks, charging infrastructure, route and charging planning, flexible tariffs, investment support	reducing local emissions and fossil fuel use while maintaining operational reliability	energy per route and parcel, charger availability, waiting time, EV utilisation, energy cost
Consolidation, microhubs and light transport modes	fixed or mobile microhubs, feeder transport, cargo bikes, e-bikes, light EVs, dedicated service zones	separating consolidated transport from local distribution and reducing conventional vehicle traffic	number of parcels per point, microhub utilisation, share of light transport modes, last-mile distance and energy
Data exchange, KPIs and adaptive management	data platform, common KPI definitions, simulation models, monitoring, scenario analysis and periodic SULP updating	improving decision quality, identifying overload thresholds and adapting measures to changes	energy, emissions, transport work, service level, infrastructure use, social and resilience indicators

The packages are interdependent and should be implemented in a coordinated sequence. For example, a delivery zone may also serve as a transhipment or charging point, and data on its use may feed the urban platform and assessment models. Similarly, APM infrastructure may be linked with a microhub, a light fleet and an information system directing the recipient to the point that best matches their daily travel patterns.

- **Delivery space management**

The first package should combine the physical designation of space with its active management. Marking a space alone does not guarantee its availability for a delivery vehicle. Rules of use, control of stopping time, the ability to respond to demand variability and access to occupancy information are needed. It is recommended that the preparation of a delivery zone system should include:

- identification of places and periods of delivery concentration,
- selection of the number, size and operating hours of zones,
- definition of the permitted service time,
- digital registration or reservation of stopping,
- physical and administrative protection against misuse,
- monitoring of actual occupancy and search time for a stopping place,
- periodic relocation, extension or change of zone functions.

Stakeholder research indicated a common need to provide legal and accessible stopping, loading and unloading spaces. The availability of such space affects service time, the number of additional trips, road conflicts and uncertainty in the delivery process [22].

Space management should be dynamic. At certain hours, a space may function as a delivery zone, while outside periods of highest activity it may be used in another way. In areas with high demand, it is justified to implement reservation and real-time information for couriers. Data from these systems should support the handling of individual stops and further planning of infrastructure location and size.

In selected locations, the zone may be developed as part of a broader system, for example by providing a fast-charging point or space enabling transhipment to a light transport mode. Such use of kerbside space links delivery space management with the development of microhubs and charging infrastructure.

➢ **APM and PUDO linked with daily mobility**

The second package should treat APM and PUDO as elements of the urban network, with their location and capacity coordinated beyond the strategies of individual operators. Their location should be based simultaneously on parcel demand, walking and cycling accessibility, courier service conditions and links with residents' daily activities. Recommended locations include:

- near places of residence or work,
- near shops, services and other regularly visited facilities,
- near public transport stops and nodes,
- along safe walking and cycling routes,
- places enabling short and legal stopping of a courier vehicle,
- locations enabling flexible capacity increases or parcel redirection.

The results of D2.2 indicate that the attractiveness of a pick-up point depends on formal availability, actual walking time and the possibility of including collection in the daily trip chain. This knowledge was used to define the parameters of HOME and APM channels in WP2 modelling [9], [22].

Network development should be coordinated with capacity management. The System Dynamics model showed that the efficiency of the APM channel depends on parcel dwell time in lockers, refill frequency, occupancy, network density and redirection rules to other parcel lockers or PUDO points. Increasing the number of machines improves accessibility, but also increases the fixed energy consumption of the infrastructure. Therefore, the most favourable approach is to match the number, capacity and location of points to the actual spatial distribution of demand [14], [23].

Policy should not rely on one-sided restrictions on home delivery. It is recommended to preserve choice while creating conditions in which out-of-home collection is convenient, predictable and beneficial in energy terms. Reducing trips made only to collect a parcel is particularly important.

➢ **Electrification combined with routing, charging and financing**

The third package should integrate decisions on vehicle purchase with planning their later operation. Fleet transformation should be based on identifying tasks for which an electric vehicle can provide the best energy and operational effect. In the first stage, priority should be given to routes:

- with predictable length and structure,
- starting or ending at a depot with access to charging,
- carried out in areas where residents' exposure to noise and emissions is high,
- enabling vehicle use for a significant part of the day,
- with range reserve in case of changes in traffic conditions,

- possible to link with charging during stopping or transhipment.

