D4.3: Wave 2 LLs Lessons Learned

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Executive summary

This deliverable report presents the outcomes of Task 4.3 of the URBANE project, which assessed the transferability of URBANE last-mile logistics innovative concepts and tools to URBANE Wave 2 Twin Living Labs. The methodology developed and work undertaken addresses a key challenge in urban logistics: how solutions developed and validated in one context can be adapted and applied in cities with different spatial, regulatory and organizational conditions.

The purpose of Task 4.3 was to demonstrate transferability as a process of structured re-application rather than direct replication. A comprehensive methodology was developed and applied, guiding cities from baseline ecosystem analysis to performance validation. Living Labs function as collaborative environments where public authorities, logistics operators, technology providers, researchers and citizens jointly define objectives, select innovations, prepare data and evaluate outcomes. This ensures that solutions are assessed within real governance and operational settings.

The work carried out in the URBANE Wave 2 Living Labs focused on distinct innovation pathways while applying the same methodological framework. In Barcelona, the focus was on optimization and digitalization of an existing low-emission logistics system. In Karlsruhe, the methodology supported the assessment of a more structural innovation involving the integration of autonomous delivery solutions with public transport. Across both cases, URBANE Innovation Transferability platform and its components or sub-components such as Digital Twins, routing models, algorithms and modeling techniques were used to extend pilot insights to longer-term and larger-scale deployment scenarios.

A central innovation of this deliverable is the design and application of a transferability framework, which structures assessment around six interrelated pillars: contextual fit, data integration, model and method transferability, technological interoperability, impact assessment, and long-term adoption potential. By combining qualitative ecosystem analysis with quantitative modelling, the framework provides cities with a practical tool to assess feasibility, identify adaptation needs and manage expectations before scaling innovations.

The main conclusion is that successful transferability depends primarily on contextual alignment rather than on the maturity of individual technologies. Optimization oriented innovations are generally more transferable, while structural changes require deeper institutional adaptation and stronger governance coordination.

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Glossary of Terms and Acronyms

ACRONYM	DECRIPTION
ABM	Agent-Based Model
ADV	Autonomous Delivery Vehicle
CO_2	Carbon Dioxide
DT	Digital Twin
eLCV	Electric Light Commercial Vehicle
GHG	Greenhouse Gas
IAR	Impact Assessment Radar
KPIs	Key Performance Indicators
LL	Living Lab
LSP	Logistics Service Provider
PI	Physical Internet
UCC	Urban Consolidation Center

1. Introduction

Task 4.3 examined how can the selected Wave-1 Living Labs of URBANE innovations be adapted and validated in Wave-2 Twinning Living Labs, with a focus on low-emission last-mile logistics solutions in Barcelona and Karlsruhe. The task developed and applied a structured transferability methodology to assess whether innovations remain viable when deployed in different urban, regulatory and organizational contexts. This methodology combines a six-step implementation process with long-term impact assessment and supports a transition from baseline ecosystem understanding to performance validation. Living Labs functioned as collaborative environments where logistics operators, technology providers, public authorities and citizens jointly defined objectives, reviewed candidate innovations, prepared datasets and selected relevant KPIs. This ensured that technical evaluation was embedded within real governance and stakeholder conditions rather than treated as an isolated technical exercise.

The application of the methodology highlighted the decisive role of local context in shaping both performance and replicability. In Barcelona, the focus was on optimization and digitalization applied to an already mature low-emission logistics system, enabling rapid adoption and validation of supporting tools. In Karlsruhe, the methodology was applied to a more structural innovation pathway involving the integration of autonomous delivery vehicles with public transport. This revealed stronger dependencies on regulatory frameworks, organizational coordination and service design considerations. Across both Living Labs, the assessment confirmed the feasibility of URBANE innovations while demonstrating that transferability depends not only on technical performance, but also on ecosystem readiness, governance clarity and stakeholder alignment. Overall, the task showed that optimization-oriented innovations are generally more transferable, while structural changes require deeper institutional adaptation and longer implementation pathways.

1.1 URBANE Outputs Mapping to GA Commitments

TABLE 2: DELIVERABLE ADHERENCE TO GRANT AGREEMENT DELIVERABLE AND WORK DESCRIPTION.

URBANE GA ITEM	URBANE GA ITEM DESCRIPTION	DOCUMENT CHAPTER(S)	JUSTIFICATION
	DELIVERABLE		
D4.3 Wave 2 LLs Lessons Learned	*Report on URBANE's approach impact assessment, covering the validation methodology, a comparative analysis across URBANE Twinning LLs KPIs and an evaluation summary on the efficiency of the Innovation Transferability Platform.*	Chapters 2,3,4	These documents cover the methodological framework and applications regarding URBANE innovations and transferability strategy.
	TASK		
Task 4.3 Wave 2 LLs management, end-user feedback and	*Task 4.3 will assess the replicability potential of URBANE solutions to scale-up successful low-emission last mile delivery models and will monitoring the impact of the measures implemented in the Twinning LLs, transferring knowledge from the Lighthouse LLs implementation.*	Chapters 4	This chapter we assess the implementation of transferability activities under the URBANE transferability actions

impact assessment			
ST4.3.1 Validation methodology	*A methodology will be designed for evaluating to what extent the solutions proposed comply with URBANE objectives. Since the implementation of URBANE solutions will be tested and demonstrated in a short timeframe, the validation methodology will include a long-term impact assessment analysis based on future estimates. A handbook on key lessons learnt and validation practices will be developed.*	Chapter 3	This chapter describes the transferability methodological framework for evaluation.
ST4.3.2 Comparative analysis across LLs	*The subtask will collect and compare KPIs and other performance indicators for Twinning LLs to assess the URBANE Innovation Transferability Platform in practice, by comparing the `baseline´ scenario with the `after implementation´ scenario.*	Chapter 5	This chapter evaluates the cross-living lab comparison under URBANE KPIs as well as the replicability and transferability performance comparison.

1.2 Deliverable Overview and Report Structure

The report guides readers from context and conceptual foundations to applied methodology and results. In more detail:

- **Chapter 2** explains the role and need of transferability modelling in urban logistics. It contextualizes the importance of scaling innovations within European research policy. The chapter emphasizes that transferability requires adaptation rather than simple replication. It discusses why transferability matters for sustainable and Physical-Internet-inspired urban logistics and introduces digital tools that enable transferability on living lab contexts.
- **Chapter 3** presents the URBANE transferability framework. This framework is organized around six pillars: contextual fit and ecosystem readiness, knowledge and data integration capacity, model and planning method transferability, technological and process interoperability, impact and KPI harmonization, and adoption, scalability and long-term viability. Each pillar defines criteria and indicators needed to evaluate whether an innovation can move from one city to another.
- **Chapter 4** describes how the transferability methodology was implemented and validated in Wave 2 Living Labs. It recounts the six-step process used to adapt Wave 1 innovations to local contexts and lists the specific tools selected by Barcelona and Karlsruhe. The chapter details how baseline conditions were established, how goals were set, how local use cases were defined and how data were prepared. It explains how common KPIs from the URBANE KPI list were applied during physical pilots or simulation trials and how the Impact Assessment Radar consolidated the results.
- **Chapter 5** provides a cross-Living Lab impact assessment. It compares the environmental, operational and digital-reliability outcomes of the Barcelona and Karlsruhe pilots. Subsections analyze innovation pathways and baseline conditions, quantify environmental impact

reductions from electrification and modal shifts, evaluate operational efficiency and temporal performance and examine traceability and data reliability challenges. Transferability Performance Index synthesis feasibility and difficulty factors across contexts and highlights how governance and regulatory conditions influence transferability.

Together, all the aforementioned sections provide a structured narrative from concept to implementation and results, guiding the reader through the logic and evidence of URBANE's transferability approach.

2. The role and need of Transferability Modeling in Urban Logistics

2.1 Transferability as a strategic imperative for EU-funded innovation and Cities

Over the past decade and recent years, European research and innovation policy[1] has consistently prioritized the scaling and transferability of innovations. Many development interventions do not scale because they lack structured and coordinated actions from multiple actors. In addition, similar policy documents like OECD 2024 guidance on scaling development outcomes notes that effective scaling requires aligned efforts from governments, industry, civil society, and research organizations[2]. Thus, the process evolves over long time periods and requires consistency in communication and knowledge exchange mechanisms. Scaling is not the simple replication of a solution. It involves adaptation, refinement, and integration into local operational and institutional contexts.

Furthermore, innovations except from demonstrating technical performance in one setting, are expected to present reliable pathways for adoption in different environments. Living Labs operate as practical testbeds where this requirement is examined in real urban conditions. For example, withing URBANE project, Wave 1 Living Labs ''Lighthouse sites'' validate mature solutions, while follower sites (i.e. Wave 2 Twin Living Labs) assess how these solutions can be adapted and integrated into local systems. Transferability therefore functions as a core criterion for determining whether an innovation can move beyond a single pilot and support wider urban transitions.

In addition, cities vary in topology, density, stakeholder networks, and market maturity, and these variations shape how an innovation can function. A concept that performs well in a compact, high-density district may require different design choices in a sparce or decentralized region. The principle is to maintain the core functionality of the solution and to recalibrate its implementation so that it fits the local context. A similar interpretation appears in guidance from

[1] European Commission: Directorate-General for Research and Innovation, *New European innovation agenda on the move – Report on the state of play of the new European innovation agenda*, Publications Office of the European Union, 2024, https://data.europa.eu/doi/10.2777/097305

[2] OECD. 2024. *DAC Guidance on Scaling Development Outcomes*. OECD Publishing. Available at: https://www.oecd.org/en/publications/dac-guidance-on-scaling-development-outcomes_621810cc-en.htm

past EU projects such as Sharing Cities[3] and GrowSmarter[4], which describe replication as structured adaptation rather than uniform duplication.

Finally, last-mile logistics is a dynamic and demanding component of urban mobility. Growth in e-commerce, higher delivery frequency, and rising service expectations have increased pressure on European cities. These recent trends generate congestion, emissions, and competition for curb space. Cities must therefore balance efficient freight flows with climate and quality of life objectives. Thus, urban logistics functions as a complex socio technical system. It links infrastructure, operators, technologies, market structures, regulations, and user behavior. Systematic reviews identify barriers that constrain change (Kervall & Pålsson, 2022)(Kervall & Pålsson, 2022). These include fragmented market structures, conflicting stakeholder interests, limited cooperation, weak knowledge exchange, misaligned incentives, and physical constraints. The influence of these barriers depends on local conditions. A measure that performs well in Helsinki or Bologna may not function in Thessaloniki or Valladolid without meaningful adaptation. This complexity supports the need for structured transferability frameworks. These frameworks help cities assess whether, how, and under which conditions a last mile innovation can be adopted.

2.2 Why transferability matters for sustainable and PI-inspired urban logistics

Under current EU policy frameworks, cities are expected to reduce greenhouse gas emissions from transport, implement zero emission urban logistics zones, and promote cleaner fleets and active travel. Meeting these objectives requires operational models and technologies that perform reliably and can be applied across different urban settings.

Europe is also advancing the principles of the Physical Internet as a long-term vision for open and modular logistics networks[5]. PI-oriented concepts such as shared micro hubs, collaborative routing, open parcel locker networks, data driven orchestration, and interoperable digital services rely on common standards and cross city learning. Their value grows when multiple cities adopt compatible methods.

Implementing PI-oriented solutions is challenging. It requires digital maturity, changes in governance, trusted data sharing processes, and viable business models. Cities must understand how an innovation operates and how it interacts with existing systems. Transferability assessment provides the structure for this evaluation.

[3] Sharing Cities. *Replication Handbook.* December 2020. Available from: https://sharingcities.eu/wp-content/uploads/sites/6/2022/07/ReplicationHandbook_Dec2020.pdf

[4] GrowSmarter. *ROAD TO REPLICATION – Guiding Cities on Smart Urban Development: Concluding Report of Follower Cities (Deliverable 7.4).* 18 December 2019. Available at: https://grow-smarter.eu/fileadmin/editor-upload/Reports/Concluding_report_on_Replication_online.pdf

[5] ALICE – Alliance for Logistics Innovation through Collaboration in Europe, *Roadmap towards Zero Emissions Logistics 2050*, European Technology Platform ALICE, December 2019, available at: https://www.etp-logistics.eu/wp-content/uploads/2019/12/Alice-Zero-Emissions-Logistics-2050-Roadmap-WEB.pdf

Beyond policy ambition, there is also a structural need to transform last mile logistics. Their operations generate a considerable share of urban emissions, congestion and curbside pressure due to fragmented routes, frequent stops and limited consolidation. While vehicle electrification reduces direct emissions, it does not address underlying inefficiencies in network design and space use. Achieving meaningful decarbonization therefore requires systemic solutions that reduce vehicle kilometers travelled, improve consolidation and enable more space-efficient delivery modes.

Environmental friendly and PI-inspired urban logistics respond to these challenges by promoting shared infrastructure, coordinated operations and interoperable systems. The Physical Internet concept provides a framework inspiring to integrate diverse delivery assets through standardized interfaces, common data structures and collaborative use of resources, moving away from siloed and proprietary logistics models. In dense urban environments with constrained curb space and competing mobility demands, such coordination is essential to improve efficiency and reduce duplication. Digital tools further enable this transition by supporting visibility, optimization and evidence-based planning, provided they are deployed within interoperable and standardized ecosystems.

FIGURE 1: PHYSICAL INTERNET CONNECTED CITY ENVIRONMENT VISION

Despite clear benefits, resistance to adoption remains a challenge. Logistics operators may be reluctant to participate in shared infrastructure or data-sharing arrangements due to concerns about costs, confidentiality or competitive advantage. Municipal authorities may face regulatory or institutional constraints, while citizens may be hesitant to accept new delivery locations or service formats. These barriers highlight the need for transparent governance, clear communication and robust evaluation frameworks.

In this context, transferability methodologies play a central role. They help cities assess how green and PI-inspired innovations interact with local regulatory, spatial, market and organizational conditions. Transferability assessment identifies adaptation requirements, clarifies readiness levels and reduces uncertainty associated with scaling. For PI-aligned solutions in particular, transferability is essential, as interoperability and standardization across cities are prerequisites for the emergence of interconnected logistics networks. Structured transferability frameworks support consistent adoption of common protocols and practices, increasing the likelihood that innovations can move from pilots to long-term operational solutions.

2.3 Digital Tools, Business Processes and Living Labs as Enablers of Sustainable Urban Logistics

Urban logistics innovation is increasingly driven by the combined pressures of decarbonization targets, rising delivery demand and constrained urban space. In response, a wide range of operational, digital and organizational innovations has emerged to improve efficiency, reduce emissions and manage conflicts with other urban functions. These innovations rarely succeed as standalone technical solutions. Their performance depends on how they are embedded in local business processes, governance structures and stakeholder ecosystems. As a result, enabling transferability requires an integrated perspective that combines digital tools, operational models and Living Lab methodologies.

Recent developments in last mile logistics reflect a shift toward consolidation, coordination and data-driven management. Shared parcel lockers, urban micro-hubs, cargo bikes, light electric vehicles, dynamic curbside management systems and autonomous delivery solutions aim to reduce vehicle kilometers travelled and improve space efficiency(Dissauer et al., 2024; Engesser et al., 2023). Their environmental benefits are well documented, particularly in dense urban areas, where repeated delivery attempts, double parking and fragmented routes contribute to emissions and congestion. However, these solutions are highly context sensitive(Ranjbari et al., 2023). Their effectiveness depends on demand density, spatial structure, regulatory frameworks, property availability and the willingness of actors to cooperate as well as on the implementation strategy(Kervall & Pålsson, 2022). This makes systematic assessment and adaptation essential for transferability.

