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Unravelling the last-mile conundrum: A comparative study of autonomous delivery robots, delivery bicycles, and light commercial vehicles in 14 varied European landscapes

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ABSTRACT

In this study, the growing need for efficient delivery services in the expanding e-commerce sector is addressed, with a focus on real-life consumption data. A comprehensive modelling framework is proposed to evaluate the efficiency of various transportation modes, including Light Commercial Vehicles (LCVs), cargo bicycles, and Autonomous Delivery Robots (ADRs). Utilizing the Google API, delivery destinations are identified, origin-destination matrices are created, and routes are optimized using Google OR-Tools and a capacitated vehicle routing problem solver. The study's robustness is further enhanced by incorporating real-life consumption data, considering diverse European contexts, varying urban scales, traffic patterns, and topographical factors, thus assessing their impact on transportation efficiency. The findings reveal that ADRs are efficient in pedestrian-focused, traffic-limited areas, while bicycles are more effective in dense city centres. This research highlights the necessity of tailoring transportation mode choice to specific urban characteristics for optimal efficiency and consumer satisfaction.

Overall, the present study offers valuable insights into optimizing delivery services in different urban settings, providing a significant model for improving last-mile delivery systems. It contributes to understanding how different transportation modes can be effectively integrated into urban logistics, addressing environmental sustainability, operational efficiency, and real-life consumer demands.

1. Introduction

The e-commerce industry is rapidly expanding, resulting in the transportation of small packages in high volumes, with varying frequency, which presents significant challenges for logistics providers (Ghajargar et al., 2016). The shift towards business-to-consumer (B2C) e-commerce is further increasing the demand for logistic services in cities. In 2020, e-commerce grew two to five times faster than before in countries such as the United States, China, United Kingdom, Spain, Germany, India, France, and Japan (Lund et al., 2021). Compared to traditional markets, e-commerce poses new challenges for companies and stakeholders, particularly in the complexity of logistics, especially the last-mile delivery, which involves delivering products from transportation hubs to final customers (Allen et al., 2018). The last-mile is the least efficient and most expensive stage of the delivery process due to challenging service levels, small orders, and a high dispersal of destinations (Macioszek, 2018). To improve the efficiency and sustainability of urban and rural delivery operations, the field of last-mile logistics has witnessed a surge of innovations (Lund et al., 2021). With the rising demand for e-commerce and the need to address environmental concerns, the focus on optimizing last-mile delivery services has become increasingly crucial.

To this end, one relevant line of research concerns evaluating the impacts of new mobility solutions in last-mile delivery contexts. Various studies utilize multi-criteria decision-making analysis (MCDA) to explore delivery methods involving mobile depots and cargo bicycles (Verlinde et al., 2014), as well as alternative urban freight systems (Navarro et al., 2016). More recently, comparisons have been made

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between diesel LCVs, eLCVs, and electric tricycles using a custom framework (de Mello Bandeira et al., 2019), and between diesel LCVs and battery electric vehicles using life-cycle assessment (LCA) (Giordano et al., 2018). In the realm of automated freight, research has focused on drone-supported delivery using a green vehicle routing problem (GVRP) (Chiang et al., 2019), as well as assessing the impact of ADRs on freight efficiency (Garus et al., 2022; Jennings & Figliozzi, 2019a).

While numerous studies have delved into various aspects of last-mile logistics and alternative delivery methods, a significant research gap remains in conducting a comparative analysis of the daily operational functionality across different last-mile solutions. Specifically, there has been limited investigation into the integration of ADRs into existing delivery systems. Additionally, existing research predominantly relies on simulations rather than empirical studies in this area. Furthermore, there is a lack of similar studies that comprehensively explore various different-sized European locations to assess the impact of scale on delivery operations and determine the most suitable method for each location.

The dynamic evolution of last-mile delivery worldwide, under the influence of globalization and technological advancements, has led to the emergence of comparable solutions across diverse countries. This trend reflects a global commitment to enhancing the efficiency of last-mile logistics. Europe's regulatory framework, characterized by openness to public scrutiny and engagement, offers valuable insights for policymakers and industry stakeholders worldwide. By examining European approaches, stakeholders can gain valuable lessons on overcoming challenges and implementing effective last-mile delivery strategies.

In response to the rapidly expanding e-commerce market, this paper aims to contribute to the growing body of research by conducting, in various European environments, a comprehensive comparison of three distinct last-mile delivery services: Light Commercial Vehicles (LCVs), cargo bikes, and Autonomous Delivery Robots (ADRs). While LCVs and cargo bikes are already established as popular solutions, the study also addresses the emerging trend of ADRs, which are relatively under-researched despite being increasingly deployed for delivery operations. This comparison reveals the most efficient service among the three, considering diverse urban and rural landscapes across Europe.

To achieve this, a robust modelling framework has been developed that enables a comparative analysis of the total duration of deliveries and the corresponding distances travelled. The investigation includes 14 different European environments, encompassing a diverse range of urban and rural settings. The cities selected for this study include mega cities, large capitals, smaller capitals, mid-sized and small cities, and a rural area. Furthermore, representation from multiple European countries has been ensured, considering variations in infrastructure, regulations, and cultural aspects. To account for the varying topography across the chosen locations, cities with flat terrains as well as others with hilly landscapes have been taken into consideration. By considering those diverse environmental factors, insights into the applicability and effectiveness of different last-mile delivery solutions across various European contexts are aimed to be provided.