Route planning should include charger location, availability, capacity, waiting time and the nonlinear course of charging. The review of EVRP methods confirms that the availability of charging stations and the possibility of waiting for a charger may significantly affect total route completion time [10].

Infrastructure development should proceed in parallel with fleet development. Charging at operator depots, microhubs, transhipment zones and selected public points should be considered. The location of chargers should be preceded by an analysis of routes, stops and required power, so that vehicles do not make additional trips only to recharge. D2.2 indicates reliable access to charging as a condition for the feasibility of EV-based variants [1], [10], [22].

It is also recommended to use flexible management of energy prices and charging schedules. The simulation of pricing strategies showed that the Time-of-Use approach may provide a favourable balance between infrastructure use and economic performance. In relation to logistics fleets, time-based tariffs may support charging outside periods of highest energy demand and help adjust charging to the operator's work rhythm [6].

Financial instruments should reduce the risk of the first stage of transformation. They may include grants or preferential financing for vehicles and infrastructure, support for pilot projects, preferential access of zero-emission vehicles to selected zones, and the development of shared charging points. Support should be conditional on monitoring the actual use of vehicles, energy and operational effects, instead of only counting purchased transport modes.

- **Microhubs combined with cargo bikes and light EVs**

The fourth package should be applied primarily in areas with high delivery density, short relations and limited possibilities for car stopping. A microhub enables the delivery of a consolidated flow by a larger vehicle, followed by the distribution of parcels between cargo bikes, e-bikes or light electric vehicles.

The condition for effectiveness is ensuring an appropriate scale. A microhub should serve a sufficiently large and regular flow so that the reduction of local routes balances the additional transhipment operations. The point must also be matched with the road and cycling network, feeder schedule and hours of highest demand.

The spatial analysis of food deliveries indicates that delivery bikes achieve the greatest potential in areas with high building intensity, short distances and significant difficulties for motor vehicles. Increasing the range of e-bikes may extend the area of their justified use, but it does not remove the need to spatially match the transport mode to the task.

A microhub may be fixed or mobile. The variant using BDF swap bodies shows the possibility of combining consolidated interregional transport with local distribution carried out by a zero-emission fleet. The same unit may serve first as a transport unit and then as a temporary supply point for the last mile. In this case, the main effect results from reorganising the whole flow architecture; changing vehicle propulsion is only one component [2].

It is recommended to start with mobile or temporary microhubs when this makes it possible to test the location and demand volume before preparing a permanent facility. If the result is positive, the point may be developed further, while if demand changes, its location or service scope may be modified.

- **Data exchange, KPIs and monitoring of effects**

The fifth package provides a common layer for all other measures. It should be based on agreeing a minimum dataset and a set of indicators enabling comparison of the baseline, pilot project and target implementation. It is not necessary to share data identifying individual recipients or parcels. In many applications, data aggregated by the following categories are sufficient:

- traffic analysis zone or another area,
- time interval,
- delivery type,
- vehicle class and propulsion type,
- HOME, APM or PUDO channel,
- type of operation, for example loaded trip, transfer or empty return.

An integrated platform should make it possible to combine operator data with information on traffic, delivery space, charging infrastructure and urban land use. Exchange rules must define the level of aggregation, access, security and responsibility for interpreting results. Research on SULP indicates that the lack of integrated databases is both a technical and organisational problem, requiring cooperation and cross-sector trust.

The KPI system should cover several scales. At the level of a single operation, energy, distance, time and number of stops should be measured, among others. At the zone level, transport work, infrastructure availability and impact concentration are important. At the city level, the achievement of energy, emission, social and spatial objectives should be monitored. Multi-scale KPIs should form the basis for SULP monitoring and periodic assessment [13].

The method developed in WP2 for grouping similar TAZs and scaling indicators may be used to extend results to a larger area. It makes it possible to reduce the number of detailed models, but requires preserving information on local demand, area, network and land-use function [15], [23].

10.2. Mechanisms for developing energy awareness

Objective A4 assumes the development of energy awareness at several levels – from customers and couriers, through logistics operators, to public authorities. This awareness should not be limited to general information about the need to reduce emissions. It should make it possible to understand how a specific decision concerning the delivery channel, route, transport mode, collection time or infrastructure location affects the whole logistics flow. An effective mechanism should combine three elements:

- information available at the moment of decision-making,
- an incentive consistent with the real energy effect,
- feedback showing the result of the selected option or implemented measure.