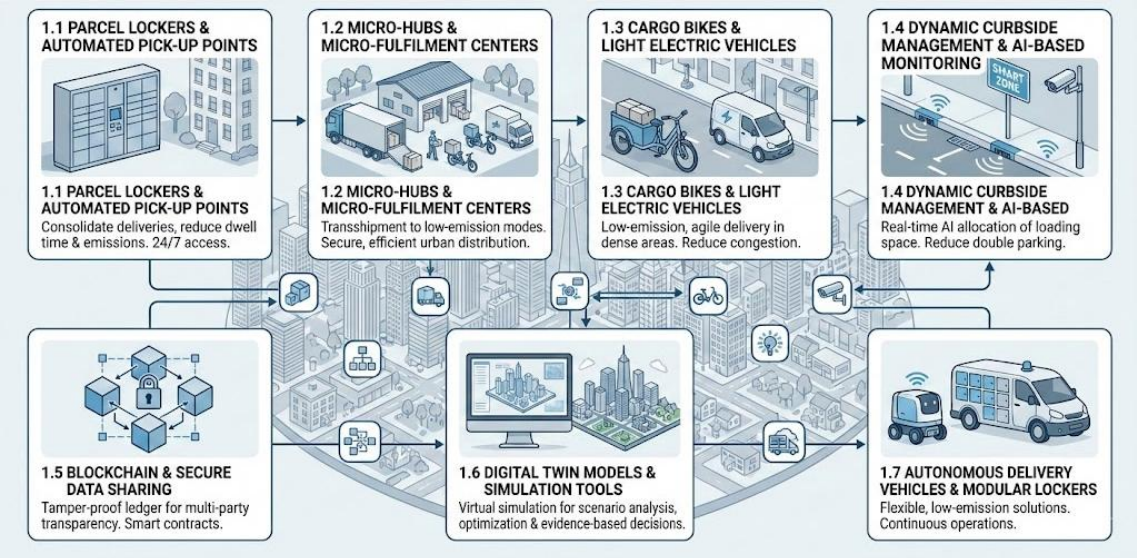

FIGURE 2: LAST MILE INNOVATIONS CATEGORIES SUMMARY

Digital tools play a central role in enabling this assessment as well. Common toolkits like Digital twins and simulation models allow cities and operators to test how innovations perform under different assumptions related to demand, fleet composition, infrastructure availability and

policy constraints. By modelling emissions, costs, curbside use and operational performance, digital twins reduce uncertainty before physical deployment and support evidence-based decision-making. In the URBANE context, digital twins are used to analyse Physical Internet – inspired delivery methods and performance indicators for structured impact assessment. This approach allows innovations to be evaluated consistently across cities while remaining adaptable to local conditions.

Trusted data sharing is equally critical for collaborative and PI-oriented logistics models. Last mile operations involve multiple actors with differing incentives, making coordination difficult without transparent and secure information exchange. Blockchain-based ledgers and event-based data platforms support traceability, accountability and automated execution of agreements through smart contracts. These tools enable shared use of infrastructure such as lockers or micro-hubs, facilitate emissions reporting and support new business models based on resource sharing. Their effectiveness depends on open interfaces and common data standards, reinforcing the link between digitalization and interoperability.

While digital tools enable analysis and coordination, they do not by themselves resolve organizational and institutional challenges. Innovations in urban logistics emerge within complex socio-technical systems involving logistics providers, retailers, technology firms, municipalities, property owners and citizens. Each actor operates under different constraints and objectives. For example, consolidation hubs may reduce vehicle kilometers for carriers but require space commitments from property owners and regulatory support from municipalities. Cargo bikes may lower emissions but depend on safe cycling infrastructure and clear access rules. These interdependencies make a multi-perspective approach essential.

Living Labs provide such an approach by offering real-world environments for co-creation, testing and iterative systemic learning. Unlike short-term demonstrations, Living Labs follow cyclical processes of planning, implementation, evaluation and refinement. They enable stakeholders to align on shared objectives while allowing implementation pathways to evolve based on evidence and feedback. The Living Lab methodology, as formalized by the European Network of Living Labs, emphasizes active user involvement, multi-stakeholder participation, real-world settings and iterative design. This structure is particularly suited to urban logistics, where technical performance, regulatory feasibility and user acceptance must be addressed simultaneously.

Evidence from previous European projects confirms the importance of Living Labs for transferability. Initiatives such as CITYLAB (https://www.citylab.soton.ac.uk/), SPROUT (https://sprout-civitas.eu/) and NOVELOG (https://www.uct.imet.gr/) showed that cross-city learning, structured reflection and policy dialogue are critical for understanding how innovations interact with local governance, market conditions and spatial configurations. These projects demonstrated that transferability cannot be achieved through replication of technical components alone. It requires insight into organizational practices, regulatory barriers, behavioral responses and institutional capacity. Living Labs create conditions for generating this insight by exposing innovations to real operational constraints and stakeholder scrutiny.

A key contribution of the Living Lab approach is its ability to support co-creation and legitimacy. Innovations that affect urban space and delivery practices require acceptance by users and

citizens. Co-creation processes improve transparency, build trust and help align commercial objectives with public goals such as emission reduction, accessibility and quality of life. This is particularly important for PI-inspired solutions, which depend on shared infrastructure and collaborative business processes. Without stakeholder buy-in, such solutions risk resistance or underutilization.

From a transferability perspective, the combination of digital tools and Living Labs enables a structured multi-perspective assessment. Digital twins, models and analytics provide quantitative evidence on performance and impacts, while Living Labs reveal qualitative insights into governance, behavior and feasibility. Together, they allow cities to identify which elements of an innovation are transferable, which require adaptation and which depend on local enabling conditions. In URBANE, this integration is operationalized through shared indicators, open interfaces and structured evaluation frameworks that support comparison between Lighthouse and Twinning Living Labs.

Overall, green and PI-inspired urban logistics require more than technological innovation. It depends on the alignment of business processes, digital infrastructures, governance arrangements and stakeholder ecosystems. Digital tools provide analytical and coordination capabilities, while Living Labs enable experimentation, learning and co-creation in real-world settings.

2.4 URBANE's transferability framework and platform

Experience from URBANE confirms that the main barrier to scaling last mile logistics innovations is not the availability of technical solutions, but their transferability across cities with diverse spatial, regulatory, organizational and market conditions. While pilot implementations can demonstrate local benefits, comparable outcomes cannot be assumed when solutions are deployed in new contexts. Transferability therefore requires systematic assessment of enabling and constraining factors before replication or scaling decisions are made.

URBANE identifies a consistent set of challenges that shape innovation transfer in urban logistics. Structural fragmentation remains a dominant issue, as logistics operators, municipalities, retailers and citizens pursue different and often misaligned objectives. This limits coordination, shared investment and data exchange, and frequently confines innovations to isolated pilots. Spatial diversity further constrains transferability, such as street layouts, building density, curbside availability and land-use patterns directly influence the feasibility and configuration of solutions. Historic and dense city centers typically require consolidation-based and low-impact delivery models, while cities with greater spatial flexibility can support a wider range of operational approaches.

Cultural, behavioral and socio-economic factors also affect adoption. Acceptance of self-service delivery, trust in automated systems and willingness to deviate from doorstep delivery vary across cities. Market structure influences the ability to deploy shared solutions, as concentrated logistics markets can coordinate more easily than fragmented ones dominated by small operators. Regulatory and governance capacity, including zoning rules, access regulations and administrative procedures, determines whether innovations can be implemented within realistic

timeframes. Differences in digital maturity and interoperability further affect the ability to integrate advanced tools and data-driven processes.

Evidence from the Wave-1 Living Labs illustrates how these factors interact in practice. Thessaloniki demonstrated the role of coordinated governance, digital twins and trusted data sharing in supporting locker-based consolidation. Helsinki highlighted both the potential and constraints of autonomous delivery solutions under demanding operational conditions. Bologna showed how open, multi-operator micro-hubs can deliver significant environmental benefits in historic urban environments when supported by viable governance and business models. Valladolid demonstrated how AI-based curbside management and alternative delivery concepts can improve efficiency and reduce emissions when integrated into urban mobility strategies. Across all cases, performance depended less on the technology itself and more on contextual adaptation, stakeholder alignment and organizational readiness.

The URBANE transferability platform integrates analytical tools, shared indicators and common methodologies to support evidence-based decision-making. It enables gap analysis, scenario exploration and impact estimation before large-scale deployment, reducing uncertainty and implementation risk. Importantly, the framework is applicable not only to research pilots but also to industry-ready solutions seeking deployment across multiple European cities. By combining real-world Living Lab evidence with structured assessment, URBANE supports the transition from isolated demonstrations to scalable, interoperable and sustainable urban logistics solutions.

2.5 Towards a structured transferability framework for Urban Logistics Innovations

One significant limitation of urban logistics innovation is not the lack of digital tools and services, but the difficulty of transferring successful pilots across cities with different regulatory, spatial, organizational and market conditions.

Transferability in urban logistics does not imply direct replication. Policy documents and guidelines, including that of the European Urban Initiative[6], consistently stresses that innovation transfer requires adaptation rather than copying. Transfer involves reproducing both observable practices and the underlying processes that enable them, while recognizing that outcomes may vary depending on local conditions. In practice, this means that logistics concepts and digital tools can be transferred only if they are adjusted to local regulatory frameworks, spatial structures, institutional capacity and behavioral patterns.

Evidence from URBANE and previous related projects cited above, confirms that transferability is inherently multi-dimensional. Technical and technological factors determine whether an innovation is compatible with local infrastructure, data availability and ICT systems. Organizational factors influence whether public authorities and logistics operators have the capacity and willingness to implement new processes or collaborative models. Thus contextual factors such as urban density, governance structures and policy priorities shape operational

[6] https://www.urban-initiative.eu/

feasibility. Behavioral factors affect acceptance by users, couriers and other stakeholders. Failure to account for these dimensions at an early stage increases the risk that innovations remain confined to pilots.

These challenges justify the need for a structured transferability framework. A systematic approach allows cities to assess whether an innovation is suitable for their context, identify adaptation requirements and clarify the conditions under which measurable impacts can be achieved. Importantly, such frameworks are not limited to research pilots but are also applicable to industry-ready solutions seeking deployment across multiple European cities.

In response, URBANE project under T4.3 introduces a multi-pillar transferability framework that reflects the complexity of urban logistics systems. The framework evaluates innovations across key dimensions including contextual fit, organizational maturity, technological readiness, business viability, regulatory alignment and compliance with Physical Internet principles. Together, these pillars provide a consistent basis for comparing cities, interpreting pilot results and supporting informed decision-making during scaling and replication.

3. TRANSFERABILITY FRAMEWORK

The methodology presented in this chapter is informed by URBANE Living Labs experiences, demonstrations, and other EU project's best practices presented in Chapter 2. It integrates principles developed through pilot evaluations and stakeholder interactions within this project. The approach addresses two methodological needs. The first is the need to reflect the operational, institutional, technological, financial and regulatory conditions in which urban logistics innovations operate. The second is the need for a clear and repeatable assessment tool that can be applied consistently across cities and solutions. This consistency supports comparable evaluations and improves strategic decision making.

To address these needs, the methodology applies a six pillar framework. The framework combines the conceptual depth of the earlier approach with a more consolidated structure that avoids overlap and aligns with European best practices. It retains most of the original methodological content, including assessment of problem–solution mapping, organizational maturity, data readiness, business model characteristics, regulatory compliance, sustainability performance, Physical Internet alignment and user acceptance. It also introduces refinements that increase operational applicability. These adjustments align the methodology with replication practices commonly used in CIVITAS, ENoLL, ALICE Physical Internet roadmaps and related initiatives.

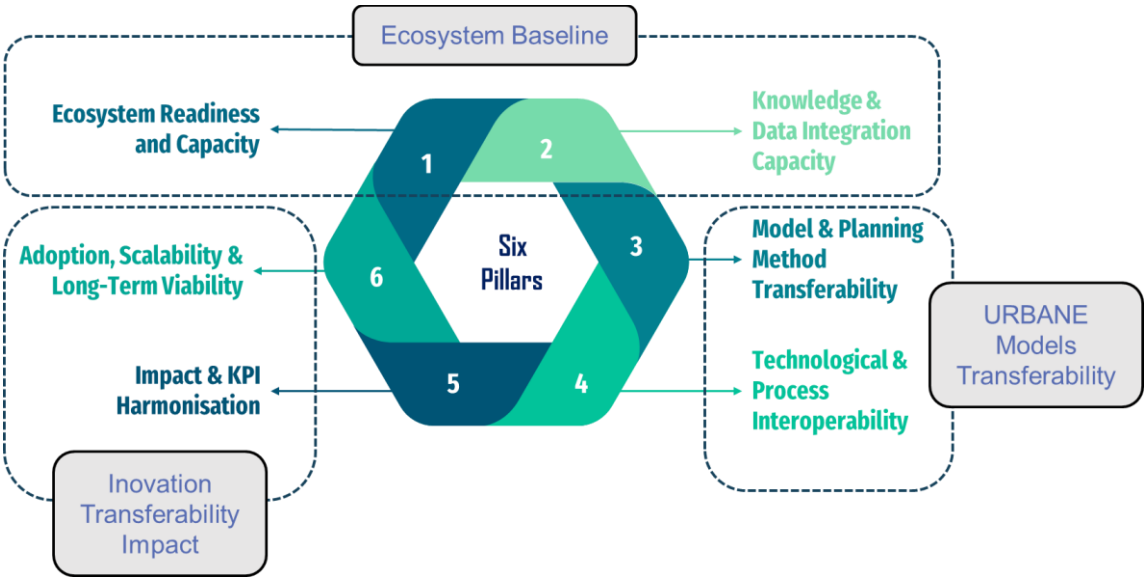

FIGURE 3: THE URBANE TRANSFERABILITY FRAMEWORK ARCHITECTURE

The six pillars form the backbone of the transferability assessment. Together they capture the institutional, analytical, technological, operational, regulatory and sustainability conditions that shape whether an innovation developed in one Living Lab can operate effectively in another. Rather than treating transfer as simple replication, the methodology recognizes that adoption depends on the fit between a solution and the environment that receives it.

The first dimension concerns the alignment between the innovation and the local context. Urban logistics challenges differ widely across European cities. Demand density, spatial conditions, user behavior and business practices can amplify or weaken the value of an innovation. Understanding how closely local needs match the assumptions of the solution is a prerequisite for meaningful transferability analysis.

A second dimension reflects the maturity of the institutional and organizational ecosystem. Even highly effective tools struggle in environments where governance is fragmented, collaboration is weak or resources are limited. Transferability depends on whether local actors can coordinate, share responsibilities and sustain the innovation beyond the pilot phase.

The methodology then examines the transferability of the analytical models and planning methods themselves. Models vary in their generalizability. Some adapt readily to new contexts while others rely heavily on specific parameters or behavioral assumptions. Assessing the robustness, transparency and calibration effort required helps distinguish between structural model limitations and contextual barriers.

A separate dimension evaluates system and process interoperability. Innovations must interface with existing digital systems, operational routines and device infrastructures. Transfer is feasible only when data streams, APIs, workflows and hardware can be connected without excessive effort. Interoperability therefore determines how seamlessly a solution can be embedded into real operations.

Impact assessment forms another essential layer. Transferability requires that the innovation can generate measurable and comparable outcomes in the receiving city using the common URBANE KPI framework. Differences in context may lead to different magnitudes of impact, but the ability to monitor environmental, operational and service effects in a harmonized manner is indispensable for assessing value and informing policy.

Finally, the methodology considers adoption, scalability and long-term viability. An innovation is transferable only if it can be absorbed into existing strategies, supported financially, accepted by stakeholders and scaled beyond its initial pilot. Long-term sustainability depends on institutional alignment, behavioral acceptance, robust business models and the capacity to maintain and evolve the solution over time.

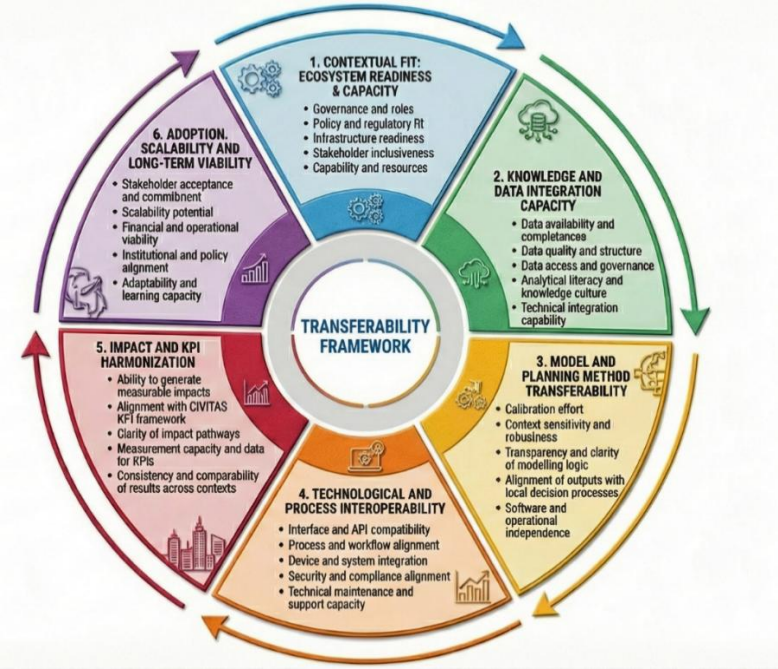

FIGURE 4: THE URBANE'S TRANSFERABILITY FRAMEWORK ELEMENTS

Together, these six pillars create a structured, holistic approach to assessing readiness and transferability. Each pillar is broken down into sub-elements with clear scoring criteria. The four-level scale (0 to 3) distinguishes between critical gaps, basic readiness, adequate conditions and full alignment. Aggregating these scores produces a detailed profile of strengths, risks and adaptation needs for each city.