By comparing the performance of these three last-mile services, an intention is set to shed light on their respective strengths, weaknesses, and overall effectiveness in diverse European environments. Additionally, the analysis of delivery durations, distances and costs could provide valuable insights into the feasibility and efficiency of each solution, facilitating informed decision-making for stakeholders in the last-mile delivery ecosystem. Furthermore, by including a rural area in the study, the aim is to explore the applicability and potential challenges faced by these delivery services beyond urban settings, where the infrastructure and requirements may differ significantly.

In summary, the contributions of this paper include:

- Studying the daily functionality of ADRs and comparing them with traditional delivery methods using real consumption data of ADRs.
- Examining the logistical operations in 14 European cities of different sizes.
- Considering topographical diversity, from flat terrains to hilly landscapes, encompassing varied urban and rural environments to evaluate how geographical conditions would affect various modes of transportation.
- Supporting informed decision and policy making through a detailed impact analysis providing insights on how to address challenges and implement effective last-mile delivery strategies to industry stakeholders and policymakers worldwide.

The subsequent sections of this paper will delve into the previous literature review on the last mile delivery operations, following the methodology employed, the findings of the analysis, and the implications for the future of last-mile delivery services.

2. Literature review

Last mile logistics is part of a complex freight transport system interrelated with a variety of urban ecosystems. In order to increase efficiency and support growing environmentally conscious movements, numerous companies already use solutions such as tricycles or bicycles (also known as cargo bicycles) and alternatively fuelled vehicles (mainly electric or hybrid LCVs) or even vehicles typically reserved for movement of people such as trams (Pietrzak & Pietrzak, 2021). Moreover, high grossing companies (such as Amazon, DHL or Google) or entirely new start-ups (such as Starship or Yape) have started to test out innovative solutions like unmanned aerial vehicles (also known as drones) and ADRs moving on land (Shaheen & Cohen, 2020). ADRs fall into one of three categories based on their design and operational capabilities: Sidewalk Automated or Autonomous Delivery Robots (SADRs), Road Automatic or Autonomous Delivery Robots (RADRs), and Autonomous Delivery Vehicles (ADVs) (Ionita, 2017; Jennings & Figliozzi, 2019b). ADR-based deliveries may also depend on infrastructures such as robot depots and stations and conventional vehicles like motherships (Simoni et al., 2020). The first category, Sidewalk Automated Delivery Robots (SADRs), operate primarily on sidewalks and navigate amidst pedestrian traffic. They are smaller in size and slower in speed, making them ideal for highly pedestrianised urban areas where road access is restricted. The second category, Road Automatic Delivery Robots (RADRs), are designed to travel on roads, often alongside other vehicles. These robots are larger and faster than SADRs, suitable for environments where road use is necessary for efficient delivery, such as suburban areas or less congested city streets. The third category, Autonomous Delivery Vehicles (ADVs), represents the largest and most advanced type of ADRs. These are autonomous vehicles equipped for cargo delivery and are capable of navigating both roads and highways. Their larger size and advanced navigation systems make them suitable for long-distance deliveries or for transporting larger parcels that smaller ADRs cannot handle. Each of these ADR types offers unique advantages depending on the specific requirements of the delivery task and the urban context, such as SADRs being more efficient in dense, pedestrian-rich environments, RADRs balancing the need for road travel and compactness, and ADVs excelling in longer-distance deliveries requiring larger cargo space.

With last mile delivery gaining significance, researchers have turned their interest towards its broad impacts. A literature review conducted by Kiba-Janiak et al. (2021) suggests that, before the popularization of e-commerce in 2016, a limited number of studies focused on optimising traditional last-mile solutions, whereas, after 2016 and the establishment of the e-commerce industry, a steeply growing number of academics focused on introduction and analysis of innovation in last mile delivery solutions. A further study connecting external factors impact on e-commerce and following environmental implications was proposed by Cheba et al. (2021). The authors found a link between internet and mobile access, macroeconomic conditions and social situation and the degree to which shopping is made online, confirming the complexity of future freight demand.

As new mobility solutions have been proposed, studies to assess their potential impacts have also started to appear. For instance, in the field of last mile delivery, de Mello Bandeira et al. (2019) have developed a framework that allowed a comparison of diesel LCVs, eLCVs and an electric tricycle in terms of social, environmental, and economic impacts. Giordano et al. (2018) followed a life cycle assessment (LCA) method to compare diesel LCVs against battery electric vehicles. The two studies analysed total capital and operational costs as well as GHG emissions. Moreover, Giordano et al. also considered air quality and De Mello Banderia heart rate of the postman. Extended multicriteria-decision making analysis (MCDA) for delivery using mobile depots complemented by cargo bicycles was performed by Verlinde et al. measuring the economic, societal, environmental and transport impact (Verlinde et al., 2014). Economic (capital and operational costs) and environmental (carbon monoxide, nitrogen oxides, non-methane hydrocarbons, particulate matter, and GHG emissions) impact assessment of mobile depots was also a topic of a case study performed in Rio de Janeiro (Marujo et al., 2018). MCDA was conducted by Navarro et al. (2016) while assessing the alternative urban freight system, that relies on cargo micro-distribution and electric tricycles in Barcelona and Valencia. The authors have focused on economic (capital and operational costs), environmental (PM, SO_2.NOx, VOC, CO and GHG emissions), transport energy (the fuel consumption and energy consumption) and operation (vehicles used, shipments, vehicles km, shipments/km, weight, tour-driving time) dimensions. Impact assessment of another type of bicycle, namely a cycle rickshaw trolley, was performed by Sadhu et al. (2014). The authors have conducted a survey with drivers to assess the impact on environment (CO, CH_4, $NO_{X,}$ PM and GHG emissions), fuel savings, traffic congestion and wellbeing of rickshaw drivers (safety, employment, and psychological impact).

