https://doi.org/10.52326/csd2025.57

IMPLEMENTATION OF EUROPEAN INNOVATIONS IN LAST-MILE LOGISTICS: OPPORTUNITIES FOR ADAPTING BEST PRACTICES TO FOSTER THE SUSTAINABLE DEVELOPMENT OF E-COMMERCE

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Abstract. The study examines contemporary trends in the development of last-mile logistics in the context of the sustainable development of e-commerce and the implementation of European innovative practices. Particular attention is given to the Polish InPost model as a successful example of delivery automation and the introduction of environmentally oriented solutions. The experience of Poland is compared with the practices of Germany and the Netherlands, where digital platforms, electric vehicle and bicycle delivery networks, as well as hybrid distribution models, are actively evolving. It is shown that these practices can be adapted and implemented for the restoration of logistics infrastructure and the digital transformation of e-commerce in post-war Ukraine. The authors have also explored the possibilities of using best practices to accelerate the modernization of logistics in Moldova as a developing market. The necessity of flexible adaptation of European models, taking into account institutional, infrastructural, and economic differences, is emphasized. The implementation of innovative solutions, including automated parcel lockers, IoT sensors, and artificial intelligence technologies, is considered as an instrument for sustainable development, enhancing competitiveness, and reducing the carbon footprint of transport operations.

Keywords: *cross-border fulfillment, digital commerce, distribution networks, electric vehicle delivery, out-of-home delivery, parcel lockers, supply chain management, urban freight transport, zero-emission zones*

JEL code: *L81, L86, L91, R41, Q55, M11.*

At present, in the era of the rapid development of electronic commerce (e-commerce), where the global volume of online sales in 2025 exceeded USD 6.4 trillion with a further annual increase forecast, last-mile logistics emerges as a critical point determining not only operational efficiency but also the environmental sustainability of the ecosystem as a whole [1]. Thus, according to Capgemini, about 41% of total supply-chain costs fall precisely on the last mile [2]. At the same time, scenario assessments by the World Economic Forum emphasize that, without systemic interventions, by 2030 urban deliveries may increase CO_2 emissions and congestion by approximately 30% under a continued inertial (business-as-usual) scenario of development [3]. In this regard, the implementation of a package of comprehensive measures—including electrification, the introduction of the OOH model, consolidation, and algorithmic routing—will, in the authors' view, make it possible to reverse this dynamic.

In the context of sustainable development, examined in depth by the authors of this study, European innovations used by other countries as benchmarks—ranging from automated parcel lockers to networks of electric-vehicle and bicycle delivery—have manifested themselves not merely as technological solutions, but also as strategic instruments for minimizing negative anthropogenic impact, optimizing transport and logistics resources, and increasing national competitiveness. These comprehensive measures, adapted with regard to local contexts, can become a catalyst for the restoration of logistics in post-war Ukraine and for the modernization of the development of e-commerce in Moldova (with a focus on EU integration through DCFTA), contributing not only to ecological transformation, but also to GDP through the scaling of green supply chains. Undoubtedly,

the implementation of the above-mentioned innovations conditions the necessity of employing effective instruments for the flexible adaptation of all participants in the logistics system, the elimination of institutional barriers, the expansion of the horizon of public-private partnership, and the creation of special preferences and incentives for strategically significant investors.

The authors of the study focus attention on contemporary trends in last-mile logistics in Europe. In 2024–2025 a number of European markets are undergoing a noticeable transformation following the growth of e-commerce. At the same time, the “last mile” remains the most cost-intensive link: according to Capgemini, about 41% of total supply-chain costs fall precisely on the last mile (a threshold benchmark; values vary by industries and countries) [4]. For the purposes of analyzing the last-mile market and its CAGR for the leading European countries that are proposed by the authors of the study as benchmarks, it is advisable to rely on validated industry indicators, namely: the growth of OOH/lockers, the dynamics of retailers’ costs, electrification/micromobility, and the deployment of digital platforms.