The following sections analyze each pillar in depth. They outline the sub-elements, scoring logic, required evidence and interpretation guidelines.

3.1 Pillar 1. Contextual Fit: Ecosystem Readiness and Capacity

This pillar evaluates whether the institutional ecosystem of a receiving city, region or operator is prepared to host and sustain an innovation that was developed and validated in another Living Lab. Transferability depends not only on the technical quality of the innovation but also on the capacity of the institutional environment that receives it. Urban logistics interventions require governance clarity, policy alignment, operational infrastructure, stakeholder coordination and sufficient human and financial resources. When these conditions are weak, even effective models, digital tools or process innovations may fail to deliver expected performance. This pillar establishes the baseline context for the transferability analysis and identifies the institutional enablers or barriers that influence adoption in Wave 2 Living Labs.

FIGURE 5: PILLAR 1 – CONTEXTUAL FIT AND ECOSYSTEM READINESS ASSESSMENT DIMENSIONS

Ecosystem readiness describes the extent to which the receiving environment can absorb the innovation without major structural changes. It requires understanding how responsibilities for urban logistics are distributed between public authorities, private operators and intermediate organizations. Many European cities work within governance environments that include overlapping mandates, fragmented responsibilities and inconsistent coordination across departments. Traffic management units, environmental divisions, urban planning authorities and economic development departments may influence urban logistics but may not work together systematically. When an innovation requires aligned action across these units, fragmentation slows implementation. Governance clarity therefore determines how quickly and reliably an innovation can enter operational routines.

The assessment also examines how the policy and regulatory environment supports the innovation. Many last mile solutions require permissions that are not universally available. These include access to loading and unloading areas, approval for temporary or dynamic curbside reallocation, data sharing agreements for operational events, legal structures for multi operator locker networks and rules for electrified fleets or low emission zones. When the regulatory framework is misaligned with the operational requirements of the innovation, deployment becomes slower and less predictable. In some cases a city may wish to adopt a new process but lacks the legal instruments needed to implement it. This pillar identifies such barriers and evaluates whether the policy environment is flexible enough to accommodate necessary adjustments.

Infrastructure readiness is another critical component. Many innovations depend on the availability of physical and digital infrastructures. Examples include micro hubs for consolidation, public spaces for parcel lockers, loading areas for new vehicle types and digital infrastructures such as APIs, dashboards, sensors and device gateways. Some solutions rely on digital twins or event-based architectures, which require specific data streams that are not always available.

A city with limited infrastructure may require phased implementation or additional investment before the innovation can operate at the expected level. A city with strong infrastructure readiness can integrate an innovation quickly and with minimal adaptation. Infrastructure

readiness therefore influences whether the technical components of the innovation can function as intended.

Stakeholder inclusiveness is central to this pillar because urban logistics involves interdependent actors whose collaboration is required for successful implementation. Couriers, retailers, transport operators, infrastructure owners, technology suppliers and municipal authorities each contribute to last mile operations. When these actors operate in isolation, innovations may be underutilized or rejected because of limited understanding, insufficient information or conflicting priorities. Stakeholder inclusiveness evaluates whether the ecosystem has structured mechanisms for dialogue, co design and operational coordination. Existing partnerships, working groups or collaborative planning processes indicate a mature environment that can align around a transferred innovation. Low levels of inclusiveness often predict slow adoption, reduced compliance and challenges in scaling or sustaining the solution. This element is important for innovations that rely on behavioral change or shared business models, such as locker alliances, coordinated routing or flexible curbside management.

Capability and resources indicate whether the receiving city or operator can maintain the innovation over time. Sustained implementation requires trained personnel who can manage digital tools, maintain data flows, interpret KPIs, supervise operations and ensure compliance with regulations. It also requires financial stability, internal budgets and managerial structures that support continuous improvement.

The results of this pillar inform the interpretation of all other pillars. Weak performance in a city with low ecosystem readiness may still indicate strong potential because the innovation succeeded under adverse conditions. Weak performance in a city with high readiness may suggest challenges related to calibration, data availability or process design rather than governance. This avoids misinterpreting operational issues as institutional failures. The findings feed directly into the contextual scaling applied later in the methodology and help adjust the final transferability score according to institutional maturity.

The assessment also identifies the support required for successful implementation. Cities with low governance maturity may require capacity building or clearer allocation of responsibilities. Cities with strong policy alignment but limited infrastructure may require spatial planning or investment support. Cities with adequate infrastructure but weak stakeholder inclusiveness may require facilitation processes to strengthen cooperation. Each scenario influences how the innovation should be introduced, calibrated and scaled. Without understanding these contextual factors, the transferability process may be misaligned with the actual needs of the receiving city or operator.

This pillar also supports fairness in cross city comparison. The evaluation therefore contextualizes performance and avoids penalizing cities that face structural challenges. The scoring framework ensures that differences in institutional maturity are captured transparently. It creates a common language for describing governance and organizational conditions across Living Labs and influences how results from other pillars are interpreted.

This pillar also contributes to long term planning processes such as Sustainable Urban Mobility Planning and Sustainable Urban Logistics Planning. Both frameworks emphasize that innovation depends on institutional readiness, governance clarity, inclusive collaboration and stable

resources. The analysis helps identify gaps that cities can address beyond the scope of the project. It also supports the development of more harmonized approaches to urban logistics planning where cities can benchmark their institutional conditions against common criteria.

The assessment uses a structured scoring table. Each sub element is scored from 0 to 3. The table provides clear descriptions that allow evaluators to assign ratings consistently. It also helps partners and policy makers understand the specific strengths and weaknesses of each ecosystem. When applied across multiple Living Labs, the table supports comparative analysis, guides interpretation of model performance and informs the development of targeted actions that strengthen readiness for future innovation adoption.

TABLE 1: PILLAR 1 – CONTEXTUAL FIT: ECOSYSTEM READINESS AND CAPACITY SCORING CRITERIA

Sub-Element	Score 0	Score 1	Score 2	Score 3
Governance and roles	Responsibilities unclear. No coordination structures. Conflicting mandates.	Partial clarity of roles. Coordination exists but weak. Mandates overlap and cause delays.	Clear governance but not consistently applied. Coordination functional in most cases.	Fully defined governance. Stable coordination mechanisms. Strong cooperation between actors.
Policy and regulatory fit	Policies contradict innovation objectives. Legal barriers present.	Partial alignment. Permissions exist but incomplete. Some regulatory constraints remain.	Policies generally supportive. Minor adjustments needed for full alignment.	Strong alignment. Policy environment fully supports innovation without modifications.
Infrastructure readiness	Required physical or digital infrastructure absent. Major investments needed.	Limited infrastructure. Only part of the innovation can operate. Additional upgrades required.	Infrastructure largely available. Some adaptations or minor investments needed.	Infrastructure fully present. Innovation can operate immediately.
Stakeholder inclusiveness	Low collaboration. Stakeholders fragmented or disengaged.	Some stakeholders involved but not consistently. Limited cooperation.	Stakeholders generally supportive. Engagement mechanisms exist but vary in effectiveness.	Strong and stable stakeholder cooperation. Active involvement in planning and operations.
Capability and resources	Very limited staff or budget. No internal capacity for operation.	Capacity exists but insufficient for full deployment. Reliance on external support.	Adequate capacity for operation with occasional support.	Strong internal capability. Stable resources and skilled staff for long-term sustainability.

3.2 Pillar 2. Knowledge and Data Integration Capacity

This pillar evaluates whether the receiving ecosystem has the knowledge base, data practices and technical foundations needed to integrate, operate and benefit from innovations transferred. The first pillar focuses on governance and institutional readiness. This second pillar examines the digital and analytical maturity that supports model calibration, decision making and operational data exchange. In modern urban logistics, the performance of an innovation depends strongly on data quality, data availability and data interoperability. It also depends on the ability of organizations to understand and operate digital tools. Without proper data foundations, analytical models, routing engines, digital twins or planning tools will not reach their expected performance. This pillar therefore assesses the knowledge and data environment that determines how well the innovation can be calibrated, integrated and used.

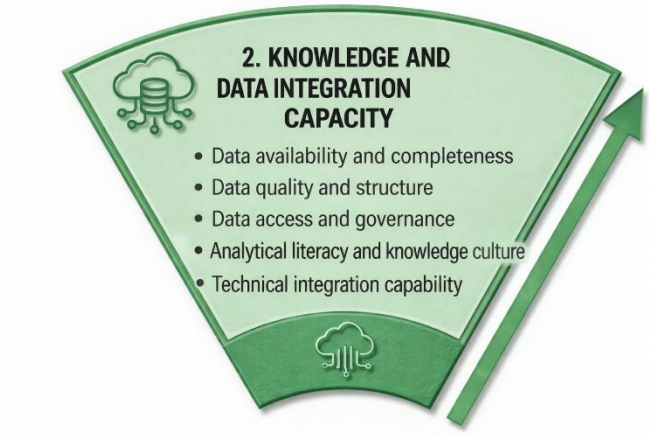

FIGURE 6:PILLAR 2 – KNOWLEDGE AND DATA INTEGRATION CAPACITY COMPONENTS

Knowledge and data integration capacity reflects how advanced the receiving ecosystem is in using data for planning, monitoring and operational coordination. Many URBANE innovations require structured inputs such as demand patterns, fleet characteristics, network topology, IoT data and behavioral indicators. Digital twins, recommendation systems, eco -routing tools, locker demand estimation modules and micro hub planning models all depend on validated and accessible datasets or information. A city or operator with weak data foundations will require additional time and support to prepare inputs. This influences both the speed of transferability and the quality of final outputs. Early evaluation of this pillar allows project partners to anticipate where calibration workloads will be high and where technical support may be required.

The pillar also considers analytical literacy and knowledge culture. Urban logistics innovations introduce new methods that rely on understanding data flows, operational KPIs, modelling assumptions and analytical logic. Local actors who are familiar with data driven decision making, model based planning and performance monitoring can engage with the transferred innovation more effectively. They can contribute during calibration, interpret model outputs and sustain analytical processes after the project ends. When data literacy is limited, the innovation may be

perceived as a black box. This reduces trust and limits long term integration. A mature knowledge culture supports collaboration, faster calibration and more accurate operationalization.

A major component of this pillar concerns the structure and quality of available datasets. Transferability depends on whether the receiving Living Lab can supply the required inputs in a usable format and at sufficient quality. Available datasets vary widely across cities. Some cities provide parcel level records, route logs, real time occupancy data and multimodal schedules. Others provide fragmented datasets that require consolidation, anonymization or reconstruction. Limited data completeness increases modelling uncertainty and may require technical workarounds that reduce transferability. High quality data describing the network, demand, assets and operational processes support accurate calibration and reliable KPIs.

Data governance and data access are also essential. Existing datasets may not be accessible because of organizational policies, privacy restrictions or unclear ownership. Transferability requires predictable data flows and clear agreements between public authorities, operators and technology partners. Models that rely on API endpoints, shared operational logs or device event streams cannot function when access permissions are unstable or when contractual barriers restrict data sharing. This pillar evaluates whether the receiving ecosystem has the required agreements, protocols and legal structures to expose or exchange the necessary data.

Technical integration capacity is another central theme. The transfer of a model or digital tool often requires alignment with existing platforms, dashboards or operational systems. For example, Digital twins may need to interface with traffic management platforms. Parcel locker assignment models may need to connect with inventory. Or a Eco routing algorithm or multimodal suggestion engines may require links with local routing services. The ability of the receiving ecosystem to integrate these systems depends on its technical architecture, degree of standardization and staff expertise. A city with modular IT systems, well documented interfaces and established integration practices can adopt and connect innovations more efficiently.

This pillar also assesses the level of internal technical support available for data preparation, integration and model operation. Urban logistics innovations require regular data updates, validation checks, troubleshooting and maintenance. A Living Lab with dedicated technical personnel can incorporate the innovation smoothly and operate it consistently. A Living Lab with limited staff may depend heavily on external partners.

The results of this pillar provide essential context for interpreting model performance in later stages of the project. A city with strong data integration capacity but lower model performance may face operational or behavioral challenges rather than technical barriers. A city that performs well despite limited data maturity may show high potential once data systems are strengthened. These insights prevent misinterpretation of results and support fair comparison across Living Labs.

The scoring table for this pillar includes five sub elements. Each sub element is evaluated on a scale from 0 to 3. The table provides clear readiness descriptions and supports consistent scoring across Living Labs. It functions as a diagnostic tool and supports interpretation of the transferability process.

TABLE 2:PILLAR 2 – KNOWLEDGE AND DATA INTEGRATION CAPACITY SCORING CRITERIA

Sub-Element	Score 0	Score 1	Score 2	Score 3
Data availability and completeness	Key datasets missing. Data fragmented or unreliable. Not suitable for calibration.	Partial datasets available but incomplete. Requires major cleaning or reconstruction.	Most required datasets available with manageable gaps. Sufficient for calibration.	Full datasets available. High completeness and reliability. Ready for integration.
Data quality and structure	Unstructured data. Inconsistent formats. Frequent errors.	Partially structured data. Quality issues common. Requires significant processing.	Structured data with moderate quality inconsistencies. Generally usable.	Well structured and validated data. High consistency and accuracy.
Data access and governance	No established procedures for data access. Restrictions prevent use.	Permissions unclear or slow. Fragmented ownership. Partial access granted.	Clear access pathways for most datasets. Minor procedural delays.	Transparent governance. Stable permissions. Predictable and open access for project needs.
Analytical literacy and knowledge culture	Limited understanding of data driven methods. Low capacity to interpret models.	Some familiarity with analytics but not widely embedded.	Adequate literacy among key staff. Ability to use and interpret model outputs.	Strong analytical culture. Staff highly familiar with models, KPIs and data workflows.
Technical integration capability	No capacity to integrate digital tools. Legacy systems incompatible.	Limited integration capability. Requires external support for most tasks.	Moderate capability with some internal technical support. Integration feasible.	Strong technical architecture and skilled staff. Integration reliable and efficient.

3.3 Pillar 3. Model and Planning Method Transferability

This pillar evaluates how effectively the analytical models, planning methods and decision support tools developed in the Wave 1 Living Labs can be transferred, calibrated and reused in Wave 2 environments. It focuses on the intrinsic characteristics of the models rather than the ecosystem conditions assessed in earlier pillars. The objective is to understand whether the modelling logic, input requirements, planning assumptions and expected outputs can be adapted to a different operational, spatial or organizational context without extensive redesign. Transferability depends on the generalizability of the model structure, the adaptability of its

parameters and the capacity of the planning method to accommodate differences in demand patterns, geographical layouts, regulatory constraints and operational behaviors.

FIGURE 7: PILLAR 3 – MODEL AND PLANNING METHOD TRANSFERABILITY DIMENSIONS

Models and planning tools within URBANE differ in scope and function. Some models are strategic and support long term planning such as multi actor locker network design, micro hub siting or demand forecasting. Others are tactical and support day to day decisions such as eco routing engines, multimodal suggestion modules, route nudging logic, locker retention time estimators or curbside allocation tools. Each class of model has distinct transferability characteristics. Strategic models often generalize more easily but depend on strong planning data. Operational models are sensitive to local conditions and depend heavily on context. This pillar evaluates the transferability of each model while considering these differences.

A major dimension of this pillar concerns the calibration effort required. A model that depends on many location specific parameters, detailed demand series or operator specific rules requires significant preparation before producing meaningful results. This reduces transferability because the receiving Living Lab must invest substantial time and technical resources to adjust the model. A model that uses more general structures, stable parameter sets and flexible inputs is easier to adopt. Evaluating calibration effort provides insight into the expected duration of the transfer phase and the level of technical support required.