For what concerns automated freight innovations, the literature has seen significant growth in response to advancements in automated technologies, however the topic requires further research. Indeed, in recent years, drones and ADRs have gained increasing attention as possible delivery options due to their potential benefits. Among the first attempts to study the impact of these new mobility solutions, Chiang et al. (2019) have performed a green vehicle routing problem (GVRP) study for drones supported by internal combustion engine delivery vehicles, focusing on costs and sustainability implications. The authors opted for a comparison of GHG emissions and variable costs of delivery for business as usual, delivery using drones and combination of vehicles. Predominantly studies focus on one operational system at a time. For instance, Jennings and Figlozzi have sought to assess the impact of ADRs on freight efficiency, total energy consumption, and emissions (Giordano et al., 2018; Sadhu et al., 2014). Meanwhile, Simoni et al. have delved into the investigation of time efficiency in a robot-assisted truck delivery system (Simoni et al., 2020). Alfandari et al. focused on examining the different tardiness functions of a truck carrying parcels from a depot to facilities where ADRs are launched for last-mile delivery (Alfandari et al., 2022), while Boysen et al. endeavoured to minimize delivery delays of ADRs launched from trucks (Boysen et al., 2018). Liu and Kaisar put forward a proposal to minimize unfulfilled customer demands in ADR deliveries from depots (Kaisar, 2023). Palacin et al. evaluated the most effective distance for ADRs operating in closed environments, such as multi-story buildings (Palacín et al., 2023). Additionally, Ensafian et al. delved into the cost optimization of autonomous mobile lockers and walking couriers (Ensafian et al., 2023).

On the other side, limited amounts of studies have assessed delivery droids in comparison to other last-mile delivery systems. Despite variations in methods and resulting outputs, all the studies have emphasized the complexity of assessing one solution over another, highlighting that it may depend on various factors, whether external (e.g., policy specification) or specific to the vehicle (e.g., number of deliveries per travel). Garus et al., showed that ADR coupled with Euro 4 LCV would be more efficient compared to other solutions (i.e., Euro 4 and 6 LCV, eLCV, ADD coupled with an eLCV or a depot station) in terms of costs savings and sustainability. However, the study underscores the absence of all-fit solutions; and that the best solutions depends the preferences on policy makers and stakeholders. Figliozzi et al., in comparing three types of autonomous vehicles (i.e., SADR, a RADR and an UAVs) with non-automated ones (i.e., eVan and a conventional van), highlighted that emissions savings is not only related to the vehicle type but other factors (e.g., involvement of vehicle mothership, number of customers, depot-service area distance, density area, etc.) (Figliozzi, 2020). In another study, Lemardele et al. showed that ADRs are more economically profitable in denser areas as Barcelona city centre, compared to drones that would be more profitable in less dense and larger service areas as the Paris suburbs (Lemardelé et al., 2021). Schneider et al., in simulations GPS traces of on-demand meal delivery trips of Liverpool, Loughborough and New-York, demonstrated that SADRs are a better option in terms of time-area requirements compared to bicycle couriers, even when the latter deliver multiple meals in a single trip, as opposed to the single delivery made by SADRs (Schneider et al., 2014). Schneider et al., in a study focusing on the London area, showed that SADRs did not performed well compared to modular and fixed lockers with autonomous delivery vans, and road-based autonomous lockers. The reason advanced by the authors being the possibility to deliver only one parcel per travel (Schnieder et al., 2022).

Further studies have delved into the operational sustainability of both drones and ADRs, revealing distinct advantages and limitations inherent to each solution (Simoni et al., 2020; Chung et al., 2020; Otto et al., 2018; Viloria et al., 2021). While aerial drones excel in speed and direct path traversal, ADRs boast several advantages including multiple compartments, higher payload capacity, and extended operational range, allowing for multiple deliveries in a single journey (Jennings & Figliozzi, 2019a; Simoni et al., 2020; Hong et al., 2018). Energy consumption emerges as a critical consideration, with drones typically requiring more energy than electric ADRs, particularly under challenging conditions or in dense urban environments (Kirschstein, 2020). Regulatory frameworks tend to favour ADRs over drones, reflecting concerns over the latter's potential risks to public safety and infrastructure (Kirschstein, 2020). Additionally, according to previous research ADRs mitigate issues of noise pollution, presenting a quieter and safer option for urban delivery (Torija & Clark, 2021; Ostermeier et al., 2022).

While there have been previous attempts to understand the systemic operation of ADRs in last-mile logistics, there remains a need to comprehensively assess their operational advantages relative to established last-mile solutions. Indeed, as highlighted above, most of the studies assess individually ADRs, making it difficult to understand their relative advantage over other solutions. Furthermore, studies comparing different solutions often focus on only one or two assessment criteria, neglecting to provide a holistic vision of the deployment of these various solutions. Also, it is crucial to recognize that the operational advantages of ADRs may exhibit varying levels of prominence across different locations, potentially leading to their complete obsolescence in certain contexts (Plank et al., 2022). Consequently, this study aims to address this gap in knowledge by conducting a thorough examination and comparison of the operational advantages of ADRs alongside popular last-mile solutions across diverse geographical locations. Especially, three different criteria are investigated (i.e., cost, duration and sustainability) in 14 different European cities, providing a unique picture of the operations of last-mile delivery systems. By elucidating the specific conditions under which ADRs excel or falter, this research endeavours to provide valuable insights into the viability and adaptability of ADRs within distinct operational environments.

3. Modelling framework

3.1. Operational model

In this scientific study, the aim was to further understand delivery services by comparing the efficiency of different transportation modes, namely the traditional LCV, a system based on cargo bicycles, and an ADR-based system. To achieve this, a systematic methodology encompassing the steps described below was followed. The whole model was written implemented as a Python script and used solely open-source libraries and APIs (application programming interface). The methodological framework is presented hereunder on Fig. 1.