- **Information on the effects of choosing a delivery channel**

The user should receive simple comparative information when choosing the delivery method. It does not have to present the exact energy value in kWh, which may be difficult to interpret without context. It may be more useful to indicate the variant recommended because of:

- the possibility of consolidation,
- short distance to the point,
- walking or cycling accessibility,
- location along the user's daily route,
- expected reliability,
- use of low-emission transport.

The information should refer to the specific case. An APM located far from the user and requiring a separate car trip should not automatically be marked as the most favourable option. The system should take into account location, the possibility of combining collection with another trip, and the current capacity of the point [11], [14], [22].

- **Price and non-price incentives**

Incentives should support variants that, under given conditions, reduce energy use in the whole process. They may include a discount for choosing a point located on an existing delivery route, free or cheaper delivery in a flexible time window, rewarding collection without a separate car trip, or the possibility of easily changing the point to one closer to daily activities.
Non-price incentives may include:

- recommending the nearest or best-connected point,
- priority information about deliveries carried out by a low-emission fleet,
- greater flexibility of collection time,
- combining several parcels into one collection operation,
- point systems and loyalty programmes,
- the possibility to set a preferred collection method permanently.

Mechanisms that formally promote an ecological solution but shift additional transport work to the customer should be avoided. Incentives should be designed on the basis of a full balance covering the operator, the recipient and the infrastructure [11], [22].

- **Tools supporting operator decisions**

At the operator level, energy awareness should be built into the planning and control system. The dispatcher or planner should have access to cost, time and energy-related information, including:

- energy per route and per parcel,
- share of empty trips,
- vehicle capacity utilisation,
- consolidation potential,
- expected battery state,
- charging availability and cost,
- impact of changing the vehicle or delivery channel,
- load on APMs, PUDOs and microhubs.

The models developed in WP2 may serve as ex ante tools, enabling the comparison of variants before implementation. For current operational decisions, model results should be linked with data on current demand, traffic, infrastructure and resource availability [23].

➢ **Communicating the effects of urban measures**

The city should present announcements of measures together with their measurable results. Communication may include:

- changes in the time spent searching for delivery spaces,
- use of loading zones,
- reduction of transport work or emissions,
- share of deliveries carried out by low-emission vehicles,
- availability of APMs and PUDOs,
- results of microhub pilot projects,
- level of acceptance among residents and operators.

Public presentation of results increases transparency, helps explain the reasons for introducing changes, and supports shared responsibility for the system. It should also show trade-offs, for example situations in which an environmental benefit requires investment, organisational change or phased implementation.

Energy awareness should therefore be treated primarily as a decision-support mechanism, with education as one supporting element. The most effective approach will be to combine communication with services that make it easier to choose the variant that is genuinely beneficial in energy terms.

10.3. Pilot projects, monitoring and adaptive policy implementation

The spatial diversity of cities and the dependence of results on demand, infrastructure and user behaviour justify the phased implementation of SULP. A pilot project makes it possible to test a solution under real conditions, collect data and compare the results with models. It should form part of a learning process and gradual policy development, with data collection, evaluation and adjustment built into the pilot design. The desired features of the SULP development process are presented in Fig. 6. The diagram includes five interrelated elements: the improvement cycle, scenario analysis, phased implementation, the learning mechanism, and response and adaptation. SULP should be treated as a "living" document, with mechanisms for periodic review and triggers for change when new technologies, regulations or user behaviours emerge. The pilot implementation process should include six main stages.

1) **Diagnosis of the baseline state.** Before starting a measure, the existing situation should be defined, including demand, route structure, energy consumption, service level, use of space and user behaviour. Without baseline values, it is not possible to determine the effect reliably.
2) **Selection of the package and formulation of the implementation hypothesis.** The pilot project should address a specific relationship, for example whether space reservation reduces search time, whether a microhub reduces vehicle distance, or whether changing the location of an APM reduces the share of dedicated trips.

3) **Ex ante scenario analysis.** Before implementation, the baseline and alternative variants should be compared in a macroscopic, microsimulation or SD model. The analysis should include average and extreme scenarios, as well as disruptions such as demand growth, infrastructure unavailability, charging constraints or changes in recipient behaviour.
4) **Limited implementation and data collection.** The pilot project should cover an area, period and group of processes that make it possible to identify effects, while still allowing the solution to be modified. The scope of data and responsibility for collecting them should be agreed before the start.
5) **Assessment of effects and consultation of results.** The results should be compared with the baseline state, assumed thresholds and stakeholder assessment. Where possible, it is useful to apply a comparison area or process that was not covered by the measure.
6) **Decision on extension, modification, reconfiguration or termination of the variant.** After assessment, the measure may be extended to further areas, modified or replaced with another configuration. The criteria for such a decision should be defined before the pilot project starts.