Context sensitivity is another important aspect. Many planning methods rely on behavioral or operational assumptions that vary between cities. Locker user behavior, parcel retention profiles and routing constraints are examples of variables that differ across contexts. A model that assumes universal behavior may produce inaccurate or unreliable outputs. This pillar evaluates how robust the model is across contexts and whether it includes mechanisms to adjust behavioral parameters, constraints or cost functions. A transferable model can adapt to local patterns without structural redesign.

Model clarity and transparency strongly influence transferability. Transfer improves when the structure of the model is documented, when inputs are clearly defined and when decision rules are understandable by local practitioners. If a model is perceived as a black box local actors may hesitate to trust its recommendations or may struggle to adapt it when needed. Transparent models support meaningful interpretation of results, informed calibration and long term sustainability. They allow local actors to operate or modify the model after the project ends.

Compatibility of model outputs with local planning routines is another component evaluated in this pillar. Transferability increases when output aligns with decisions that local actors already make. For example recommendations related to parcel allocation, routing configurations, demand forecasts etc should map to existing workflows. When outputs require changes in organizational processes, or when they demand new interfaces or work routines, transferability decreases. A transferable model produces outputs that support existing operational and planning practices.

The reliance of a model on specific software environments or external tools is also considered. Models that depend on proprietary systems, specialized licenses or high performance computing resources may not be accessible in all receiving cities. Transferability increases when the model can be executed on common platforms, when it uses open or widely supported dependencies or when it can run through containerized or cloud based formats. T

The stability and maturity of the modelling logic also influence transferability. Models that have been validated across multiple scenarios or tested under varied conditions show more predictable behaviour when transferred to new cities. A model that is still experimental or untested outside its original context may behave unpredictably. Stability and demonstrated performance across different conditions increase transferability.

Interpretation of results from this pillar is important for understanding the overall transferability of an innovation. A model with high intrinsic transferability may still perform poorly in a city with weak data or limited technical capacity. In these cases low performance reflects context rather than model limitations. A model with weak intrinsic transferability may still appear to perform well if heavily adapted or simplified, but this performance may not generalize. This pillar helps evaluators distinguish between structural limitations of the model and contextual constraints identified in earlier pillars.

Concluding, this pillar supports the project objective of developing solutions that are replicable, scalable and aligned with broader European goals such as the Physical Internet vision and data driven urban logistics frameworks. Evaluating model transferability ensures that innovations developed in the project can be reused beyond the original pilot cities and can contribute to a shared European toolbox for sustainable last mile logistics.

The scoring table below summarizes the assessment across five sub elements. Each sub element is rated on a scale from 0 to 3.

TABLE 3: PILLAR 3 – MODEL AND PLANNING METHOD TRANSFERABILITY SCORING CRITERIA

Sub-Element	Score 0	Score 1	Score 2	Score 3
Calibration effort	Requires extensive redesign. High number of unknown parameters. Not usable without major work.	Requires significant calibration with many local adjustments. Slow adoption.	Requires moderate calibration. Most parameters can be adapted easily.	Ready for direct calibration. Minimal adjustments needed. Smooth adoption.

Context sensitivity and robustness	Model assumptions do not generalize. Highly sensitive to local patterns.	Partially transferable with limited generalizability. Some assumptions break under new conditions.	Generally transferable with adjustable behavioral or operational parameters.	Highly robust. Adapts easily to different contexts with stable performance.
Transparency and clarity of modelling logic	Logic unclear. Inputs and decision rules poorly documented. Perceived as black box.	Logic partially documented but difficult for practitioners to follow.	Clear documentation with understandable assumptions. Users can interpret outputs.	Highly transparent and well structured. Fully understandable for local planners.
Alignment of outputs with local decision processes	Outputs not usable in local workflows. Requires major procedural changes.	Outputs partially relevant but integration with decisions is difficult.	Outputs support most planning or operational decisions with some adjustments.	Outputs map directly to local decisions. High relevance and usability.
Software and operational independence	Requires specialised or unavailable software. Dependencies block deployment.	Some dependencies create obstacles. Needs external technical support.	Runs on common environments with manageable requirements.	Fully portable and independent. Easily deployable across systems.

3.4 Pillar 4. Technological and Process Interoperability

This pillar examines whether the transferred innovation can be integrated into the technological and operational systems of the receiving Living Lab. It evaluates the compatibility of digital tools, software platforms, data interfaces, devices and operational workflows that the innovation requires in order to function as intended. The previous pillar focused on the intrinsic transferability of the model or planning method. This pillar therefore evaluates the degree of alignment between the innovation's architecture and the existing technological environment of the receiving city.

Interoperability reflects the ability of devices, digital platforms, and services to exchange data and coordinate actions in a predictable manner. Many of the project's innovations rely on event and operational based data. Thus digital services and tools of stakeholders along the supply chain must communicate through stable protocols, documented interfaces and compatible standards. When these conditions are not present, the innovation may require custom integration, manual data processing or temporary workarounds. These adaptations reduce transferability and often increase operational risk.

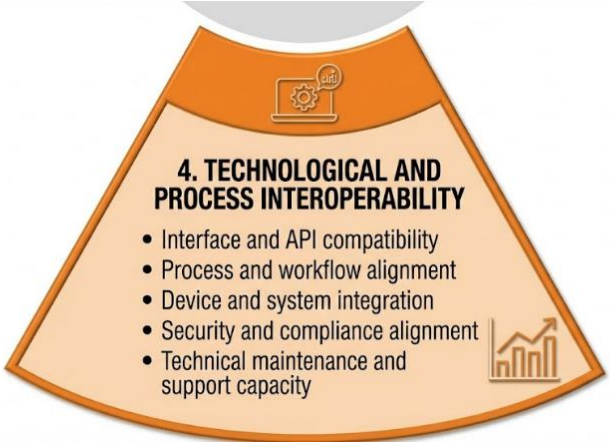

FIGURE 8: PILLAR 4 – TECHNOLOGICAL AND PROCESS INTEROPERABILITY LAYERS

A central dimension of this pillar concerns the availability of standardized interfaces. Innovations that depend on structured APIs for event exchange, routing queries, occupancy updates or device messages require the receiving ecosystem to maintain compatible communication endpoints. If the city uses proprietary formats or closed systems, integration becomes complex and time consuming. The capacity to expose or consume APIs is therefore a core component of interoperability. Cities that maintain modular and well documented digital systems can adopt innovations more rapidly than cities that rely on rigid legacy architectures.

Process interoperability is equally important. Many innovations depend on coordinated workflows that connect multiple actors. Examples include parcel locker events that must align with routing plans, consolidation activities at micro hubs that require defined unloading windows, digital twin updates that depend on periodic event streams or curbside booking functions that must communicate with enforcement or traffic management processes. When local workflows are fragmented or incompatible with these requirements, the innovation cannot be embedded into daily practice. This pillar evaluates whether the operational processes required for the innovation can be adopted or adapted by local actors.

Device integration forms another essential component. Some innovations rely on hardware such as sensors, access control units, parcel lockers, vehicle telematics or IoT communication nodes. These must be compatible with the local infrastructure in terms of connectivity, communication technology, power requirements, physical design and security protocols. If devices use standards that are not supported locally, integration may require additional equipment or system upgrades. These requirements influence the cost, timing and reliability of the transferred innovation.

Cybersecurity and data protection are important determinants of interoperability. If the innovation requires data flows that do not match the receiving city's privacy or security policies, integration may be delayed until safeguards are implemented. Requirements related to authentication, encryption, identity management and data storage shape the ease of deployment. Cities that maintain structured cybersecurity procedures often integrate innovations more smoothly because they already operate standardized methods for securing digital systems.

System scalability is also relevant for assessing interoperability. Some innovations generate increasing event volumes as adoption expands. If local systems cannot process additional loads, operational performance may decline. Transferability is enhanced when the receiving ecosystem uses scalable or cloud compatible infrastructures that can accommodate growth without degradation. This ensures long term operability once the innovation becomes part of routine practice.

Technical support and maintenance capacity form an additional dimension of interoperability. Even when systems are compatible, integration requires personnel who can troubleshoot issues, maintain APIs, update configurations and ensure continuous operation. If the receiving city lacks such staff, integration may function initially but fail over time. This pillar therefore evaluates not only compatibility on paper but the presence of internal capacity to sustain interoperability throughout the innovation's lifecycle.

The interpretation of results from this pillar clarifies whether integration challenges stem from the innovation or from the local environment. For example, a city that shows low interoperability but high model transferability may require targeted upgrades or additional interfaces. A city with high interoperability but low model transferability may face challenges related to context sensitivity or calibration rather than integration. This distinction helps evaluators understand the root causes of performance variations and supports more accurate recommendations.

Interoperability assessment is essential for determining whether transferred innovations can scale beyond pilot conditions. Technical and process alignment is required before innovations can become part of wider digital ecosystems, multimodal management environments or coordinated urban freight strategies. Without strong interoperability, innovations remain isolated solutions that cannot support the goals of digital transformation, Physical Internet compatibility or integrated logistics planning. This pillar therefore informs whether the innovation can transition from a demonstration environment to long term operational use.

The scoring table below translates the five sub elements of this pillar into a scale from 0 to 3. It supports consistent evaluation across Living Labs and captures the degree of technical and operational alignment required for successful integration.

TABLE 4: PILLAR 4 – TECHNOLOGICAL AND PROCESS INTEROPERABILITY SCORING CRITERIA

Sub-Element	Score 0	Score 1	Score 2	Score 3
Interface and API compatibility	No compatible interfaces. Systems cannot exchange data.	Partial compatibility with major integration gaps. Requires extensive work.	Generally compatible with manageable differences. Integration feasible.	Fully compatible interfaces. Smooth API communication.
Process and workflow alignment	Processes incompatible. Innovation cannot fit local workflows.	Partial alignment. Requires significant redesign or manual steps.	Processes are mostly compatible with some adjustments.	Full alignment. Innovation integrates directly into existing workflows.

Device and system integration	Devices or systems incompatible. Requires new hardware or major upgrades.	Partial compatibility. Integration possible but resource intensive.	Compatible with minor adaptations. Device and system links feasible.	Fully compatible systems and devices. Integration straightforward.
Security and compliance alignment	Security or privacy conflicts block integration.	Partial compliance. Requires corrective measures and additional safeguards.	Mostly compliant. Some minor adjustments required.	Fully compliant. Security and privacy frameworks aligned.
Technical maintenance and support capacity	No internal capacity to maintain integrations.	Limited capacity. High dependence on external support.	Adequate capacity for routine maintenance with some assistance.	Strong and stable capacity. Integrations can be maintained independently.

3.5 Pillar 5. Impact and KPI Harmonization

This pillar evaluates whether the transferred innovation can generate meaningful, comparable and decision relevant impacts in the receiving Living Lab. It examines the capacity of the receiving ecosystem to measure these impacts in a consistent manner and to align them with the Key Performance Indicators used across the project. While previous pillars analyze ecosystem readiness, data conditions, model adaptability and system interoperability, this pillar focuses on the outcomes that innovation produces. It considers whether the innovation can deliver measurable improvements in efficiency, sustainability and service quality, and whether these improvements can be assessed using the harmonized URBANE impact assessment framework.

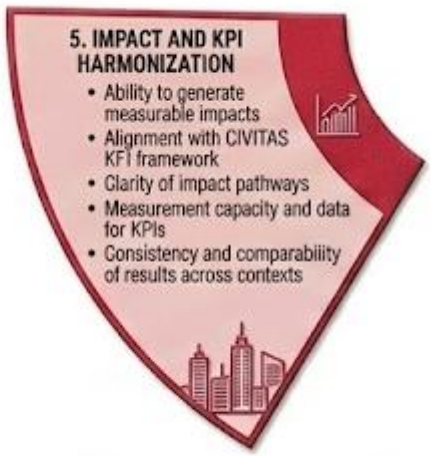

FIGURE 9: PILLAR 5 – IMPACT AND KPI HARMONIZATION FRAMEWORK

Impact on urban logistics is multidimensional. Innovations can influence operational performance, vehicle kilometers travel, emissions, energy use, congestion, infrastructure utilization, service levels, workforce productivity and user behavior. The degree to which these impacts can be captured depends on the availability of data, the quality of the KPI definitions and the alignment between the innovation's design and the operational characteristics of the receiving city. This pillar therefore evaluates both the intrinsic ability of the innovation to produce outcomes and the capability of the receiving ecosystem to measure those outcomes within the common framework applied across the project.

Transferability requires that KPI definitions remain comparable across Living Labs. Harmonized indicators enable transparent benchmarking between Wave 1 and Wave 2 and support consistent interpretation of policy implications. For example, when a locker planning model is transferred from one city to another, reductions in emissions or delivery distance must be calculated using the same formulas and data conventions. If KPIs cannot be harmonized, observed differences may reflect methodological variation rather than genuine differences in performance.

The reliability of KPI measurement is strongly shaped by the alignment between the innovation's impact pathways and the local environment. Some innovations produce noticeable effects only in cities with high delivery density or advanced digital infrastructure. Others require specific organizational arrangements or infrastructure to unlock benefits. The aim of the pillar is not to judge whether the magnitude of the impacts is identical across cities but to ensure that the innovation produces traceable, interpretable and policy relevant effects that can be measured using common indicators. If impacts cannot be observed or quantified, the innovation's transferability remains limited even if technically functional.

A central dimension concerns the clarity of the impact mechanisms. Transferability requires a clear understanding of how innovation creates benefits and how these benefits translate into measurable KPIs. When impact pathways are explicit, differences in performance across cities can be interpreted with confidence. When pathways are unclear or depend heavily on conditions that vary, the comparability of impacts becomes more challenging. This pillar therefore evaluates whether the impact logic developed in Wave 1 can be maintained in Wave 2 or whether significant reinterpretation is required.

Another important aspect is the capacity of the receiving Living Lab to collect the data needed to compute KPIs. The URBANE framework includes indicators on environmental performance, operational efficiency, economic value, user experience and social impact. If monitoring systems cannot provide the necessary inputs, the harmonized framework cannot be applied. In such cases, the innovation may still function, but its impacts cannot be assessed in a way that supports cross city comparison. Conversely, a Living Lab with strong measurement capacity contributes more reliable and comparable evidence for the evaluation of the innovation.

Impact and KPI harmonization also depends on the stability of monitoring over time. Some impacts appear immediately, such as reduced detours or shorter delivery time windows. Others emerge gradually, such as behavioral changes in the use of shared lockers or long term reductions in emissions. This pillar therefore evaluates whether the receiving ecosystem can maintain consistent monitoring and whether the innovation produces impacts that can be

observed within the project timeframe and beyond. Both short term and long term effects are relevant for determining the value of transferability.

The interpretation of results from this pillar clarifies whether observed performance reflects the innovation's inherent qualities or specific contextual factors. A city that produces moderate impacts but achieves strong KPI harmonization may reveal realistic and context aligned outcomes. A city that presents large numerical improvements but lacks harmonized KPIs may produce results that are difficult to interpret or compare. This pillar therefore ensures that numerical outputs are supported by common methodological rules and that differences reflect actual performance rather than inconsistencies in measurement.

Harmonized KPIs increase policy relevance. Transferability depends not only on technical replication but also on the ability of policy makers to understand and trust the results. When indicators follow common definitions, cities can integrate innovation outcomes into their Sustainable Urban Mobility Plans and Sustainable Urban Logistics Plans with greater confidence. Harmonized KPI frameworks also support European scale comparability and reinforce alignment with wider policy objectives related to the Green Deal, energy transition and Physical Internet oriented logistics.

The scoring table below reflects the five sub elements that constitute this pillar. Each element is rated from 0 to 3 using definitions that enable consistent interpretation across Living Labs. The table supports transparent evaluation and informs the interpretation of transferability outcomes.