To supplement simulation data with practical insights unstructured interviews were utilized. This involved engaging with five bicycle couriers from a leading American crowd-sourced delivery company operating in European capitals. Key questions asked included: 'How many deliveries can you carry per trip?', 'What is your usual delivery load?', and 'How many deliveries do you typically make per day?'. Additionally, conversations with three professionals from a European ADR company centred around questions like: 'What is the daily delivery capacity of your ADRs?' and 'What is the maximum number of deliveries an ADR can make in a single trip?'. These unstructured interviews provided vital operational perspectives, significantly enriching the analytical framework of our study.

To identify suitable delivery destinations, the Google API, a powerful map-based interface that provides access to a comprehensive database of points of interest (POIs) within a specific geographic range, was employed (Businesses and Other Points of Interest, 2023). A list of services and establishments to which the deliveries could be made was retrieved by utilizing latitude and longitude coordinates. This approach allowed us to consider a wide range of potential destinations, enabling a comprehensive analysis of the delivery routes. The POIs per each urban context were saved to serve as possible delivery points.

To account for stochastic variations and ensure the robustness of the findings, the subsequent steps of the methodology were repeated 100 times. In each iteration, 21 POIs (1 origin point and 20 delivery points) were randomly drawn, representing a one-day delivery scenario. The selection of 20 delivery points in the study is premised on replicating a realistic daily demand for a typical restaurant engaged in food delivery services in an urban environment. This figure is derived from an interview conducted with food delivery carriers.

Moreover, this number allows for a diverse range of delivery distances and locations, providing a comprehensive understanding of the logistical challenges and efficiencies associated with using ADRs. By catering to 20 different delivery points, the study can effectively assess how the considered modes of delivery perform under realistic urban

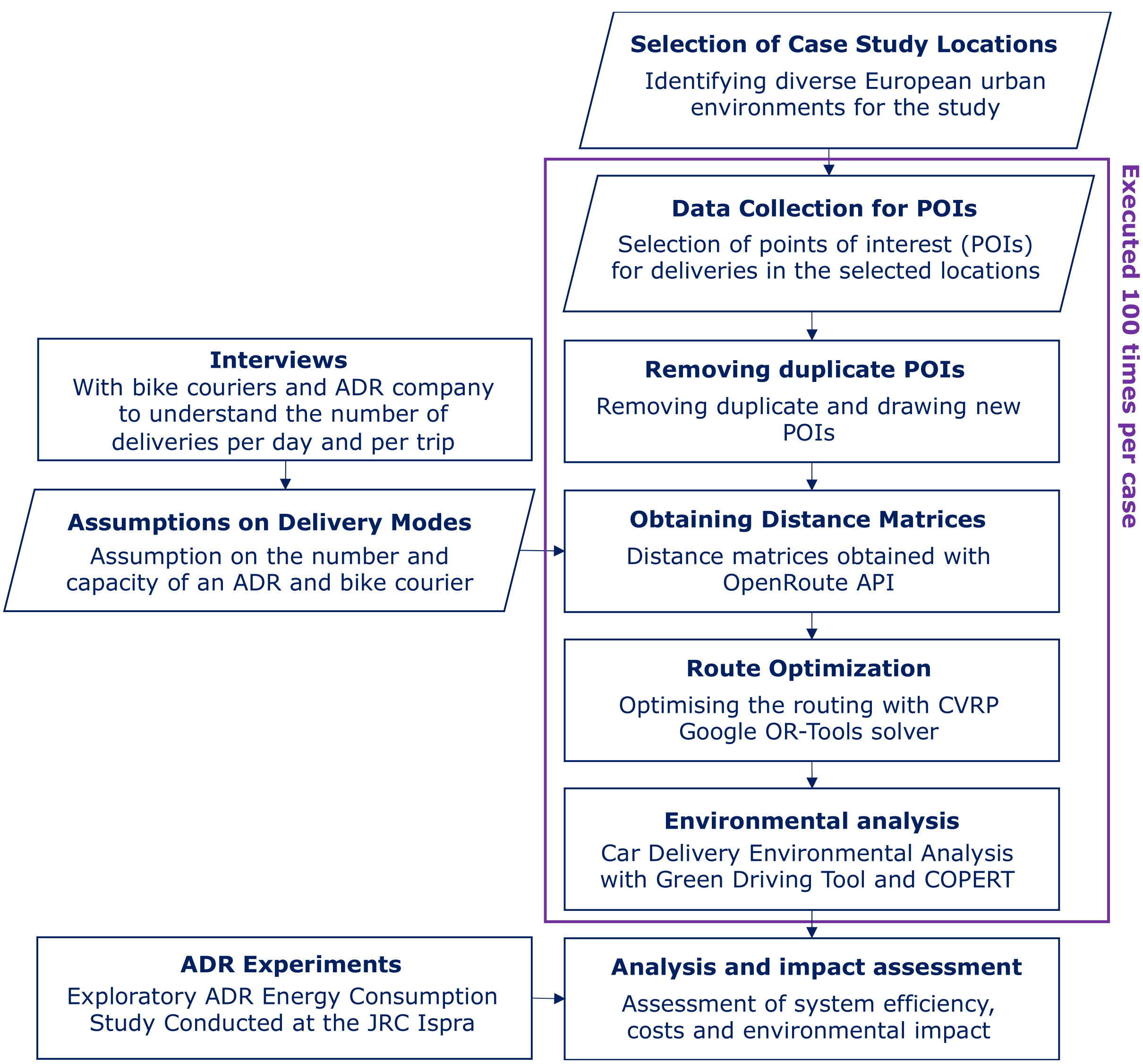

Fig. 1. Methodological framework flowchart.

delivery conditions, including navigating different distances, traffic conditions, and varying urban layouts.