Key trends on which attention is focused:

- *diversification of carriers and OOH-delivery.* Thus, according to the results of 2023, more than 155,000 parcel lockers were operating in Europe (≈+29% year-on-year), and about 44% of European e-shoppers chose OOH options (lockers/PUDO) when such an option was available. Therefore, it can be stated with confidence that this is becoming a stable consumer habit rather than a niche practice. In 2025, according to Geopost, lockers ranked second by preference among delivery methods [5]. At the same time, 84% of business entities in Europe and the United Kingdom noted an increase in last-mile costs in 2024, which strengthens interest in OOH scenarios and consolidation [6].

- *greening and urban policy.* Scenario models of the World Economic Forum show that a package of measures (OOH/lockers, consolidation, EV/LEFV, algorithmic routing) is capable by 2030 of reducing CO_2 emissions and congestion by ~30% relative to the inertial scenario, as well as of cutting costs. In parallel, EU cities are scaling up profile initiatives (including such as POLIS/Green-Log; pilots of digital twins in the LEAD project, author’s note) [3].

- *digitalization (AI/IoT) and operational efficiency.* First and foremost, it is a matter of the fact that OOH eliminates a significant share of repeat trips: in dense cities up to ~20–25% of first attempts at home delivery may end in failure, whereas lockers practically eliminate this risk, converting delivery into “a single run” [7]. At the same time, AI/IoT instruments in last-mile logistics demonstrate double-digit improvements in reducing “empty” kilometers and stabilizing SLA. The cases analyzed by the authors indicate a reduction of empty mileage by ~10–15% in adjacent segments, which results in lower fuel costs, more economical consumption of it, reduced emissions, and better utilization of transport capacities [8].

Within the framework of this study, OOH (out-of-home) delivery is construed as the receipt/sending of parcels outside the recipient’s home address: primarily through APM/parcel lockers (automated parcel machines) and PUDO points (pick-up/drop-off points), integrated with digital platforms (in-app notifications, contactless access, slots, etc.). This differs fundamentally from traditional home delivery in that the last mile is reallocated toward the consolidation of stops and the reduction of the “last meters,” that is, the costliest and carbon-intensive segment of the route.

A logical question arises: why are OOH/lockers a systemic instrument of sustainability? First, due to the consolidation of dozens, and at times hundreds, of deliveries that are closed at a single point, thereby reducing total mileage and the density of stops. Second, due to a sharp reduction in repeated delivery attempts. Third, the integration of OOH + electrified and micromobility delivery (EV/LEFV) + AI/IoT routing makes it possible to create a cumulative effect, namely: scenario models of the WEF show the potential for double-digit reductions in emissions and costs while simultaneously improving SLA and the predictability of urban traffic [9, 10].

Presented below is a summary table of the key trends in last-mile logistics in Europe (2024–2025), aggregating the key indicators on the development of OOH/lockers, the impact on costs, the share of the “last mile” in expenditures, electrification/micromobility, and the deployment of AI/IoT (Table 1). The table separates factual data for 2024 and directions/expectations for 2025–2026,

recording the presumed impact on sustainability (in particular, cost, mileage, CO_2, SLA, author's note). It should be noted that the factual data may vary across EU countries; however, the values used reflect the most representative European estimates and corporate reporting data.

Table 1. Key trends in last-mile logistics in Europe (2024–2025)