TABLE 5: PILLAR 5 – IMPACT AND KPI HARMONIZATION SCORING CRITERIA

Sub-Element	Score 0	Score 1	Score 2	Score 3
Ability to generate measurable impacts	No observable impact. Innovation does not influence measurable performance indicators.	Some impacts present but weak or inconsistent. Difficult to interpret.	Clear impacts in several KPI categories. Magnitude meaningful.	Strong and stable impacts across multiple KPIs. Highly relevant for planning and operations.
Alignment with CIVITAS KPI framework	KPIs cannot be computed. No alignment with indicator definitions.	Partial alignment. Some KPIs computable but with deviations from definitions.	Most KPIs aligned with methodology. Minor adjustments required.	Full harmonization with CIVITAS KPI definitions. Indicators are fully comparable.
Clarity of impact pathways	Impact logic unclear. No identifiable mechanism linking innovation to KPIs.	Pathways partially understood but context sensitive and unstable.	Clear pathways for most KPIs. Reasonable interpretability.	Strongly defined pathways. Impact mechanisms fully transparent and stable.
Measurement capacity and data for KPIs	Required data unavailable. KPI	Limited data availability. Measurement	Adequate data with minor gaps. KPI	Full data availability and stable monitoring. High

	measurement not feasible.	possible but low reliability.	measurement feasible.	reliability of KPI computation.
Consistency and comparability of results across contexts	Results not comparable. Indicators inconsistent across cities.	Limited comparability due to methodological differences.	Reasonable comparability with some contextual adjustments.	High comparability. Indicators stable and interpretable across contexts.

3.6 Pillar 6. Adoption, Scalability and Long-Term Viability

This pillar evaluates whether the transferred innovation can be adopted, scaled and sustained in the receiving Living Lab once the project support phase concludes. Earlier pillars focus on institutional readiness, data maturity, model adaptability, interoperability and KPI harmonization. This pillar shifts attention to the longer-term prospects of innovation and examines whether it can become a stable element of the urban logistics system.

Long-term viability is essential for ensuring that innovation provides durable value and contributes to strategic objectives. Transferability is successful only when an innovation can be absorbed into routine operations and remain effective under the city's own governance, technical and financial conditions.

FIGURE 10: PILLAR 6 – ADOPTION, SCALABILITY AND LONG-TERM VIABILITY FACTORS

Adoption depends on the willingness and capacity of key actors to integrate the innovation into established practices. This includes public authorities, logistics operators, technology suppliers and sometimes end users such as couriers, shippers and residents. Sustainable adoption requires that stakeholders view the innovation as beneficial, feasible and aligned with their operational or strategic aims. If perceived benefits are unclear or misaligned with incentives, the innovation may remain limited to pilot status. This element therefore evaluates the presence of stakeholder engagement, acceptance and indications of commitment to continued use.

Scalability is another fundamental aspect of transferability. Some innovations operate effectively at pilot scale but lose efficiency when expanded. Others rely on manual processes or fragile data flows that cannot support widespread deployment. To be meaningfully transferable, the innovation must be capable of expansion across districts, operators or system components without major redesign. Scalability also concerns the ability to support additional use cases, higher demand volumes or more complex operational structures. The structural robustness of the model, the capacity of local systems and the adaptability of organizational processes all influence scalability.

Financial viability is central to long-term sustainability. A technically successful pilot may still fail if its maintenance and operational costs cannot be covered. This element evaluates whether financial arrangements, budget allocations and business models can support the innovation once project funding ends. It considers whether operators perceive clear economic value, whether municipalities can allocate the necessary resources and whether the expected benefits justify continued investment. Financial viability also includes the ability to maintain infrastructure, update software, store and process data and provide staff training.

Institutional alignment influences long-term viability. Innovations must fit within the city's policy frameworks, planning strategies and regulatory conditions. When an innovation supports existing goals such as emissions reduction, multimodal logistics, consolidation, digital transformation or Physical Internet alignment, long-term uptake becomes more probable. If the innovation requires changes that the city is not prepared to pursue, sustainability becomes less likely. This sub-element therefore evaluates whether the innovation is embedded in strategic plans, policy documents or operational guidelines that guide future decisions on urban logistics.

Adaptability and learning capacity play a crucial role. Urban logistics evolves due to changing demand patterns, infrastructure conditions, regulatory reforms and market dynamics. Innovations that cannot adapt to these changes lose relevance and impact. Conversely, innovations that incorporate feedback, adjustable parameters and modular updates remain resilient. Transferability therefore depends on whether the receiving ecosystem can operate the innovation independently, update it as conditions change and interpret performance indicators to support continuous improvement.

Partnership stability contributes to long-term viability. Many innovations rely on cooperation between municipalities, logistics operators and technology providers. When these partnerships continue beyond the project period, the innovation gains stronger institutional grounding. If partnerships are temporary or limited to the pilot, the innovation may not persist after the project ends. This sub-element evaluates whether cooperation agreements, working groups or contractual structures support sustained collaboration.

Cultural and behavioral acceptance is also relevant. Urban logistics innovations often require adjustments in daily routines. Examples include new delivery practices, adoption of shared lockers, use of new routing tools or engagement with digital coordination platforms. Long-term sustainability depends on whether users internalize these changes and perceive them as beneficial. Resistance to behavioral change can limit long-term adoption even when the innovation is technically robust. This element therefore assesses whether behavioral signals indicate positive acceptance in the early stages of deployment.

Cocluding, this pillar also supports decisions regarding replication beyond Wave 2. Innovations that achieve high scores on long-term viability are suitable candidates for broader European adoption and could form part of future reference frameworks for sustainable last mile logistics. Innovations with weaker viability may still be promising but require refinement, simplification or targeted deployment conditions. By assessing adoption, scalability and sustainability explicitly, the pillar ensures that the transferability evaluation reflects both current performance and future prospects.

The scoring table below summarizes the five sub-elements that constitute this pillar. Each is rated from 0 to 3 to support transparent evaluation and consistent interpretation across Living Labs.

TABLE 6: PILLAR 6 – ADOPTION, SCALABILITY AND LONG-TERM VIABILITY SCORING CRITERIA

Sub-Element	Score 0	Score 1	Score 2	Score 3
Stakeholder acceptance and commitment	No acceptance. Stakeholders unwilling or uninterested in continued use.	Limited acceptance with uncertainty about ongoing commitment.	General acceptance with moderate confidence in continued use.	Strong commitment from key stakeholders. Clear intention for long-term adoption.
Scalability potential	Innovation cannot scale. Strong constraints prevent expansion.	Limited scalability. Significant redesign needed for larger deployment.	Moderate scalability with manageable adjustments.	Highly scalable. Can expand across contexts without structural changes.
Financial and operational viability	No sustainable funding or operational capacity. Innovation stops after project.	Partial viability with unclear budget or resource availability.	Reasonably viable with stable but limited resources.	Fully viable. Stable funding and operational capacity for long-term use.
Institutional and policy alignment	Innovation misaligned with local policies or strategies.	Partial alignment with limited institutional support.	Good alignment with existing plans and strategies.	Strong alignment. Innovation embedded in strategic frameworks.
Adaptability and learning capacity	No ability to update or adapt innovation. Dependent on external support.	Limited adaptability. Updates possible but difficult.	Moderate adaptability. Local staff can adjust core elements.	Highly adaptable. Innovation can evolve with local conditions and be maintained internally.

3.7 Evaluation Model for Transferability Assessment Methodology

To evaluate how effectively each Living Lab adopted and operated the URBANE innovations during the transfer phase, we introduce a Transferability Performance Metric that explicitly accounts for the difficulty of the local context. The rationale is that Living Labs with weaker contextual and organizational foundations (Pillars 1–2) face greater challenges in integrating new tools. Therefore, achieving successful adoption under difficult conditions constitutes higher performance. Conversely, Living Labs with strong governance structures, mature ecosystems, and favorable contextual conditions face fewer barriers; adoption here is expected and should not inflate the performance score. The metric therefore separates the assessment into two components. The first is the ecosystem difficulty, derived from Pillars 1 and 2, and the second performance and feasibility, derived from Pillars 3–6.

In more detail, Pillars 1 and 2 are normalised and averaged to form a **Context Score**:

$$C = \frac{\hat{P}_1 + \hat{P}_2}{2}$$

A high value of Cindicates an easy and supportive ecosystem, while a low value reflects difficult conditions. To incorporate this into performance evaluation, the context is inverted so that more difficult environments increase the performance score. For this purpose, we define a **Context Difficulty Factor (CDF)**:

$$CDF = \frac{1}{1 + C}$$

This expression ensures stable behavior across all Living Labs. When contextual readiness is low (C is small), the CDF approaches 1, increasing the performance score. When contextual readiness is high, the CDF approaches 0.5, preventing overestimation of performance in favorable conditions.

The operational and feasibility performance of the innovation is captured by the average of Pillars 3–6:

$$F = \frac{\hat{P}_3 + \hat{P}_4 + \hat{P}_5 + \hat{P}_6}{4}$$

This score reflects how well the Living Lab was able to integrate, operate, and benefit from the URBANE innovations, independent of contextual difficulty.

The final **Transferability Performance Index (TPI)** combines the two components:

$$TPI = F \cdot CDF$$

This formulation rewards Living Labs that achieved strong operational performance despite difficult ecosystem conditions and moderates the score where favorable conditions made

adoption straightforward. The result is a balanced and context-aware metric that better reflects the real-world effort, capacity and success demonstrated by each Living Lab in the transferability phase.

The resulting Transferability Performance Index ranges between approximately 0.30 and 1.00, depending on the combination of feasibility (F) and contextual difficulty (CDF). Higher values indicate that a Living Lab delivered strong operational performance under demanding conditions, while lower values signal either limited performance or an adoption environment that did not require significant adaptation effort. In general, TPI values above 0.75 reflect strong transferability performance, indicating that the Living Lab not only integrated the URBANE tools effectively but did so under moderate or high contextual difficulty. Scores between 0.50 and 0.75 represent solid performance, typically observed when feasibility was high but contextual difficulty was moderate, or when contextual difficulty was high but operational performance remained stable. Values below 0.50 usually indicate limited transferability performance, either because the Living Lab faced challenges in operating the innovation or because exceptionally favorable contextual conditions did not require substantial effort to achieve the observed results. This interpretation enables a consistent evaluation of how well each Living Lab performed relative to its starting conditions and provides a clear benchmark for comparing transferability outcomes across diverse contexts.

4. Implementation of the Transferability Frameworks to URBANE Wave 2 LLs

This chapter describes how the URBANE Transferability Methodology applied and validated in the two Wave 2 Living Labs. The objective is to document in a structured and comparable manner how each city adopted selected Wave 1 innovations.

The URBANE transferability process uses a structured methodological pathway that guides cities from situational understanding to validated assessment of adopted innovations. The pathway is represented visually as an ascending route in the project's mountain graphics. It reflects the principle that successful transferability depends on a clear sequence of actions combined with space for iterative refinement. Cities apply innovations from earlier Living Labs while respecting their own constraints, priorities, and readiness levels.

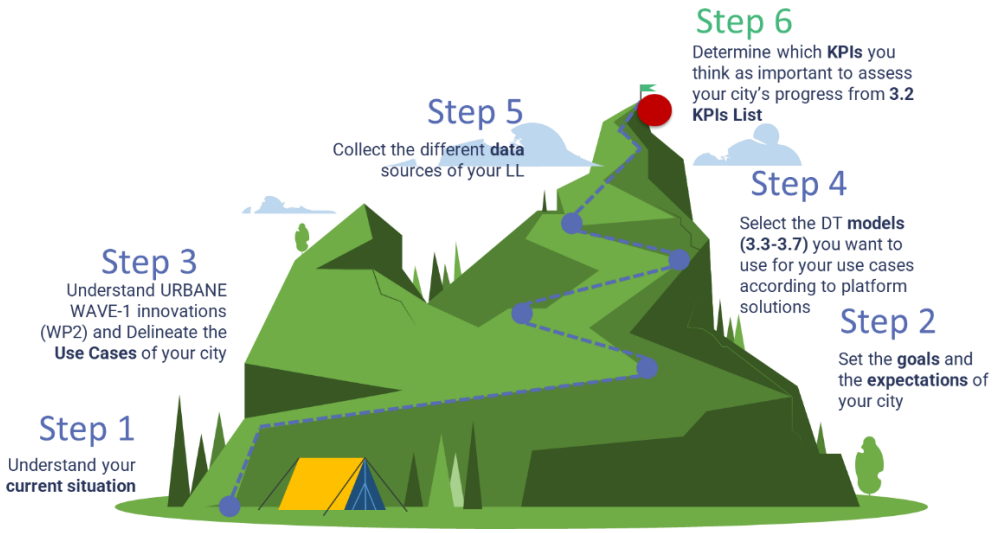

FIGURE 11 URBANE WAVE 2 LLS METHODOLOGICAL STEPS

In more detail, to ensure consistent implementation and comparability across LLs, the project followed a six-step methodology as illustrated in Figure 11:

Step 1 – Understanding the Current Situation

The process begins with an objective analysis of the local context. Each city establishes a baseline description of its logistics ecosystem. This baseline includes the organization of delivery flows, operational constraints, behavioral patterns of logistics actors, regulatory conditions, and the physical and spatial characteristics of the urban area. This step creates the reference frame against which innovation suitability and performance improvements can be assessed. It ensures that the transfer process builds on verifiable local conditions.

Step 2 – Setting Goals and Expectations

Cities then define the expected outcomes of the adoption of Wave 1 innovations. Goals must reflect the city's mobility strategies, sustainability targets, and operational challenges. They must also remain realistic considering data availability and institutional capacity. Clear expectations guide decisions on which innovations are examined, how they are configured, and which elements require adaptation. This step links the methodological framework to the strategic direction of the city.

Step 3 – Understanding Wave-1 Innovations and Defining Local Use Cases

Cities study the innovation portfolio developed during Wave 1. The purpose is to establish a clear understanding of each tool's functional capabilities, underlying logic, and data requirements. Cities map these capabilities to their goals and define specific use cases. These use cases represent the operational or analytical questions that the transferred solutions will address. The step ensures that the transfer process focuses on context specific adaptation.

Step 4 – Selecting the Appropriate Models and Tools

After the use cases are defined, each city identifies the models, digital twin components, analytical tools, or operational concepts that match its needs. The approach is modular. The URBANE platform offers a set of interoperable components and each city selects only those required for its context. This keeps integration manageable and ensures that innovations are selected on the basis of relevance, data readiness, and expected impact.

Step 5 – Collecting and Structuring Data Sources

Data collection links the conceptual design to technical implementation. Cities gather the datasets needed to parameterize the selected tools and to support the evaluation process. The methodology emphasizes data sufficiency and data harmonization. Data sufficiency ensures that the minimum viable dataset exists for meaningful application. Data harmonization ensures that datasets follow structures compatible with Wave 1 models and the URBANE platform. This promotes comparability and reduces integration effort.

Step 6 – Selecting KPIs for Evaluation and Validation

Lastly, cities select KPIs from the project's common evaluation framework. The KPI set ensures methodological coherence because all cities evaluate innovations with indicators grounded in service performance, operational efficiency, environmental impact, and process readiness. Each Living Lab selects the KPIs that match its goals, chosen innovations, and data availability. The evaluation remains systematic and context sensitive. KPIs form the basis for determining whether the adopted innovations offer measurable value and whether the transferability process

This methodological pathway introduced clarity, consistency, and comparability in the implementation of innovations across Wave 2 cities. following sections explain how the methodology was implemented in each Wave 2 Living Lab and how performance was assessed through the common KPI framework.

4.1 Transferability and Replication Activities in the Karlsruhe Living Lab

The Karlsruhe Twinning Living Lab applied the structured transferability pathway defined in URBANE to support the replication of innovations developed in Wave 1 cities. Karlsruhe operates in a distinct context because its last mile concept integrates autonomous delivery vehicles with public transport system. Trams form the central element of the mobility solutions in the city. The transferability process required alignment between Wave 1 tools and the regulatory, infrastructural, and operational characteristics of Karlsruhe's mobility system.

The methodological implementation followed the six step URBANE pathway. These steps covered the analysis of the local situation, the definition of goals and expectations, the examination of Wave 1 innovations and local use cases, the selection of suitable models and tools, the preparation of data sources, and the identification of KPIs for evaluation and validation.