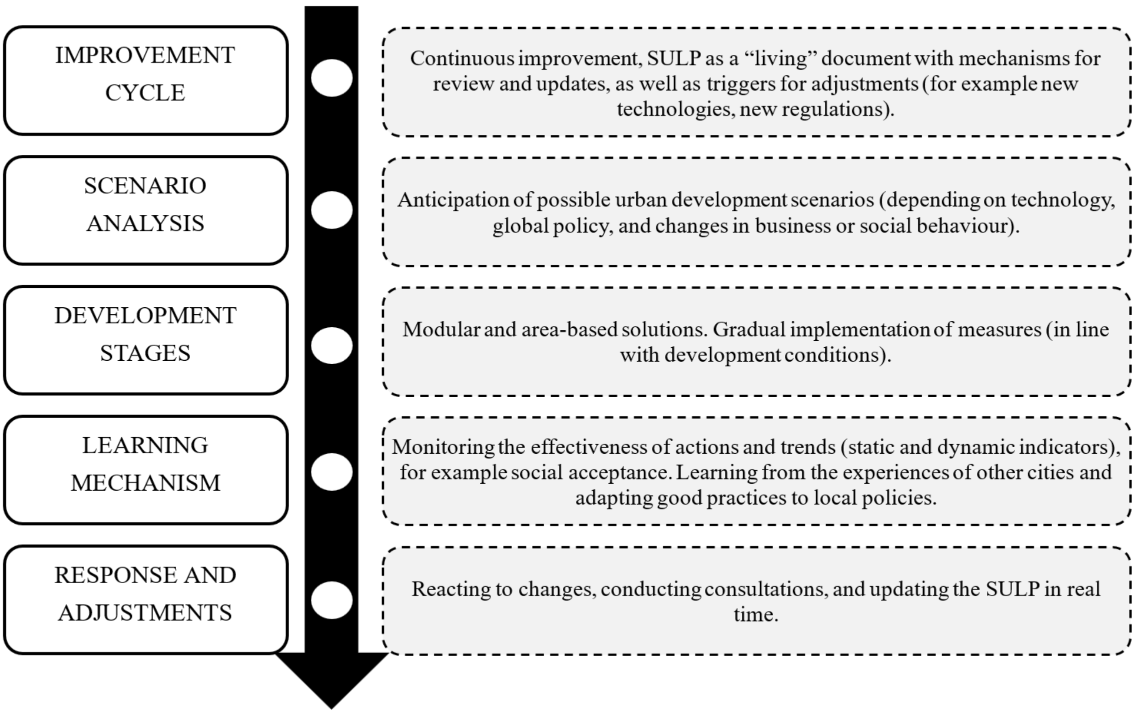

Fig. 6. Desired features of the adaptive SULP development process
Source: [13].

Monitoring should begin before implementation and continue throughout the period of operation. The scope of indicators depends on the package, but it should include at least the energy effect, service quality, infrastructure use, operating costs and social effects. For delivery zones, search time for a stopping place and occupancy should be analysed, among others. For APMs, capacity, parcel dwell time, redirections and the way recipients reach the point are important. For electrification, energy use, charging availability, queues and the ability to complete routes should be monitored.

Warning indicators showing that the system is approaching its service capacity limit are particularly important. These may include:

- increasing share of failed deliveries,
- longer search time for a stopping place,
- high and persistent locker occupancy,
- increase in redirections to other channels,
- decrease in service level,
- charging queues,
- increase in dedicated car trips,
- exceeding the assumed energy consumption or unit cost.

System Dynamics modelling shows that the consequences of changes may appear with a delay. Demand growth may initially improve unit efficiency through consolidation, and then lead to infrastructure overload, redirections and lower service quality. Monitoring should therefore include average values, trends and capacity thresholds [14], [23].

Policy should also take disruptions into account. For an electrified fleet, this may be a power outage or charger unavailability; for cargo bikes, weather conditions; and for APMs, a sudden increase in demand or longer collection time. The analysis should identify alternative channels, resource reserves and reconfiguration rules.