Once the delivery points were obtained, measures were taken to eliminate duplication and ensure unique delivery destinations. POIs that were closer than 10 m were removed from the list to avoid doubling the places of delivery. If the number of unique POIs fell short of the required 21, additional random draws were conducted until a complete set of 21 distinct POIs was obtained. This step ensured a representative sample of delivery destinations for the analysis.

Origin-destination (OD) matrices were computed using the Open Route API (Services | Openrouteservice, 2023), which provided route distances and duration of travel for car, bicycle, and walking trips between the identified 21 POIs. This API was crucial in generating accurate distance data for each pair of POIs for the different modes of transportation. The calculated routes took into account topographical variations, and urban layouts, ensuring that the distances reflected realistic travel scenarios. These OD matrices were directly obtained from this latitude and longitude of POIs, forming a data-driven and accurate basis for our analysis of the efficiency and effectiveness of various delivery modes. The walking OD matrix, with its lower speeds (up to 7.2 km/h) and ability to function on sidewalks, represented the ADR. For this study, a small and relatively slow SADR was chosen as a reference point, as those vehicles are expected to be present in European cities where the tendency is to create limited traffic zones and increase pedestrian areas. Both distance and duration matrices were obtained and recorded, providing insights into the spatial and temporal aspects of the delivery routes.

Google OR-Tools was utilized to optimize the delivery routes and determine the number of journeys required for each transportation mode within a given system (Perron, 2022). This open-sourced toolset enabled the input of OD matrices for the 20 delivery POIs and 1 origin POI, and the application of the capacitated vehicle routing problem (CVRP) solver. The capabilities of Google OR-Tools were leveraged to aim for the optimization of the service routes and the maximization of the utilization of vehicles, by minimizing travel distances and enhancing overall delivery efficiency. Reasonable assumptions about the capacity and availability of vehicles were made through expert interviews conducted with the developers of the ADRs and individuals who worked delivering food with a cargo bicycle. Based on these interviews, it was assumed that the LCV could carry the entire load of 20 parcels in a single journey, the capacity of the ADR was determined to be 3 parcels and the cargo bicycle could accommodate up to 4 parcels. Based on the capacity of the modes and the number of parcels required to be delivered (20), the last-mile delivery systems were determined to comprise either 7 cargo bicycles, 9 ADRs or a single LCV. The operational model of the delivery is represented on the following Fig. 2.

Throughout the study, the total duration and distance travelled by each transportation mode to deliver all parcels for the 100 runs per city were recorded. These recorded metrics were then used to calculate an average distance and duration, which served as quantitative indicators for comparing the efficiency of the LCV, cargo bicycle, and ADR. In the initial stages of this study, the choice of conducting 100 simulations was determined based on a balance between computational efficiency and the depth required to encompass the stochastic variability inherent in urban delivery scenarios. The 100 iterations figure was selected to ensure a broad capture of data while remaining feasible for computational processing. Subsequent to this preliminary decision, a thorough convergence analysis was employed to validate the adequacy of the simulation count. The analysis monitored the stabilization of key performance metrics across simulations, confirming that convergence in the results was consistently achieved.

In order to enhance the comprehensiveness of the study, the methodology was extended to include the following steps and considerations:

1. Diverse European Locations: To capture a broader perspective, the process of obtaining POIs, origin-destination matrices, and optimization was repeated 100 times for 14 different areas across Europe. These areas were carefully selected to represent various European countries, encompassing a range from north to south and from west to east considering variations in infrastructure, regulations and cultural aspects.
2. Varied City Sizes: Cities of different population sizes (mega cities, large capitals, smaller capitals, mid-sized and small cities and a rural area) were intentionally chosen to investigate the impact of scale on the delivery operations. This ranged from smaller cities such as Oulu to mega-cities like Paris. By including cities with varying population densities, the aim was to assess which mode of delivery could be more suitable to a given location.
3. Traffic Limitations: Cities with low traffic zones were deliberately included to examine the influence of traffic restrictions on the delivery services. Insights into the adaptability of the solutions in different urban contexts were gained by assessing the impact of traffic limitations on the operational efficiency of each transportation mode.
4. Location Variability: Both strictly central areas and locations slightly further away were strategically selected when searching for POIs. This decision was based on the understanding that European city

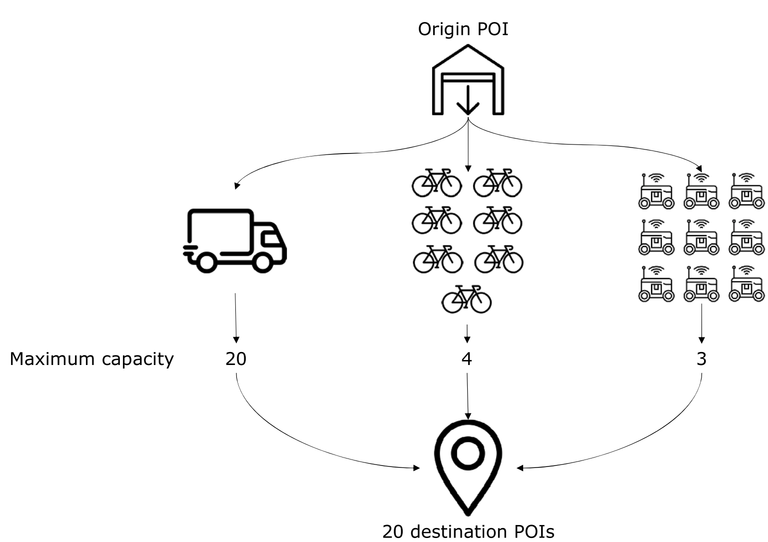

Fig. 2. Operational model of deliveries.

centres often feature narrower streets and one-way traffic systems, which could affect the performance of the last-mile delivery.