The first step focused on developing an objective understanding of the local context. Karlsruhe is a medium sized German city with a long-standing integration of tram and regional rail services. This system forms the mobility backbone of the city and defines the feasibility of integrating autonomous delivery vehicles into tram movements. The Living Lab concept examined in D4.2 requires autonomous delivery vehicles to move short distances to tram stations, board the tram as passengers, travel to another part of the city, and complete the delivery through another short autonomous trip. A clear understanding of these operational conditions was necessary because the use of public transport for freight is subject to regulatory restrictions. The assessment examined the physical characteristics of tram stops, the availability of multifunctional areas inside trams, passenger safety requirements, platform accessibility, and the interaction between autonomous vehicles and tram timetables. These factors defined the realistic boundaries within which transferred innovations could operate.

The second step involved defining the goals and expectations of the Living Lab. Karlsruhe aimed to examine whether autonomous delivery vehicles could be combined with the tram network to create a sustainable and efficient form of last-mile transport. The methodological work required a precise formulation of these aims. Karlsruhe requested to assess the operational feasibility of the autonomous vehicle and tram concept, to identify regulatory and infrastructural constraints, to quantify environmental impacts, and to apply a consistent evaluation framework that enabled comparison with Wave 1 cities. These expectations directed the methodological pathway and ensured that the transfer process generated insights relevant to the operational characteristics of Karlsruhe while remaining consistent with the URBANE framework.

The third step focused on understanding Wave 1 innovations and defining the corresponding local use cases. Wave 1 produced and used digital tools, models, data schemas, and operational concepts such as the two echelon distance model for multi-leg trips, the COPERT emissions models hosted in CitICore app, the blockchain event logging schema developed in URBANE Transferability Platform, and the Impact Assessment Radar Policy design tool etc.

The methodological work examined these components and identified those relevant to Karlsruhe. Emissions models, distance calculation tools, scenario modelling functions, and the blockchain event logging schema matched the requirements of the Shop to Customer use case. This case involves recording events such as parcel pick up, loading onto the autonomous vehicle, tram boarding, and delivery confirmation. The selection of innovations was based on the situational analysis and aligned with the goals defined in the second step.

The fourth step required the Living Lab to determine which components of the URBANE Digital Twin platform could be transferred without modification and which required adaptation. Karlsruhe selected the Agent-based Model, and the CitlCore what-if platform, which were executed through the URBANE Digital Twin Portal. These models provided structured calculations of distances, travel segments, and emissions for both autonomous delivery vehicles and conventional diesel vehicles. This enabled a consistent comparison between tram based and road-based delivery scenarios. The modular design of the URBANE platform allowed Karlsruhe to select only the models required for its context. Karlsruhe also adopted the Wave 1 blockchain event scheme to represent parcel handling in the B2C delivery use case. At this way, the methodological focus on interoperability and common data structures across Living Labs achieved.

The fifth step focused on data collection and preparation. Karlsruhe assembled data from the tram operator, municipal planning datasets, socio economic datasets, and sources describing autonomous delivery vehicle capabilities. Geospatial coordinates for tram stops, delivery points, and depots were collected and harmonized into common projection formats. Timetable data for tram line 5 were processed to identify feasible journeys for autonomous vehicle boarding. The analysis considered constraints such as availability of multifunctional areas, crowding conditions, and station accessibility. Autonomous delivery vehicle movement parameters, including an average pedestrian speed of 3km/h, were integrated to generate realistic travel times. In cases where detailed data were not available, such as unsuccessful delivery attempts or detailed parcel profiles, publicly available statistics and industry averages were used. The objective was to collect the minimum viable dataset required to apply the selected tools and support meaningful KPI analysis.

The sixth step involved defining the KPIs used for evaluation and validation. The URBANE KPI catalogue supports structured cross city comparison. Karlsruhe selected KPIs that aligned with its operational goals and with the capabilities of the chosen digital models according to URBANE KPIs catalogue. Operational KPIs included travel time per segment, the number of accessible stations for robot boarding, and the feasibility of integrating autonomous vehicles into scheduled tram services. Environmental KPIs focused on emissions per delivery, energy consumption, and comparative performance between autonomous vehicle and tram scenarios and diesel truck deliveries. Process and service KPIs addressed feasibility constraints, passenger interactions, and spatial accessibility across the tram network. The Impact Assessment Radar served as an additional evaluation tool. It allowed results to be visualized and compared with Wave 1 Living Labs using a consistent multi-dimensional structure to understand the differences in context and layout.

4.2 Transferability and Replication Activities in the Barcelona Living Lab

The Barcelona Living Lab applied the transferability guidance defined in URBANE to support the adoption of Wave 1 innovations in a dense metropolitan environment. Barcelona aimed to replicate the micro consolidation and cargo bike last mile model demonstrated in Bologna. The replication process covered operational practices, business logic, data structures, digital tools, and innovation enablers developed in Wave 1.

The process began with a detailed understanding of the local context. Barcelona is a dense metropolitan area with an established zero emission logistics strategy led by the Metropolitan Area of Barcelona. The city has a mature ecosystem of cycling logistics operators. Vanapedal participated as the logistics partner of the Living Lab. Through workshops, meetings, and operational field visits, the Living Lab defined the baseline conditions that would structure the transfer process. These conditions included the existing use of cargo bikes for last mile deliveries, the ongoing adoption of micro consolidation approaches in the historic center, the regulatory constraints linked to access restrictions and pedestrian priority zones, and the operational routines followed by Vanapedal for sorting, loading, and routing. Establishing this baseline ensured that the transferability process focused on context specific adaptation instead of direct replication.

Once the local situation was defined, the next step involved formulating the goals and expectations of the Living Lab. Barcelona aligned its objectives with the URBANE ambition to digitize last mile operations. The Living Lab aimed to improve operational efficiency, increase the reliability of parcel consolidation, and enhance visibility across the delivery chain. Barcelona also pursued a strategic objective. The city aimed to demonstrate how data driven tools and platform integration can improve the competitiveness of zero emission logistics operators. The Living Lab formulated its goals to remain comparable with Bologna to support a credible assessment of transferability. These expectations directed the selection and application of innovations in the subsequent steps.

The third step involved understanding Wave 1 innovations and identifying those relevant to Barcelona. Because the Living Lab replicated Bologna's micro hub model, it focused on transferring the organizational and business logic used in Bologna to coordinate multiple logistics service providers in a shared consolidation model. Joint workshops between Bologna and Barcelona supported the analysis of operational flows, governance structures, data exchange requirements, and the technological components that enabled Bologna's model. During these interactions, Barcelona identified that continuous parcel tracking without adding workload to couriers was a missing capability in its current operations. This insight led to the selection of a portable RFID system integrated into cargo bike boxes. This system became the main digital enabler for transferring Bologna's data driven micro hub operations in the context of Barcelona.

After identifying the relevant innovations, the Living Lab selected the specific tools, models, and technologies to integrate into its operational framework. Barcelona adopted the blockchain based smart contract system developed in Wave 1. This enabled automatic logging of parcel handling events along the delivery chain. The Living Lab also integrated routing models validated

in Bologna. These models optimized cargo bike routes based on parcel positions, micro hub constraints, and operational windows. The models were accessed through the URBANE Transferability Platform. Finally, Barcelona also incorporated the Digital Twin environment CitlQore, which enabled structured scenario analysis for first mile and last mile configurations.

Data collection and preparation formed a critical step in the methodological pathway. Barcelona prepared datasets containing parcel identifiers, geographic coordinates of deliveries and micro hubs, timestamps for operational events, routing information, and cargo bike operational parameters. The introduction of RFID technology played a central role in strengthening data quality. By placing RFID antennas inside cargo bike boxes, the Living Lab ensured automatic detection of parcel events during real operations. These events included loading, unloading, and re consolidation activities. This reduced data gaps that often create barriers when deploying digital tools in last mile logistics. Barcelona also implemented local data to blockchain pipelines. These pipelines encoded each parcel event such as parcel loaded, parcel classified, or parcel delivered and transmitted it to the URBANE blockchain. This ensured full traceability and alignment with Wave 1 data structures. For simulation tasks, additional datasets were prepared within the Digital Twin environment, including energy consumption parameters, operational times, and spatial movement constraints. This ensured compatibility across analytical modules.

The final methodological step was the definition of KPIs for evaluation and validation. Barcelona aligned its indicators with the URBANE evaluation framework to ensure cross Living Lab comparability. Because Barcelona replicated a specific Bologna innovation, the Living Lab also incorporated Bologna's KPIs for direct comparison of operational efficiency, parcel handling performance, and consolidation effectiveness. KPIs related to technological performance were included to assess whether the transferred digital tools operated reliably under Barcelona's conditions. These KPIs covered RFID detection accuracy and the integrity of blockchain logged events. Additional KPIs assessed routing efficiency, time per delivery, and the performance of re-consolidation activities. These KPIs created a multi-level assessment structure that supported the validation of both operational and technological aspects of transferability.

4.3 Transferability Performance Analysis Across Living Labs

Furthermore, the analysis incorporates a context aware performance index. The index adjusts operational outcomes by the relative difficulty of the local environment. This ensures that results reflect both the technical success of tool deployment and the influence of institutional, regulatory, and organizational conditions. The index corrects differences in governance maturity, policy alignment, structural readiness, and the organization of Living Lab activities.

4.3.1 Contextual Readiness and Ecosystem Conditions

Contextual readiness forms the foundation for the assessment. It is measured through Pillars 1 and 2 of the URBANE transferability framework. These pillars assess governance clarity, policy and regulatory alignment, infrastructure suitability, stakeholder inclusiveness, capability availability, data governance, data quality, analytical literacy, and technical integration capacity.

These elements correspond to the core principles of SUMP and SULP processes in Europe. These processes emphasize coordination across departments, evidence-based planning, cooperation among stakeholders, and the creation of stable data and governance structures. Cities with higher maturity in these areas tend to integrate innovations more efficiently. Cities with fragmented or underdeveloped structures require greater coordination effort.

Using the validated scoring formula in Evaluation Model for Transferability Assessment Methodology, and according to the scores reported on Figure 12 the context scores are:

- **Barcelona**: $C_B = 0.433$
- **Karlsruhe**: $C_K = 0.367$

Both cities operate in moderately supportive environments. Neither displays a fully institutionalized ecosystem capable of supporting large scale innovation uptake independently. This is consistent with patterns observed across many European cities. Karlsruhe's slightly lower readiness score reflects its more restrictive regulatory environment and a more fragmented organizational setting. The prohibition on mixed passenger and freight operations on tram lines is a structural constraint that influences both operational feasibility and the available innovation pathways.

To incorporate contextual difficulty in the performance assessment, the context score is transformed into a Context Difficulty Factor (CDF):

- **Barcelona**: $CDF_B = 0.698$
- **Karlsruhe**: $CDF_K = 0.732$

These values indicate that both Living Labs faced comparable contextual difficulty during the implementation of URBANE innovations. Neither encountered severe structural limitations. Both required active coordination, alignment activities, and practitioner involvement to address governance and data readiness gaps. Barcelona's slightly lower difficulty factor reflects stronger baseline institutional and data governance. Karlsruhe's higher factor reflects the influence of stricter regulation on autonomous delivery vehicles.

4.3.2 Operational Feasibility and Performance of the Innovations

Pillars 3 to 6 assess the operational feasibility of the innovation. These pillars evaluate model calibration, interoperability, impact measurement capability, institutional embedding, and long-term viability. These are the dimensions most influenced by the URBANE tools and methodological guidelines.

The feasibility score for each LL shows a clear differentiation:

- **Barcelona**: $F_B = 0.750$
- **Karlsruhe**: $F_K = 0.683$

Barcelona displays stronger operational and institutional capacity to integrate the URBANE innovations. This arises from better alignment with municipal strategies, more consistent data

integration pipelines, and clearer long term adoption pathways. Barcelona benefits from an ecosystem already familiar with zero emission logistics and guided by SULP influenced structures.

Karlsruhe performs well in technical areas such as model transferability and interoperability. Its lower performance in Pillar 6 reflects reduced institutional alignment and long-term scalability. Regulatory constraints and the absence of an established institutional framework for freight operations within the tram system reduce feasibility. This pattern is common in cities with tightly regulated transport operations, where autonomous delivery technologies remain constrained until regulatory updates occur.

The feasibility results illustrate two widely observed insights. The first is that the transferability of digital tools is generally high when supported by stable technical specifications. The second is that long-term innovation uptake is often limited by institutional, regulatory, and organizational factors rather than by technical constraints.

4.3.3 Computation and Interpretation of the Transferability Performance Index

The Transferability Performance Index (TPI) combines contextual difficulty and operational feasibility into a single measure:

$$TPI = F \cdot CDF$$

The resulting values are:

- **Barcelona**: $TPI_B = 0.523$
- **Karlsruhe**: $TPI_K = 0.500$

These values place both Living Labs in moderate performance range. They indicate meaningful adoption under moderately difficult conditions. The difference between the two cities reflects the interaction between feasibility and context. Barcelona shows a stronger operational trajectory, while Karlsruhe benefits from a slightly higher difficulty factor.

The results indicate that both Living Labs implemented the URBANE innovations to a degree consistent with their institutional and regulatory conditions. The values show that the innovations are technically viable and operationally transferable, even under conditions that are not optimal.

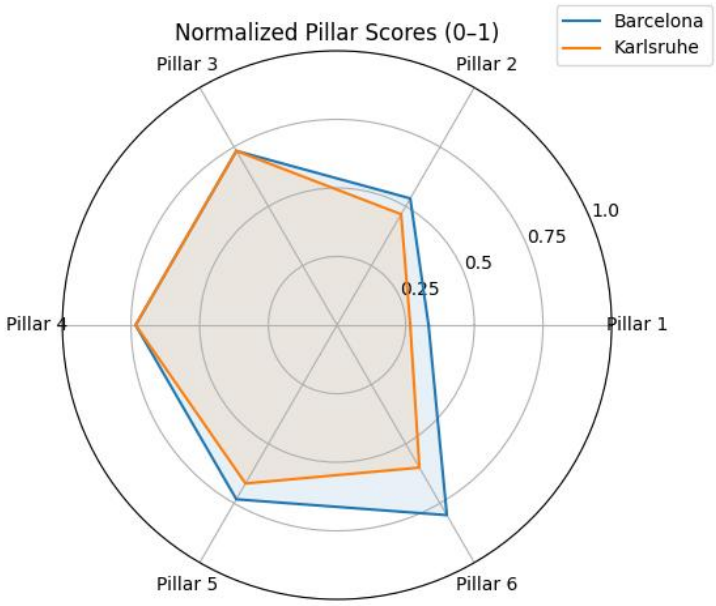

FIGURE 12: SPIDER PLOT OF TRANSFERABILITY PERFORMANCE OF BARCELONA AND KARLSRUHE LLS ACROS 6 PILLARS

The overall assessment indicates that the URBANE transferability platform and its methodological tools performed reliably across the two Wave 2 Living Labs. The digital components, including model calibration routines, transferability workflows, interoperability specifications, and impact monitoring structures, operated consistently despite differences in institutional and operational conditions. This level of consistency is notable within the European freight domain, where regulatory and organizational heterogeneity often limits replication.

The analysis also shows that contextual maturity and the organizational structuring of Living Lab activities remain only partially developed in both cities. Pillars 1 and 2 produce mid range scores. These scores reflect incomplete governance clarity, partial alignment across municipal departments, and limited formalization of multi actor processes. These patterns align with observations from SUMP and SULP evaluations, where governance integration between freight and passenger domains remains a persistent challenge.

The lower feasibility score in Karlsruhe reflects the influence of regulatory barriers affecting tram-based operations and autonomous robot movement. This is a structural constraint and not a limitation of the URBANE tools. In such settings, improvements in transferability depend on regulatory engagement rather than changes to the technical framework.