Extending a pilot project to further areas should be preceded by an assessment of spatial and functional similarity. The TAZ clustering and KPI scaling method may support the selection of zones where a similar impact mechanism is expected. In clearly different areas, local parameterisation and renewed scenario analysis are necessary [15], [23].

Adaptive implementation means that SULP provides a framework for successive decisions, including objectives, packages of measures, indicators, data sources, intervention thresholds and update rules. This makes it possible to develop solutions gradually, maintain system resilience, and respond to changes in demand, technology, regulations and urban operating conditions.

11. Description of the WP2 repository and dataset

The WP2 repository provides the data and tools used in research on the energy assessment of urban delivery processes. Its main components are the survey results and the last-mile microsimulation model, together with input data, scenario configurations and the procedure for processing results. The dataset was made available in the Zenodo repository under DOI: 10.5281/zenodo.20512796 under the CC0 licence [16].

1) Survey data

The survey dataset includes 2,427 questionnaires collected in Poland in 2024 using CATI and CAWI methods. The research covered parcel recipients, couriers and people carrying out different types of deliveries, logistics operators, and representatives of cities, municipalities and districts. The data were integrated into one Excel file containing variables related to, among others, delivery organisation, vehicles used, working and service time, parking, charging infrastructure, customer preferences and conditions for implementing urban logistics solutions [16].

The dataset does not contain names, surnames or contact details of respondents. Individual records were marked with anonymous identifiers. The sample was purposive and stratified, therefore the data are primarily intended to identify tendencies, process parameters and differences between stakeholder groups, and not to statistically represent the whole urban logistics market [16].

2) Simulation models and scenario results

The modelling part includes a discrete-event model developed in FlexSim 25.1 for the central part of Katowice. The model represents seven delivery methods, including food deliveries, boxed meal deliveries, parcel deliveries directly to recipients and to parcel lockers, customer trips to collect parcels, and drone-based variants [16].

The repository contains the model, network and spatial data, vehicle and scenario parameter tables, demand data, a register of performed operations, and a Python script for calculating KPIs. The results can be analysed by delivery channel and vehicle type, taking into account time, distance, energy consumption, CO_2 emissions, number of parcels, and the share of service, transfer and return trips [16].

The microsimulation model is linked with the other WP2 components: macroscopic modelling, KPI scaling between traffic analysis zones, and System Dynamics analyses. Their assumptions and results are presented in report D2.3 and in the project publications [23].

3) Scope of use and reuse potential

The repository documentation describes the file structure, scenario parameters, model tables, the method of demand generation, route planning and result processing. This makes it possible to reproduce the analyses, prepare custom scenario configurations and further develop the model.

Transferring the results to other cities or operator systems requires adapting data on the transport network, demand, vehicles, service points and user behaviour. The dataset is primarily intended for scientific and methodological use and complements reports D2.1–D2.3 and the publications documenting the WP2 results.

12. Conclusions

The synthesis carried out within M2, based on survey research, macroscopic and microscopic modelling, KPI scaling and System Dynamics analyses, made it possible to assess the adequacy of SULP measures from the perspective of the E-Laas objectives. The results confirm that improving the energy efficiency of urban logistics requires a proper combination of process organisation, infrastructure, transport modes, data and user behaviour.

1) The SULP measures assessed as adequate are primarily instruments that improve the operating conditions of the whole delivery system. These include active management of loading and unloading spaces, digital reservation and monitoring of delivery space, data

exchange, the use of KPIs, route optimisation and order consolidation, and planning of the APM and PUDO network with consideration of walking and cycling accessibility and links with residents' daily trips. These measures can be applied regardless of the dominant vehicle technology and form the basis for further system transformation [13], [22], [23].