5. Topographical Considerations: The topography of each city was also considered in the study. This involved cities with predominantly flat terrain as well as those characterized by hilly landscapes. By examining cities with varying topographical features, the aim was to assess how the different modes of transportation would be influenced by geographic conditions.
6. Range Considerations: Regarding the selection of POIs, our methodology was designed to ensure both stochastic variability and robustness in our results. The initial range for searching POIs was based on the specific characteristics of each city. However, to guarantee a comprehensive and varied sample, this range was extended in cases where the initial number of POIs was insufficient. This extension was crucial in allowing us to include a diverse set of urban layouts and densities, thereby enhancing the reliability of our findings. The cities were categorized based on their size, density, capital city status, topography, choice of a central area, and the range for POIs, as depicted in Table 1. This categorization and the flexibility in the range of POIs ensured a robust and representative analysis of different urban environments. The ranges were set to 250 m for larger cities, 500 m for smaller cities, and 1500 m for rural areas. This adjustment considered the geographical distribution of points of interest in different urban and rural settings.

Table 1 represents a classification of cities used for the study, providing various characteristics for each city while Fig. 3 provides a visual representation of all considered locations. The cities are categorized based on their size, density (number of persons per km^2), capital city status, topography, choice of a central area, and the range for points of interest (POIs). The size of the cities ranges from small to large, while their densities vary from low to very high. The central area column indicates whether the central area of a city was used as a reference point for the POIs search. This information is indicative as the central areas of European cities tend to be unsuitable for heavy traffic. Moreover, the column Low Traffic Zone indicates whether the central point of searching for POIs was placed in a zone with limitation for traffic. Those limitations could include fully pedestrian areas, areas for pedestrian and cyclists as well as low emission zones. Finally, the last column presents the range used as an input to Google API which looked for points of interest within this range. This classification provides a systematic framework for analysing and comparing cities based on key characteristics relevant to the study.

3.2. Economic analysis

To calculate the cost of a last mile delivery system, various factors were considered depending on the mode of transportation used. For a Light Commercial Vehicle (LCV), the cost was determined by summing up the fuel consumption and the labour cost of the courier per hour (Delivery Driver Salary in Italy, 2023; Average Delivery Driver Salary in Germany, 2023). Assuming a typical for an LCV average fuel consumption of 10 litters per 100 km, the cost is calculated by multiplying this consumption by the average fuel price in each of the European Union (EU) countries for 2022 (Fuel Price Comparison | European Alternative Fuels Observatory, 2023). For an ADR, the cost was calculated based on its average electricity consumption. With a total battery capacity of around 0.5 kilowatt-hours (kWh), the cost is derived by multiplying the electricity consumption by the average electricity price in the EU for 2022 (Electricity Price Statistics, 2023; Electricity Prices, 2023; Supply, Transformation and Consumption of Electricity, 2023). Whereas, the cost of using a bicycle for delivery was estimated to be equivalent to the salary of a bike rider, taking the salary of bike drivers for food delivery as a benchmark (Anfuso, 2023; Uber Eats - Zarobki, 2023).

3.3. Environmental analysis

The methodology for calculating emissions and fuel consumption of Light Commercial Vehicles (LCVs) in this study was based on expert interviews and two tools from the European Commission: The Green Driving Tool and COPERT. The Green Driving Tool, developed by the EC's Joint Research Centre, evaluates the impact of driving behaviour and vehicle efficiency on emissions. It requires data on vehicle specifications and driving patterns, such as engine size, fuel type, average speed, and idling times (European Commission, 2021). This tool simulates real-world conditions to estimate emission reduction potential through eco-driving and efficient operation.

Additionally, COPERT (Computer Programme to Calculate Emissions from Road Transport), developed by EMISIA and recommended by the European Environment Agency, was used for detailed emission analysis (Ntziachristos & Samaras, 2020). It models emissions from various vehicle categories, incorporating factors like vehicle technology, age, fuel type, and driving patterns, along with environmental conditions. the car deliveries were represented as post-2020 diesel LCVs in the N1-1 category adhering to Euro 6 standards, ensuring accurate emission characterization using COPERT and the Green Driving Tool. Furthermore, the routes for the navette service were obtained from the operational model, and this data was integrated into our simulations to closely mirror the actual transport conditions and enhance the precision of our emissions and fuel consumption assessments.

An experimental approach was chosen for the environmental study of ADRs to best represent the real consumption of such innovations. The capabilities and performance of Yape, an ADR designed for last-mile delivery solutions, were examined. This ADR, standing approximately one meter tall and weighing about 54 kg, is equipped with a secure cargo compartment that can transport goods up to 10 kg. It incorporates advanced technological features including an array of sensors like

Table 1
Classification of cities used for the study.