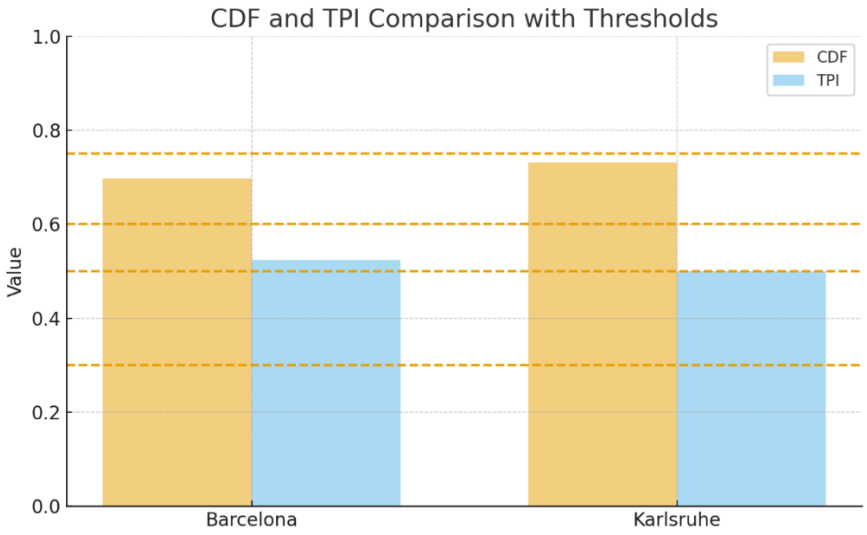

FIGURE 13: CONTEXT DIFFICULTY FACTOR (CDF) AND TRANSFERABILITY PERFORMANCE INDEX (TPI) COMPARISON ACROSS WAVE-2 LIVING LABS

The results show that the main limitations are institutional and organizational instead of technological. The URBANE platform is calibrated for replication. The Living Labs require stronger internal processes, clearer governance structures, and improved stakeholder coordination to support higher levels of transferability. Without such improvements, future replication efforts may continue to achieve only moderate performance even when the technical tools function effectively.

From a planning and governance perspective, the findings indicate a need to reinforce the operational models of Living Labs and to strengthen their institutional embedding. Practical experience in urban freight planning and SUMP and SULP implementation shows that Living Labs benefit from:

- clearer governance architectures and defined roles
- systematic data governance and interoperable information flows
- formalized engagement protocols among actors
- stronger institutional anchoring to ensure continuity beyond project cycles
- early involvement of regulatory authorities to address structural constraints
- capacity building to improve analytical and operational literacy within municipal teams

These actions do not require modifications to the URBANE tools. They require organizational and institutional reinforcement. Strengthening these areas will increase contextual readiness and improve feasibility and TPI outcomes in future replication environments.

5. Comparative Impact Assessment of the Barcelona and Karlsruhe Living Labs

This subsection provides a comparative analysis of the impact assessment results for the Barcelona and Karlsruhe Wave 2 Living Labs. Both Living Labs share the objective of supporting the decarbonization of last mile distribution and improving operational performance through digitalization, automation, and multimodal logistics. Despite this common direction, the two Living Labs operate under different baseline conditions, regulatory settings, and innovation pathways. These differences shape the type, magnitude, and scalability of the observed impacts. The analysis synthesizes environmental, operational, and data related effects and incorporates the Transferability Performance Index results to support a holistic comparison.

5.1.1 Environmental Impact Assessment

Both Living Labs achieve environmental benefits, and the mechanisms underlying these benefits differ. In Barcelona, the primary impact arises from electrification of the first consolidation leg. The baseline relies on vans with internal combustion engines transporting pallets to micro hubs. The simulation conducted in the Living Lab estimates that replacing these vans with electric alternatives reduces daily CO_2 emissions from about 18,000 grams to about 7,200 grams. This corresponds to a reduction of nearly sixty percent. The intervention requires no major restructuring, which makes it replicable in other cities using micro hub systems.

Karlsruhe evaluates environmental performance through two use cases. In the Shop to Customer scenario, the AMR to tram configuration reduces emissions per delivery from 1,096.2 grams for diesel trucks to 111.35 grams. This reduction is close to ninety percent. A second use case examines internal transport movements, where AMRs replace short internal trips. Annual savings of 0.39 tonnes of CO_2 are possible. These improvements result from the renewable electricity used in the tram network and the efficiency of AMRs. The relative impact is therefore high, although the regulatory constraints affecting freight by tram limit short term scalability.

Across both Living Labs, environmental outcomes depend strongly on the initial maturity of the baseline system. Barcelona begins from a low emission configuration, which limits the absolute reduction potential. Karlsruhe starts from a more carbon intensive baseline, which results in higher relative reductions. These patterns show the influence of context on decarbonization potential.

5.1.2 Operational Efficiency and Temporal Performance

Barcelona's operational improvements result from digitalization of parcel handling and routing activities. Manual scanning, consolidation, and route preparation previously contributed to daily operational delays. RFID based automated recognition and algorithmic routing reduce these delays. Baseline and pilot comparisons show that average delivery time per parcel decreases from 10 minutes and 55 seconds to 5 minutes and 26 seconds. This represents an improvement

of about 50%. The gains are associated with fewer manual errors, reduced handling time, and more efficient route construction.

Karlsruhe shows a more complex relationship between innovation and temporal performance. AMRs achieve high completion rates in simulations, ranging from 98% to 100% depending on the scenario. When integrated with trams, delivery time becomes sensitive to the public transport timetable. In the Meals on Wheels use case, the AMR and tram transfer required up to thirty minutes. This duration is unsuitable for temperature sensitive goods. Automation and multimodality therefore introduce temporal dependencies that require coordination and may require regulatory adjustments. Internal AMR routes operate consistently. Multimodal chains depend on scheduled services.

The comparison indicates that Barcelona reduces process friction in a single mode system, while Karlsruhe's performance depends on the interaction between autonomous systems and public transport. Barcelona achieves higher short term operational gains. Karlsruhe's longer-term performance depends on institutional coordination and timetable adjustments.

5.1.3 Traceability, Data Quality, and Digital Reliability

Traceability is a challenge for both Living Labs. Barcelona moves from a baseline without automated traceability to a post pilot state where about eighty percent of parcels are detected using RFID. Performance limitations arose from the single antenna configuration, which produced missed readings. The three antenna design resolved most errors.

Karlsruhe faces interoperability challenges rather than detection failures. The integration of AMR systems, tram control systems, and blockchain components requires alignment across independent systems with different communication and regulatory requirements. End to end digital reliability requires a unified ICT architecture capable of linking robot movements with tram data and handover events. The pilot validated individual components. The integration process revealed that multimodal logistics based on public transport requires higher levels of digital coordination than single mode systems.

Both Living Labs show that reliable traceability depends on both technology and organizational structures. Digitalization improves data availability while revealing integration gaps that must be addressed before scaling.

5.1.4 Transferability Performance Index (TPI)

The Transferability Performance Index measures how effectively each Living Lab adopts and operationalizes innovations relative to its context. Barcelona reaches a value of 0.523. Karlsruhe reaches a value of 0.500. The difference is modest.

Barcelona's difficulty factor is 0.698. This reflects a moderately challenging environment. The feasibility score of 0.750 shows good alignment between the innovation and the city's regulatory and operational framework. The innovation fits the existing micro hub and cargo bike system.

Karlsruhe's difficulty factor is 0.732, influenced by regulatory barriers associated with freight on trams and the alignment required to integrate AMRs. The feasibility score of 0.683 is lower

because the innovation requires regulatory interpretation, physical adjustment of transfer points, and organizational coordination.

The comparison indicates that optimisation oriented innovations in mature systems are more readily transferable than structural innovations that require changes to governance frameworks. Karlsruhe has the potential for higher environmental benefits once regulatory and institutional barriers are addressed.

5.2 Long Term viability and scaling up Wave-2 LL innovations

The following two subsections present the continuous approximation models used to evaluate the long term and large-scale viability of the innovations implemented in Barcelona and Karlsruhe. These models extend the Level 2 quantitative tools originally developed for the URBANE Impact Assessment Radar in Deliverable D3.5.

The purpose is to provide a structured analytical framework that moves beyond pilot scale observations and captures how the tested solutions behave when applied across broader service areas, higher parcel volumes, and alternative operational configurations. The models are designed to support strategic planning and to quantify performance under conditions that cannot be directly tested during real world pilots.

The scope of the modelling covers two distinct innovation pathways. The first concerns the use of shared urban microhubs and cargo bikes in dense metropolitan environments, as applied in Barcelona. The second concerns the introduction of autonomous delivery vehicles in short range last mile operations, which is conceptually relevant for both cities but was examined in detail in the Barcelona context. Both models use continuous approximation to represent spatial structure, routing effort, fleet size, and system wide cost and emission outcomes. This methodology replaces detailed network mapping with aggregate parameters such as service area, parcel density, vehicle capacity, and average trip length. This approach allows partners to evaluate system behavior under many different design points without constructing full network models.

The methodological pathway follows the same logic for both innovations. First, the main operational elements of each system are abstracted into a small set of variables and structural assumptions drawn from established literature in freight transport and last mile logistics. Second, these variables are combined into closed form expressions for route distance, driving time, fleet size, energy use, labor effort, and total cost. Third, these expressions are applied across a range of scenarios where penetration rates, hub densities, or robot shares change. The outputs form a consistent set of KPIs that link demand volumes, spatial characteristics, and technology choices with long term performance indicators. This pathway supports transparent comparison of alternative designs and identifies parameter ranges where the proposed innovations are operationally viable, cost efficient, and capable of delivering measurable environmental gains.

5.2.1 Microhub Methodological Framework of long-term evaluation.

The microhub evaluation model is used in the Barcelona Living Lab to quantify how shared urban microhubs and cargo bikes affect the performance and sustainability of last-mile operations. Within the URBANE Impact Assessment Radar this model supports Level-2 assessment, where simplified but quantitative representations of logistics systems are used to test "what-if" scenarios. The objective is not to reproduce all details of the operator's network, but to provide a transparent and robust way to compare alternative configurations of microhubs, fleet mixes and demand allocation rules, and to express their impact in terms of costs, emissions and basic operational requirements.

The model represents a stylized urban delivery system in which several logistics service providers (LSPs) operate in a common service area. This area corresponds to the part of the Barcelona metropolitan zone that is relevant for the use case. Each LSP l is characterised by a daily parcel demand D_l (parcels per day) to be served in this area. Under the baseline configuration all parcels are delivered directly from each LSP's main depot, located at the periphery of the city, using diesel vans. Under the innovation scenario a share α of the total demand is routed through a network of M shared urban microhubs inside the city. Each microhub is served by a trunk flow from the LSP depots and performs last-mile delivery with cargo bikes.

The spatial structure is modelled through continuous approximation. The total service area A (km²) is a model input. In the baseline case each LSP's depot serves the whole area. In the microhub scenario the area is divided evenly between the M microhubs, so that each hub covers A/M. Customer locations are assumed to be uniformly distributed over the corresponding service region. The average distance from a depot or hub to the outer part of its service region is approximated by an effective radius r_{eff} derived from the area, using the relationship $A = \pi r^2$ and an empirical factor that accounts for the fact that first and last stops are usually not at the extreme boundary. This provides a consistent way to adjust travel distances as the number of microhubs changes, without mapping individual addresses.

Routing is also described in aggregate terms. Both vans and cargo bikes are modelled as performing closed delivery tours that start and end at their depot or microhub. For a given depot covering area A_d and a vehicle that carries N parcels on a route, the average route length L (km) is approximated as

$$L = 2.5\sqrt{A_d\, N} + 2r_{\text{eff}}(A_d).$$

The first term reflects the internal tour that connects many stops within the service region. The second term reflects the access and egress legs between the depot and the tour. In the current application N is taken equal to the vehicle capacity Q, so vans and bikes operate at or close to full load on each route. The number of last-mile routes for each leg of the system is then given by demand divided by capacity. For example, for an LSP that keeps $(1-\alpha)$ of its parcels on direct van delivery, the number of van routes per day is approximately $(1-\alpha)D_l/Q_{\text{van}}$. For the microhub leg, the parcels assigned to microhubs are split across the M hubs and the number of cargo-bike routes is computed in the same way.

Route duration is derived from route length and dwell times. Each vehicle type has a characteristic driving speed s (km/h) and a dwell time dw per stop (hours per parcel). The average time needed to complete one tour is

$$T = \frac{L}{s} + N\,dw.$$

This duration is used to estimate the total driving time and the approximate number of vehicles of each type that are required to operate the system in a given time window (for example, an 8 hour shift). Total van driving time is the sum of route times over all LSPs. The required van fleet is then given by total van hours divided by the shift length. The same approach is used for cargo bikes.

Costs are broken down into three main components: transport, labor and handling. Transport costs represent fuel and energy use. For diesel vans, fuel consumption is expressed as liters per kilometers and multiplied by a fuel price (euro per liter). For cargo bikes and electric vehicles, energy and maintenance can be represented by a cost per kilometer. Labor cost is proportional to driving time, using an hourly wage for van drivers and cargo-bike riders. Handling costs capture all parcel handling activities at depots and microhubs: sorting, scanning, loading and unloading, internal movements and fixed facility overheads. These are modelled as a cost per parcel at the LSP depot and a cost per parcel at the microhub, which allows the user to reflect higher unit costs in small urban hubs.

Emissions are linked linearly to distance driven by fuel type of the vehicles. A well-to-wheel or tank-to-wheel emission factor in kg CO_2-equivalent per kilometers is assigned to diesel vans and to the trunk vehicles that connect the LSP depots to the microhubs. In the current Barcelona use case, cargo bikes are assumed to have negligible direct emissions. Total CO_2 emissions are therefore obtained as the sum of distance driven by vans and trunk trucks multiplied by the corresponding factors. Dividing by the total number of parcels gives CO_2 per parcel, which is used as a core KPI for the Impact Assessment Radar.

The trunk connection between depots and microhubs is represented in a simplified way using an average trunk distance per parcel. This parameter captures the typical line-haul required to move one parcel from the LSP depot to the microhub network, aggregated over all hubs. It can be calibrated from real operational data (for example average depot-hub distance and typical loading factors) or set from planning assumptions. The trunk leg contributes to both transport cost and emissions, and becomes more important when a large share of parcels is sent through the microhub system.

The main decision variables and scenario drivers that the model considers are therefore: the total service area A; the number of microhubs M; the number of LSPs and their daily demands D_l; the share α of each LSP's demand that is routed through microhubs; vehicle capacities Q_{van} and Q_{bike}; speeds and dwell times for vans and bikes; fuel and energy consumption parameters; labor costs per hour; and handling costs per parcel at depots and microhubs. For each combination of these inputs, the model produces a consistent set of indicators: cost per parcel for the direct LSP system and the microhub system, their breakdown into transport, labor and handling, total emissions and emissions per parcel, total kilometers driven by mode, total number of routes, and approximate fleet size by vehicle type.

Within the Impact Assessment Radar, the microhub evaluation model is used as a Level-2 quantitative tool to compare "design points" for the Barcelona Living Lab. By changing the number of microhubs, their coverage and the share of demand they handle, the partners can

explore how total cost per parcel and CO_2 per parcel evolve, and identify ranges where microhubs are operationally and environmentally attractive. The model is simple enough to be understood and adjusted by stakeholders, yet rich enough to support a structured discussion of trade-offs between cost, emissions and service effort. In the following sections the results of selected scenarios are presented through a set of plots showing the sensitivity of cost, emissions, kilometers and fleet size to the microhub design choices.

The microhub experiments show a very clear and almost linear trade-off between cost, emissions and the intensity with which the microhub system is used. For each area size (20, 50 and 80 km²) the baseline point at $\alpha = 0$, where all demand is served directly by LSP depots with vans, is identical across microhub configurations. As the share of demand routed via microhubs increases from 0 to 0.5, total cost per parcel rises with a slope that depends strongly on the number of hubs M. With only two hubs the cost penalty is substantial: for $\alpha = 0.5$, cost per parcel increases by about 23% in the 20 km² case, 28% in the 50 km² case and 31 % in the 80 km² case compared to the baseline. This corresponds to an increase of roughly 4.6–6.2 % in total cost per parcel for every additional 10 percentage points of demand sent through the micro hub system when M = 2.

As the number of hubs increases, the marginal cost of using the micro hub network drops sharply. For M = 4, the same 50 % microhub share leads to cost increases of about 10–13 %, or around 2.1–2.7 % per 0.1 step in α. When the network is denser (M = 6), the total cost impact becomes modest: the 0–0.5 shift in α raises the cost per parcel by only 4.7–5.5 % depending on area, which is equivalent to about 1.0 % per 10 percentage points of additional microhub volume. With eight hubs the system is almost cost-neutral: the total cost per parcel increases by less than 1.5 % over the whole range of α, with marginal increases below 0.3 % per 0.1 increment in α. In other words, by increasing M from 2 to 8 the marginal cost of shifting volume to microhubs is reduced by roughly a factor of twenty, even though the city area grows from 20 to 80 km².