2) Fleet electrification, cargo bikes, light electric vehicles, microhubs, access regulations and drones were assessed as conditionally adequate measures. Their effectiveness depends on spatial structure, demand density, route length, parcel type, infrastructure availability, recipient behaviour, and the organisational and investment capacity of operators. Electrification should be combined with route and charging planning, cargo bikes with microhubs and dense service areas, and APMs with limiting dedicated car trips made by recipients [2], [7], [14], [23].
3) Multi-level intermodal systems, mobile microhubs, developed B2B and pharmaceutical scenarios, and the integration of autonomous transport modes with the energy system are recommended for further research and development. The developed methodology, attribute structure and models provide a basis for developing these directions in further research applications and pilot projects. The combination of consolidated interregional transport with a zero-emission last mile is particularly promising [2], [10], [19].
4) The most important inhibitors to achieving the E-Laas objectives include limited data availability and consistency, insufficient space and delivery service infrastructure, the costs and risks of fleet transformation, charging availability, recipient behaviour, limited institutional cooperation, and the spatial differentiation of urban areas. Data, infrastructure and the capacity to coordinate measures have the most cross-cutting importance, because they affect the design, implementation and assessment of most SULP instruments at the same time [22], [23].
5) The WP2 results support all main E-Laas objectives. The models and scenarios enabled the representation of urban logistics tasks as flows, in line with objective A1; the assessment of operational and complementary energy use, in line with A2; and the analysis of spatial and temporal differentiation of effects, in line with A3. Stakeholder research, the analysis of recipient behaviour, and recommendations concerning information and incentives support the implementation of objective A4, related to developing energy awareness among customers, operators and public authorities [21], [22], [23].
6) The WP2 dataset is a durable result enabling further use of the developed methodology. The shared survey data, microsimulation model, input data, scenario parameters, result-processing script and documentation increase the transparency of the work and make it possible to replicate and develop further analyses. Applying the dataset in other cities requires local parameterisation of the network, demand, fleet, infrastructure and user behaviour, but its structure provides a common basis for comparing last-mile logistics variants [16].

The final decision indicates that energy-efficient SULP should be integrated and adaptive. The greatest potential lies in packages combining space management, consolidation, properly selected fleet, energy infrastructure, user information and continuous monitoring. SULP should be developed in stages, using pilot projects, scenario analysis and periodic updates based on observed results.

References

[1] Izdebski, M., & Jacyna, M. (2025). Predictive models of energy expenditure of electric delivery vehicles in urban service enterprises. In X. Qu, W. Zhang, Y. Liu, & Y. Yiping (Eds.), *Proceedings of the 14th Asia-Pacific Conference on Transportation and the Environment* (APTE 2025). Atlantis Press. https://doi.org/10.2991/978-94-6463-972-8_19

[2] Jachimowski, R., et al. (in preparation). Multi-level parcel distribution system based on rail transport, BDF swap bodies, and zero-emission last-mile logistics.

[3] Jacyna, M., Guze, S., Żochowska, R., Jaskowski, P., Kulcsár, B., Koniak, M., Franke-Wąsowski, P. (in preparation). Supply chain resilience in urban logistics network in terms of disruptions – a systemic approach using Semi-Markov model.

[4] Kłodawski, M. (in preparation). The use of UAVs in Last-Mile Logistics: opportunities, constraints and potential benefits of Autonomous Drone Delivery Systems (ADDS)

[5] Kłodawski, M., Lewczuk, K., & Gao, J. (2025). Last-mile delivery energy consumption: Insights from a simulation-based analysis. In X. Qu, W. Zhang, Y. Liu, & Y. Yiping (Eds.), *Proceedings of the 14th Asia-Pacific Conference on Transportation and the Environment* (APTE 2025). Atlantis Press. https://doi.org/10.2991/978-94-6463-972-8_17

[6] Kotylak, P., Jacyna, M., Wasiak, M., Żak, J., Kulcsár, B. (in preparation). EV charging station energy pricing strategy for changing environmental conditions using a simulation model.

[7] Lewczuk, K., & Kłodawski, M. (in preparation). Event-driven microsimulation for energy assessment of multi-mode urban last-mile logistics systems.

[8] Murawski, J. (2025). Logistics Market Stakeholders in the Context of Sustainable Development and ESG. Annual Set the Environment Protection, 27, 837–854. https://doi.org/10.54740/ros.2025.067

[9] Murawski, J., Paszkowski, J. (2026). Customer Preferences for Courier Services in Poland – Results of Survey Research. In: Sierpiński, G., Naumann, S., Macioszek, E. (eds) Transport Systems Development – Methods and Solutions. TSTP 2025. Lecture Notes in Networks and Systems, vol 1789. Springer, Cham. https://doi.org/10.1007/978-3-032-14826-1_10

[10] Murawski, J., Szczepański, E., Kulcsar, B., Jacyna, M., Wu, J., Zhou, F., Wang, K., Zhang, W. (in preparation). Advancements in Electric Vehicle Routing Problems: A systematic review of research trends.