Development trends	Assessment of development as of 31.12.2024	Forecast/direction of development for 2025–2026	Impact on sustainable development
OOH/lockers (out-of-home)	In Europe by the end of 2023 — ~155 thousand parcel lockers (+29% YoY); ~44% of e-shoppers choose OOH when the option is available	Lockers become No. 2 by popularity as a delivery method in Europe (after home delivery)	Consolidation of stops, fewer "empty" trips and repeat attempts, reduction of mileage/CO_2
Impact on last-mile costs	84% of companies in Europe and the United Kingdom noted an increase in last-mile costs in 2024	The impact stimulates a shift to OOH, multi-carrier models, and tariff segmentation	The shift to OOH/consolidation and digital orchestration reduces cost per parcel and carbon intensity
Share of last mile in costs	≈41% of total supply-chain costs fall on the last mile	Remains a key bottleneck; focus on optimization through OOH/AI/EV	Reduction of the share through consolidation and electrification; potential for a noticeable decrease in CO_2
Electrification and micromobility	Scaling of EV fleets among operators: DHL Group reports >42 thousand EVs for delivery operations	Further expansion of EV/LEFV and the introduction of ZEZ (zero-emission zones) in a number of EU cities	Reduction of tailpipe emissions; in conjunction with OOH — cumulative reduction of CO_2 per parcel
Digitalization (AI/IoT)	Transition from pilots to production deployments: cases demonstrate a 10–15% reduction in "empty" kilometers due to dynamic routing	Real-time algorithms are scaled (ETA, capacity, time windows, risk-scoring)	Less mileage, higher stop density, double-digit reductions in costs/emissions in conjunction with OOH/EV
Urban policy and sustainability scenarios	WEF: without measures, growth of emissions/congestion by 2030; a package of measures (OOH+EV+algorithms) reduces CO_2/congestion by ~30% vs. "do-nothing"	EU cities activate projects of sustainable urban logistics, scaling best practices	Systemic reduction of emissions/congestion while improving SLA

Subsequently, the authors conducted an in-depth analysis of advanced foreign practices along three complementary trajectories of last-mile development. In particular, the Polish InPost model was examined, which demonstrates the scalability of OOH-infrastructure (parcel lockers/PUDO) and process automation as the basis for reducing costs and stabilizing SLA. German cases were also studied (in particular, DHL and others), which illustrate how electrification and hybrid distribution schemes (in this case, EV + algorithmic routing, author's note) make it possible to optimize the cost structure and the carbon profile without deterioration of the customer experience. The Dutch experience was likewise analyzed as a benchmark, which demonstrates the potential of micromobility and bicycle networks in dense urban fabric and ZEZ zones. Taken together, these practices act as referent models in the formation of KPIs and adaptation roadmaps.

We begin with an assessment of the Polish experience. In the authors' view, InPost is the largest operational example in Europe of a scalable OOH paradigm. Thus, in 2024 the company processed ≈1.09 billion parcel deliveries (+22% YoY), confirming that the consolidation of the last mile through APM/locker networks can sustain double-digit growth rates with high SLA reliability. At the same time, the network of automated parcel machines reached 46,977 locations at the end of 2024, and in 2025 the company continued to increase capacity and volumes (in particular, in Q1 2025 272 million parcels were dispatched, of which 174.2 million within the territory of Poland) [11, 12].

It should also be noted that the development strategy of InPost is aligned with the scenario agenda for achieving sustainability indicators. Thus, the analytical data indicate a double-digit reduction in CO_2 per parcel (≈13–32%) when substituting address delivery with lockers in dense urban networks. Consequently, it can be affirmed that the InPost model is not only about strategic

goals of scaling and obtaining economic results, but also about goals of structural compatibility with the climate policy of the EU [3, 9].

Thus, the benchmarking of Poland rests on: (1) the scale of the network and the dynamics of volumes (operational feasibility of OOH under peak load); (2) internationalization (transfer of the model from Poland to the UK/FR/EU markets without loss of efficiency); (3) integration with consumer preferences (the growth of the OOH share as a behavioral norm); (4) environmental effectiveness in conjunction with EV/algorithms; (5) competitive resilience (pressure from marketplaces developing their own locker networks—a risk factor that the model must take into account). On this basis, it is appropriate to use InPost as a referent model for countries with tasks of scaling e-commerce and decarbonizing urban logistics (including for the post-war reconstruction of Ukraine, author’s note), with adaptation to legal frameworks, the distribution of demand density, and the structure of partnerships (PPP).