Emissions per parcel show a very different pattern. For a given area size the CO_2 curves collapse into a single line for all values of M, because emissions are driven almost entirely by diesel vehicle kilometers and the microhub density does not change the total amount of van and trunk distance in the current formulation. What changes with α is the split between direct van delivery and low-emission cargo-bike tours. Across the three areas, increasing α from 0 to 0.5 reduces CO_2 per parcel by approximately 47–48 %, and the reduction is almost perfectly linear: each additional 10 percentage points of demand allocated to microhubs cuts emissions per parcel by about 9.3 - 9.7 %, regardless of the number of hubs. The microhub share therefore offers a powerful lever on emissions, and the plots show that very significant reductions are already achieved at intermediate penetration levels such as $\alpha = 0.3$–0.4.

The fleet plots help interpret what these percentage changes mean in operational terms. In the representative case with A = 50 km² and M = 4, moving from $\alpha = 0$ to $\alpha = 0.5$ halves the number of vans required for last-mile operations (from about 253 to 127 vehicles), while the number of cargo bikes increases linearly from zero to roughly 190 units. Each 10 % increment in α removes about 25 vans from the system and adds around 38 cargo bikes. Combined with the cost and CO_2 curves, this shows that at moderate to high microhub densities the operator can almost decouple emissions from total cost: a 40–50% reduction in CO_2 per parcel can be achieved with

only a few percentage points increase in cost per parcel, provided that enough hubs and cargo-bike capacity are deployed

5.2.2 ADV methodological Framework of long-term evaluation.

The evaluation of Autonomous Delivery Vehicles for last-mile logistics is constructed as a simplified continuous-approximation model that complements the microhub analysis in the Barcelona Living Lab. While the microhub model focuses on reconfiguring the depot and vehicle structure (urban hubs and cargo bikes), the ADV model evaluates the effect of introducing small, autonomous robots that perform short, direct trips with very low operating costs and no on-board labor. Within the Impact Assessment Radar this represents a Level-2 analytical tool that allows partners to test modest ADV penetration rates (for example 5 %, 10 % and 20 % of daily demand) and quantify their impact on costs, emissions and basic fleet requirements.

The starting point is the same demand representation as in the microhub model. The service area A denotes the urban zone under consideration in Barcelona, expressed in km². Within this area, a set of logistics service providers (LSPs) operates with a combined daily parcel volume D_{tot} (parcels per day). In the baseline all parcels are delivered by conventional diesel vans from one or more depots. The ADV scenario assumes that a fraction γ of the total demand is served by autonomous robots. For the current analysis, γ is treated as a scenario parameter taking values $\gamma = 0.05, \gamma = 0.10$ and $\gamma = 0.20$. The remaining fraction $1 - \gamma$ is still served by the existing van fleet under the same routing assumptions as in the baseline.

The ADV operating pattern is intentionally kept simple. Robots are modelled as small vehicles that carry one or a few parcels at a time (average load Q_{ADV}, typically in the range of 1-3). They do not perform long multi-stop tours as vans do (Garus et al., 2024). Instead, their work cycle consists of short, direct legs: an approach from their base to the pickup point (for example a depot, microhub or designated handover location), a direct trip from pickup to delivery, and then a repositioning leg towards the next pickup area. For the purposes of continuous approximation, each parcel served by an ADV is associated with an average distance travelled by the robot that can be expressed as a function of the spatial scale of the system. A simple and transparent way is to define an average ADV distance per parcel $l_{\text{ADV}}(A)$, which subsumes the expected depot-to-pickup, pickup-to-delivery and repositioning distances in a compact form. This parameter can be calibrated from pilot data (for example average robot trip distance observed in the Barcelona trials) or estimated using geometric arguments based on the area size and typical origin-destination patterns.

Under this representation, the total daily distance driven by ADVs is approximately

$$K_{\text{ADV}} = \gamma \, D_{\text{tot}} \, l_{\text{ADV}}(A),$$

since each of the γD_{tot} parcels assigned to robots generates on average $l_{\text{ADV}}(A)$ kilometers of robot movement. The corresponding travel time is obtained by dividing by the average ADV speed s_{ADV} (km/h). If one ADV operates during an effective working window H (hours per day), the number of robots required in the district can be approximated by

$$N_{\text{ADV}} = \frac{K_{\text{ADV}}}{s_{\text{ADV}} \, H},$$

which provides a simple indicator of fleet size for different market shares γ. Because ADVs are highly automated, the model assumes there is no driver labour cost associated with these movements. Supervision, control-room staffing and maintenance can be represented separately if desired, but they are not treated as a per-vehicle-hour labour term.

The residual van system is treated as in the microhub model but with reduced demand. For each LSP, only a fraction $(1-\gamma)$ of its parcels remains on conventional van delivery. If we denote the average van route length over the service area by $L_{\text{van}}(A)$ and the van capacity (parcels per route) by Q_{van}, the total van distance becomes

$$K_{\text{van}} = (1-\gamma)\, D_{\text{tot}}\, \frac{L_{\text{van}}(A)}{Q_{\text{van}}}$$

The detailed expression for $L_{\text{van}}(A)$ can be taken from the existing continuous-approximation formulation (for example $L_{\text{van}} = 2.5\sqrt{AQ_{\text{van}}} + 2r_{\text{eff}}(A)$), but the ADV model does not require expanding this further; it simply uses the fact that removing a share γ of the volume reduces van distance and van driving time proportionally. The total van hours follow directly from $K_{\text{van}}/s_{\text{van}}$, and the van fleet size is obtained by dividing by the working hours per vehicle.

Cost components are computed in a way that highlights the structural difference between vans and ADVs. For vans, the model keeps the same structure as before: transport costs from fuel consumption (liters per kilometers times fuel price), labor costs from driving time and wage per hour, and handling costs per parcel at the depot. These are all applied to the reduced van system with $(1-\gamma)D_{\text{tot}}$ parcels. For ADVs, transport cost is dominated by energy and maintenance. It is modelled as a cost per kilometers $c^{\text{km}}_{\text{ADV}}$ that includes electricity and basic maintenance, multiplied by the total ADV distance K_{ADV}. There is deliberately no per-hour labor term for ADVs, so labor savings can be quantified by comparing the van labor cost in the baseline with the van labor cost in the scenario with robots. Handling costs per parcel remain associated with the depot or microhub where the robot picks up the parcel; the ADV leg itself does not introduce extra handling beyond what is already accounted for at the node.

Emissions are linked to vehicle energy use. For the residual van system, a CO_2 emission factor in kg/km is applied to K_{van} as in the baseline. For ADVs, the emission factor depends on the electricity mix and vehicle efficiency; it can be expressed as kg CO_2 per km and applied to K_{ADV}. If a zero-emission assumption is adopted for small electric robots in a decarbonized electricity system, their direct emissions can be set to zero and the ADV leg only affects emissions through the reduced diesel van mileage. In both cases, dividing total emissions by D_{tot} yields a CO_2-per-parcel KPI that can be directly compared across the three market share scenarios.

The key inputs to the ADV model are therefore: total area A, total demand D_{tot}, market share γ (tested at 0.05, 0.10 and 0.20), average ADV distance per parcel $l_{\text{ADV}}(A)$, speeds s_{ADV} and s_{van}, working hours H, energy or fuel consumption parameters and emission factors, as well as the unit costs per kilometers and per hour. For each scenario, the model provides a coherent set of outputs: total distance and emissions for vans and robots, cost per parcel broken down into van transport, van labor, ADV transport and handling, and estimated numbers of vans and ADVs required. These indicators can then be used in the Impact Assessment Radar to illustrate under which demand shares and parameter ranges the introduction of ADVs delivers measurable cost

or emission benefits in the Barcelona use case, and to what extent labor savings and increased system complexity balance each other.

The ADV sensitivity analysis shows a very regular and almost linear improvement in cost performance as the ADV market share γ increases. For all three areas (10, 20 and 30 km²) the baseline at γ = 0, where all parcels are delivered by vans, is the most expensive configuration in terms of cost per parcel. As 5 % of the demand is shifted to robots (γ = 0.05), total cost per parcel falls by about 4.8 % in the 10 km² area, 4.8 % in the 20 km² area and 4.8–4.9 % in the 30 km² area. At 10% ADV share (γ = 0.10) the reduction reaches roughly 9.6–9.7 % compared with the baseline. When 20% of the demand is handled by ADVs (γ = 0.20), cost per parcel drops by about 19.3% in the 10 km² case, 19.2 % in the 20 km² case and 19.1 % in the 30 km² case. In other words, every 10 percentage points of ADV penetration reduce cost per parcel by almost 9.5–10%, and this relative effect is remarkably stable across different area sizes. However, there is a upper bound on the number of robots a company can operate in parallel and a city can integrate.

The underlying mechanism is straightforward. Van kilometers and van hours decrease in proportion to the residual demand $(1 - \gamma)$, which cuts both fuel and labor costs. ADVs introduce an additional transport cost term that is proportional to their distance travelled, but this cost consists only of energy and maintenance, without an associated driver wage. In the parameterisation used for the Barcelona case the ADV cost per kilometers is significantly lower than the combined fuel and driver cost of a van kilometre. As a result each parcel that shifts from van delivery to an ADV generates a net saving. The near-perfect linearity of the curves reflects the linear structure of the model as the routing costs are proportional to distance, distance is proportional to volumes, and so the share γ enters only as a scalar split of demand between the two technologies.

Emissions per parcel follow an even simpler pattern. Since ADVs are assumed to have zero direct emissions, the total CO_2 per parcel is directly proportional to the share of demand that remains on diesel vans. For every area, increasing γ from 0 to 0.05 reduces emissions per parcel by exactly 5 %, to 10 % at γ = 0.10, and to 20 % at γ = 0.20. This holds for all three area sizes. Larger areas start from a higher CO_2 baseline because van routes are longer, yet the percentage reduction is fixed by the model structure and equals the percentage of demand that is transferred to zero-emission robots. The ADV share therefore acts as a very clean control knob on emissions: every 1% of volume that moves to ADVs reduces last mile CO_2 per parcel by 1%.

The fleet estimates complete the picture from an operational point of view. In the 20 km² case, for example, the van fleet requirement falls from about 44.5 vehicles at γ = 0 to around 35.6 vehicles at γ = 0.20, which is a reduction of roughly 20 %. At the same time, the ADV fleet grows from zero to about 80–81 operating units. Similar proportional changes are observed in the other areas. This confirms that the cost and emission gains are not coming from a reduction in service effort, but from a shift in how that effort is provided. Vans gradually give way to robots that provide the same delivery function with much lower variable cost and, in this setting, no tailpipe emissions. However, the acquisition cost of a robot and operational software costs might affect the break-even point significantly.

6. Lessons Learnt and Key Outcomes

This section synthesizes the main lessons and key outcomes. It combines the detailed experiences from Barcelona and Karlsruhe with the broader methodological insights and framework developed in the project. From the transferability point of view, the main lessons derived are that Living Labs are not only useful for piloting. Beyond the qualitative lessons, the transferability activity delivered several concrete outcomes that are relevant for future deployments and for the wider URBANE ecosystem.

- The concept of separating context related pillars from implementation and performance related pillars and combining them into indicators such as the Transferability Performance Index and the Context Difficulty Factor, proved useful for interpreting results. Cities with lower contextual scores can still achieve good transferability performance if they invest in coordination, capacity building and careful piloting, but they require more support.
- The open architecture design of the Digital Twin, routing tools and traceability components has shown that modules developed in one context can be re-used with relatively limited adaptation elsewhere. The main changes concern data integration, parameter values and user interfaces rather than core algorithms. These outcomes collectively demonstrate that the URBANE approach is not a collection of isolated tools. It is a coherent toolbox that can support cities at different stages of readiness and with different priorities, provided that context is understood and engagement is maintained.
- The pilots provided quantified evidence of environmental and operational benefits. In Barcelona, the combination of electrified first mile and cycle logistics reduced emissions significantly while lowering handling times and improving traceability. In Karlsruhe, the modelling showed that tram based logistics with electric robots can offer a low emission alternative to diesel based last mile operations, especially when the energy mix is already decarbonized.

In addition, Karlsruhe LL made very clear that non-technical constraints can dominate the pace and feasibility of transfer. Integrating freight operations into an existing public transport system raises legal, safety and organizational questions that city administrations and operators cannot answer alone. The project partners had to engage with external authorities such as the regional technical supervisory authority and the national rail agency. The objective was to clarify under which conditions passenger and freight services can share infrastructure and rolling stock, which safety standards apply and how responsibilities are allocated in case of incidents.

The main lessons for transferability are:

- Early mapping of the regulatory landscape is essential. Cities need a clear overview of relevant laws, safety standards, labor regulations and data protection obligations before they define detailed pilots. This mapping should be documented in an accessible manner for all actors in the ecosystem, including private operators and technology providers.

- Institutional procedures move slower than pilot timelines. Project planners must accept that regulatory change, or even the creation of temporary exemptions and experimental permits, often requires formal decisions at higher administrative levels. This cannot be fully controlled by the consortium. It must be anticipated and treated as an external constraint.
- Long term policy goals and strategies matter as they reduce implementation variance. Concepts such as climate neutrality targets, Sustainable Urban Mobility Plans, Sustainable Urban Logistics Plans and commitments to zero emission zones create a stable direction of travel. This gives operators and technology providers the confidence to invest in new solutions, even if regulatory details are not yet fully resolved.

A concrete outcome of the transferability activity is the recognition that any scaling strategy must combine technical deployment plans with a regulatory roadmap. This roadmap should identify which aspects are under local control, which require regional or national engagement, or even depend on European standardization or guidance. It should also link the innovations to the systemic challenges and long-term goals of the city. Without this alignment, pilots remain isolated experiments that are difficult to justify in the political arena.

In terms of public perception and acceptance of new last mile deliveries services models and/or vehicles, these are not automatic, but they can be very supportive when innovations are framed correctly and when they respond to visible urban challenges. This leads to three practical conclusions regarding systemic readiness:

- Use cases must be screened for hidden social functions. Cities and operators should analyze who benefits from the human presence associated with a service and what would be lost if this presence is removed. Automation is better directed towards functions that are mainly technical or that free up human time for higher value interactions.
- Communication with citizens must be transparent and proactive. New technologies in public space, such as robots or sensors, can generate distrust if their purpose is unclear. The Living Lab approach, with public events, demonstrations and open channels for feedback, proved to be an effective way to build legitimacy.
- Ecosystem engagement cannot be a one-off consultation phase. It must be continuous, from initial problem framing to pilot design, implementation, evaluation and redesign. Living Labs offer this continuity if they are properly resourced and anchored in local institutions.

Finally, experiences in Barcelona and Karlsruhe, and their integration into the URBANE framework, lead to a set of recommendations for future transferability efforts in other cities:

1. **Start from context and long-term goals.** Before selecting specific innovations, cities should clarify their systemic challenges, long term climate and mobility targets and their current ecosystem readiness. This alignment creates clear motives for operators and technology providers and makes pilots part of a broader transition pathway.
2. **Design solutions as open, modular systems.** Use open-source components where possible, define clear APIs and data models, and document configuration guidelines. This

reduces adaptation costs and makes it easier to integrate with local ICT infrastructures and data spaces.

3. **Identify sub processes that require local adaptation.** Use process mapping to identify which elements of the innovation are generic and which are context dependent. For example, parcel loading procedures, handover points between modes or robot operating zones may need to be redesigned for each city. Build explicit adaptation strategies for these sub processes into the transfer plan.
4. **Invest in data pipelines and model calibration.** Ensure that basic operational data can be collected and shared in a structured way. Use pilots to calibrate models but keep model structures generic. Maintain a feedback loop where new data continuously improves predictions and supports decision making.
5. **Treat regulation and institutions as integral parts of the design.** Include legal experts and relevant authorities from the beginning. Prepare a regulatory roadmap that clarifies which approvals are needed, at which level, and within what expected timeframe. Avoid framing regulatory issues as external obstacles. Instead, treat them as co designed work packages.
6. **Integrate social dimensions in use case selection and evaluation.** Screen for hidden care functions or social roles. Prioritise automation in areas where it frees human resources for tasks that require empathy, judgment or complex interaction. Include indicators on social inclusion and local economic resilience in the evaluation framework.
7. **Use Living Labs as the coordination backbone.** Anchor the transferability process in a Living Lab or similar structure that can convene stakeholders over time, manage expectations and facilitate joint learning. Equip this structure with the tools and frameworks developed in URBANE so that they become part of the standard way of working.

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