[11] Paszkowski, J., & Żochowska, R. (2025). Method of estimation of car trips induced to pick up parcels from parcel lockers. *Archives of Transport, 75*(3), 205–223. https://doi.org/10.61089/aot2025.dc8mxg43

[12] Paszkowski, J., Szczepański, E., & Murawski, J. (2025). Environmental impact assessment of urban freight transport based on macroscopic traffic modelling. *Rocznik Ochrona Środowiska, 27*, 746–766. https://doi.org/10.54740/ros.2025.060

[13] Szczepański, E. (2025). Designing and Evaluating Sustainable Urban Logistics Plans within a Stakeholder-based Framework. Annual Set the Environment Protection, 27, 652–666. https://doi.org/10.54740/ros.2025.052

[14] Szczepański, E. (in preparation). System Dynamics for APM-based last-mile logistics analysis.

[15] Szczepański, E., et al. (in preparation). Clustering-based estimation of last-mile delivery KPIs across Traffic Analysis Zones.

[16] Szczepański, E., Izdebski, M., Jachimowski, R., Jacyna, M., Kłodawski, M., Lewczuk, K., Murawski, J., & Paszkowski, J. (2026). Dataset for E-Laas WP2 - Survey research results and simulation model (Deliverable D2.2, D2.3) (1.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.20512796

[17] Szczepański, E., Izdebski, M., Jachimowski, R., Jacyna, M., Kłodawski, M., Lewczuk, K., Murawski, J., & Paszkowski, J. (2026). Updating state of the art based on a review of the scientific literature and analysis of reports and other sources (Project E-Laas, Deliverable D0.1). Warsaw University of Technology.

[18] Szczepański, E., Izdebski, M., Jachimowski, R., Jacyna, M., Kłodawski, M., Lewczuk, K., Murawski, J., & Paszkowski, J. (2026). Development of a set of attributes characterizing the scenario and the reference case (Project E-Laas, Deliverable D0.2). Warsaw University of Technology.

[19] Szczepański, E., Izdebski, M., Jachimowski, R., Jacyna, M., Kłodawski, M., Lewczuk, K., Murawski, J., & Paszkowski, J. (2026). Identified scenarios of logistics systems, Inventory of reference cases with description (Project E-Laas, Deliverable D0.3). Warsaw University of Technology.

[20] Szczepański, E., Izdebski, M., Jachimowski, R., Jacyna, M., Kłodawski, M., Lewczuk, K., Murawski, J., & Paszkowski, J. (2026). Repository of cases characterizing logistic system scenarios (Project E-Laas, Milestone M0). Warsaw University of Technology.

[21] Szczepański, E., Izdebski, M., Jachimowski, R., Jacyna, M., Kłodawski, M., Lewczuk, K., Murawski, J., & Paszkowski, J. (2026). Assumptions for questionnaire and simulation research (Project E-Laas, Deliverable D2.1). Warsaw University of Technology.

[22] Szczepański, E., Izdebski, M., Jachimowski, R., Jacyna, M., Kłodawski, M., Lewczuk, K., Murawski, J., & Paszkowski, J. (2026). Synthetic knowledge of the needs of potential E-Laas users and identified user preferences regarding the services offered (Project E-Laas, Deliverable D2.2). Warsaw University of Technology.

[23] Szczepański, E., Izdebski, M., Jachimowski, R., Jacyna, M., Kłodawski, M., Lewczuk, K., Murawski, J., & Paszkowski, J. (2026). D2.3: Simulation model with indicators of the energy assessment of distribution systems in the relation between the logistics centre and the customer's door for conducting research. Comparative analysis of distribution systems scenarios (Project E-Laas, Deliverable D2.3). Warsaw University of Technology.

[24] Szczepański, E., Jachimowski, R., & Rudyk, T. (2024). Simulation studies of fleet vehicle selection in terms of pollutant emissions. *Combustion Engines, 196*(1), 80–88. https://doi.org/10.19206/CE-169802

[25] Szczepański, E., Paszkowski, J. S., Jacyna, M., Wang, K., & Gao, J. (2025). Scaling urban logistics microsimulation: Traffic Analysis Zone similarity assessment to estimate simulation results. In X. Qu, W. Zhang, Y. Liu, & Y. Yiping (Eds.), *Proceedings of the 14th Asia-Pacific Conference on Transportation and the Environment* (pp. 24–34). Atlantis Press. https://doi.org/10.2991/978-94-6463-972-8_4