In the authors’ view of this study, the German experience can serve as a validated benchmark for the transition to a low-carbon “last mile,” since it combines large-scale fleet electrification with hybrid operational models (namely, the use in deliveries of e-vans + cargo bikes/micro-hubs + algorithmic routing based on AI/IoT, author’s note), which rests on a mature CEP market [13, 14]. In this context, it is appropriate to focus on the largest operator—DHL Group, which as of September 2025 operates over 42,000 electric vehicles for the collection and delivery of parcels worldwide. Such indicators confirm the technological and operational feasibility of e-deliveries at large scales and form a kind of “umbrella” for the operations of Post & Parcel Germany (P&P DE). At the same time, in July 2025 it was announced that 2,400 new Ford Pro E-Transit / E-Transit Custom vehicles would be delivered for P&P DE by the end of that year, amounting in total to about 4,900 Ford e-vans in the divisions, and a further increase of the overall e-fleet of P&P DE is planned [15, 16]. All this demonstrates a managed “rhythm” of ramping up the volume of operations and the market, as well as the integration of electrification with the operational optimization of the last mile. In parallel, implementation is being carried out in segments of particular complexity (in particular, within the framework of large-size freight deliveries). Thus, in February 2025 DHL 2-Mann-Handling put 21 e-vans into operation in a number of German states, and Hermes since the end of 2023/beginning of 2024 has been ensuring fully emission-free delivery in Hamburg while using approximately 176 e-vans and 8 e-cargo bikes [17, 18]. The foregoing demonstrates that the electrification of deliveries is possible even in dense urban areas, provided that the infrastructure is modernized and routes of goods logistics are organized in a progressive manner [19]. At the level of the macro-context regarding development potentials, it is appropriate to cite data on the CEP market of Germany: its size is estimated at ≈ USD 29.5 billion (2025), which sets a realistic economic framework for scaling solutions [20].

In terms of content, Germany’s development trajectory in the context of the issue under study is consistent with the scenarios of sustainable urban logistics: packages of measures that include OOH/lockers, electrification (EV/LEFV), and algorithmic routing are capable of significantly reducing CO_2 emissions and congestion. It is precisely such a “hybrid” (EV fleet + digital orchestration + reliance on nodal pick-up points, author’s note) that makes German practices representative for use as a benchmark. The analytical assessments demonstrate the compatibility of technological solutions with urban policy (including ZEZ) and confirm that a reduction in carbon intensity can be achieved without deterioration of SLA and with a controllable unit cost of delivery. Consequently, the German case is appropriate for use as a referent model for countries planning an accelerated electrification of the last mile and its integration with OOH/micromobility on a mature digital basis [3].

In the authors’ view, it will be rational to use the German benchmark for the post-war restoration of Ukraine’s logistics system as a hybrid of the EV model + OOH/micro-hubs + algorithmic orchestration, however, with due regard for phased remediation, the restoration of damaged facilities, and the smooth adaptation to innovations of this type. First and foremost, it is advisable to begin with the scaling of depot charging (overnight) for e-vans and micro-hubs in the

main logistics corridors (in such cities as Kyiv, Lviv, Dnipro), combined with the accelerated deployment of the OOH network (APM/PUDO) on retail/shopping center/railway station sites.

For Moldova, taking into account the lower density of demand and cross-border logistics, it will be rational to implement the German approach in a lightweight version, namely the scaling of the use of e-vans with depot charging + cargo bikes in the center of Chișinău + a nodal OOH network on partner sites (we are speaking primarily about supermarkets and filling stations, author's note), organically integrated with cross-border corridors (RO/EU). In the authors' opinion, the priority may be minimal CAPEX through PPP and leasing, the unification of digital processes (including e-CMR/e-invoicing, track & trace, etc., author's note), and multi-carrier operations through open interfaces, in order to be able optimally and quickly to achieve the effect of consolidation as with DHL/Hermes.

The experience of the Netherlands in the context of organizing parcel delivery logistics turned out to be rather unique. The authors of the study examined the experience of using the bicycle network and micromobility as a benchmark.