City	Size	Density	Capital city	Topography	Central area	Low Traffic Zone	Range for POIs
BARCELONA	Large	Very High	No	Hilly	Yes	No	250
BRUSSELS	Large	High	Yes	Mostly flat	Yes	No	250
CLUJ NAPOCA	Small	Medium	No	Hilly	No	No	250
FLORENCE	Small	Medium	No	Hilly	Yes	Yes	250
GOTHENBURG	Mid-sized	Low	No	Mostly flat	Yes	Yes	250
ISPRA	Rural area	Low	No	Mostly flat	No	No	1500
KARLSRUHE	Mid-sized	Medium	No	Mostly flat	No	No	250
OSTRAVA	Small	Low	No	Hilly	No	No	500
OULU	Small	Low	No	Mostly flat	No	No	500
PARIS	Mega city	Very High	Yes	Mostly flat	Yes	Yes	250
PORTO	Small	High	No	Hilly with steep slopes	Yes	Yes	250
THESSALONIKI	Small	High	No	Hilly	Yes	No	250
VILNIUS	Mid-sized	Medium	Yes	Mostly flat	Yes	No	250
WARSZAWA	Large	Medium	Yes	Mostly flat	Yes	No	250

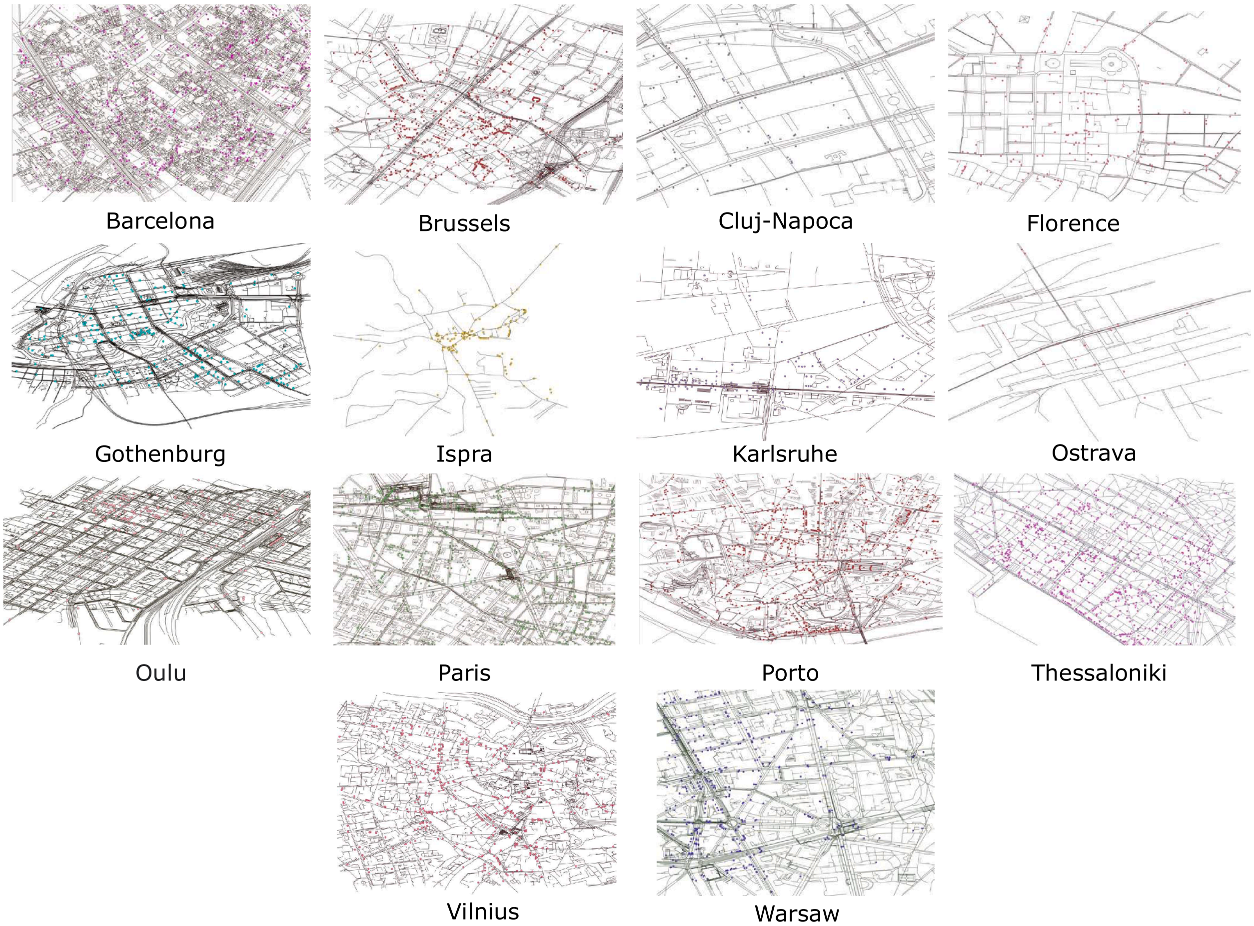

Fig. 3. Networks maps with POIs of analysed locations.

cameras, 3D sensors, LiDAR, ultrasonic sensors, and GPS, which are instrumental in facilitating its navigation through complex urban environments (YAPE, 2021).

The evaluation of Yape consisted of two experimental phases conducted at the Ispra site of the European Commission's Joint Research Centre (JRC). Overall, 74 successful deliveries were conducted during which data on energy consumption of ADRs was collected. Both experiments were conducted within a restricted traffic zone at the JRC Ispra site, specifically chosen to replicate the pedestrian-dominated urban environment where ADRs are expected to operate. The customer journey in these experiments was meticulously structured, encompassing several stages from sender and receiver registration on the ADR platform to the final delivery confirmation. This comprehensive process involved the ADR travelling to and from the base station, interaction with senders and receivers through a QR code-based system for loading and unloading, and real-time notifications to all parties involved. Data collected throughout these experiments included battery signal data, ADR statistics, and manually recorded environmental data. The granularity of the data, especially the high-frequency battery signal recordings, provided a detailed view of Yape's electrical consumption and performance under various operating conditions.