The Netherlands demonstrate an institutionally and operationally mature model of micromobility last mile, in which bicycle networks/cargo bikes and electrified vans (EV) are successfully integrated with the policy of zero-emission zones for urban freight transport (ZEZ) and with the digital orchestration of routes. Thus, from 1 January 2025 the country introduced ZEZ in at least 15 cities with subsequent expansion to 29 municipalities (within development programs up to 2030, author's note). This framework demonstrates an acceleration of the substitution of internal combustion engines in delivery and stimulates the shift of part of the "last meters" to LEFV/e-cargo bikes [21, 22, 23].

Thus, at the level of operators PostNL declared the following goal: "zero delivery emissions in at least 27 city centers by 2025" and a target of emission-free last mile by 2030 (from the sorting center to the recipient/OOH point) [24].

At the same time, the market of specialized bike operators is developing in parallel. In this context, it is appropriate to note the Fietskoeriers.nl network, within which 35 hubs operate, as well as 750 couriers who handle 15,000+ parcels per day, which indicates a stable operational capacity of bicycle delivery in large and medium-sized cities [25].

Data from scenario studies show that, with a high share of cargo bikes in dense city centers and the performance of the remaining delivery volume using EV vans, significant savings in mileage/costs and reductions in emissions are achieved. In particular, in one of the reviews for the Netherlands it is modeled that, at approximately 80% share of cargo bikes in dense city centers, the economic effect and decarbonization are maximal [26, 27]

Summarizing all of the above, it can be asserted that the linkage ZEZ → electrification → micromobility → digital routing/OOH forms a transferable "hybrid" configuration in which unit-cost and CO_2 per parcel decrease simultaneously, while network nodes (lockers/PUDO) increase stop density and reduce the share of re-deliveries.

In the authors' view, the Dutch experience can in the future be transformed in Ukraine into a hybrid configuration of "e-cargo bikes + EV vans + OOH nodes (parcel lockers/PUDO) + micro-hubs," relying on the phased introduction of urban windows/logistics corridors with zero emissions (ZEZ) in the central districts of large cities. At the first stage, it will be advisable to deploy a network of micro-hubs at the junction of trunk and intra-urban flows, reassigning the "last meters" to e-cargo bikes and partially to walking/bicycle delivery to OOH points. At the second stage, to scale the OOH network with the integration of algorithmic routing (ETA/slotting/capacity) and the unification of APIs for multi-carrier operations.

For Moldova, as a country with lower demand density and pronounced cross-border logistics (RO/EU), a targeted implementation and adaptation of the Dutch model will be effective. In the authors' opinion, it will be appropriate to deploy a project for the introduction of micromobility in the center of Chișinău (e-cargo bikes + micro-hubs) in combination with EV vans on feeder legs, a rapidly scalable OOH network on partner sites (in particular, on the premises of supermarkets, filling

stations, transport hubs, author’s note), followed by the introduction of e-CMR/e-invoicing/track & trace as the digital foundation.

As a result of the conducted study, the authors formulated the following conclusions and generalizations. At present, the problem of increasing the sustainability and efficiency of the “last mile” in electronic commerce is particularly urgent and significant, since it is precisely this segment of the supply chain that forms the largest share of transactional costs, creates peak loads on urban infrastructure, and determines the carbon intensity of delivery. A comprehensive analysis has shown that sustainable trajectories for scaling e-commerce rest on three mutually complementary blocks: (1) OOH infrastructure (parcel lockers/PUDO) as a mechanism for consolidation and the reduction of re-deliveries; (2) electrification and micromobility (EV/LEFV, e-cargo bikes) as the basis for decarbonization and the reduction of noise and particulate pollution in cities; (3) digital orchestration (AI/IoT routing, slotting, ETA, open APIs for multi-carrier operations) as an instrument for increasing stop density and the predictability of SLA while controlling unit-economics. As a result of the analysis of development trends, it is proposed to use the experience of Poland (a scalable OOH model—InPost), Germany (industrially validated electrification and hybrid delivery models), and the Netherlands (micromobility in conjunction with urban ZEZ policy) as benchmarks for designing national development roadmaps.

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