Critical data regarding its energy efficiency was derived from the detailed experiments conducted with the Yape. Specifically, the average energy consumption of the ADR per meter was calculated. This calculation was a key outcome of the experiments and was facilitated by the comprehensive data collection process. Furthermore, data on grid emissivity for each European country was utilized to translate this energy consumption into environmental impact. This data, sourced from Eurostat, provided official and reliable figures on the carbon intensity of electricity generation in different European countries (Emissions of Greenhouse Gases and Air Pollutants, 2023; EEA, 2023). By applying these emissivity values to the energy consumption figures of the ADR, the GHG, PM10 and NO_x emissions associated with the operation of an ADR were estimated. This approach allowed us to understand not just the energy efficiency of the ADR, but also its environmental footprint.

This combined summary integrates the algorithmic steps for both the comparative efficiency analysis and the environmental impact assessment of different transportation modes in last-mile delivery services. It outlines the methodological process, from data collection to route optimization and environmental evaluation, culminating in a comprehensive output that includes both operational and environmental metrics.

3.4. Algorithm explanation and data description

The following description outlines the data sources and key components and processes of our algorithm, demonstrating its capability to provide a holistic analysis of sustainability and operational effectiveness in last-mile delivery systems.

3.4.1. Data sources

1. Google API for POI Identification:
   a. The initial coordinates for each city were chosen manually.
   b. The Google API was utilised to obtain all POIs in the area withing range from the initial point.
2. Experimental ADR Energy Consumption Data:
   a. Central to our study is the experimental data on the average energy consumption of ADRs. This data was meticulously collected

from an extensive experimental campaign, measuring energy usage under various operational scenarios.
  b. Using grid emissivity data from Eurostat, we translated the ADR's energy consumption into environmental impact metrics, including GHG and NOx emissions (Emissions of Greenhouse Gases and Air Pollutants, 2023).
3. Interview Data for Operational Parameters:
  a. To inform our analysis of operational efficiency, we conducted expert interviews with service providers. These interviews provided critical data on the number of deliveries and the capacities of both bikes and ADRs used in real-world scenarios.

Algorithm Inputs:

- Initial coordinates (latitude, longitude), step size for grid generation, radius for POI search, types of POIs (restaurants).
- Transportation modes (car, bicycle, ADR) with their capacities and quantities.
- Environmental factors (GHG emissions, PM10, CO, NOx) and energy consumption per meter data for ADRs.
- Pollution data per country.

Process:

1. POI Identification:
   - Create a grid around the central point using Google Places API to identify POIs within a specified radius.
   - Store POIs with details like latitude, longitude, and name.
2. Distance Matrix Computation:
   - Use the Open Route Service API to compute distance matrices for each transport mode among POIs.
   - Optimize routes using the OR-Tools library to minimize travel time or distance.
3. Route Optimization:
   - Define parameters like the number of deliveries and vehicles.
   - Run simulations for each transportation mode to collect data on distances and durations.
4. Impact Assessment Car:
   - Calculate fuel consumption using the optimised route and the Green Driving Tool.
   - Calculate the emissions for post-2020 diesel LCVs in the N1-1 type vehicle using COPERT.
   - Compute mean values for distance, duration, and environmental parameters.
5. Impact Assessment ADR:
   - Determine energy consumption for ADRs based on calculated distances and average ADR energy consumption data taken from experimental campaigns.
   - Assess environmental impact using energy consumption data and country-specific pollutants' values.
   - Compute mean values for distance, duration, energy consumption, and emissions.
6. Impact Assessment Bicycle:
   - Consider bicycles as non-polluting, with zero emissions and energy consumption.
   - Compute mean values for distance and duration.

Output:

- A set of optimized routes for each transportation mode.
- A DataFrame summarizing environmental impacts, including distances, durations, fuel/energy consumption, and emissions.

4. Results and discussion

4.1. Operational efficiency

The three figures below provide a comprehensive summary of the average distances in kilometres (Fig. 4), durations in minutes of delivery trips (Fig. 5), along with the associated costs per kilometre in € (Fig. 6), for the researched delivery modes. The results are averages, as they were obtained through simulations of a given delivery runs with 20 delivery points conducted 100 times, ensuring a robust and reliable dataset.

The average distances travelled per mode of transportation for deliveries are as follows: for ADR, the average distance was approximately 43.63 km; for bikes around 47.33 km, and for cars it was about 37.44 km. In general, the distance covered by an LCV is the smallest because of its ability to deliver all parcels during a singular trip. The available ADRs could deliver 3 parcels, as compared to 4 parcels delivered by bicycles, however they can use the pavement, which optimises their journey, as cyclists must often follow a longer route on which a bike lane is present.

Fig. 4 is visual representation of the average distances per mode and city. It is important to mention that in rural areas like Ispra, the points of interest are generally farther away compared to urban or suburban areas. Hence, there might be a notable difference in average distances for Ispra deliveries, but the specific results are as follows: for ADR, the average distance is 129.25 km; for bikes, it is 113.36 km, and for cars, it is 68.08 km. Due to the high difference in results, the data for Ispra is not included in the graph to ensure better readability and clarity.

An analysis of the average distances travelled per mode of transportation reveals notable variations among different city scenarios. Firstly, in cities with central locations characterized by streets often designed with pedestrian areas, cars and bicycles could face disadvantages due to potential one-way streets. In this analysis it is shown that in certain European centres with high presence of one-way streets like Vilnius or Warsaw the use of ADRs becomes an advantage in terms of distance, despite the need to use multiple robots. In fact, the average distance covered by the ADRs was lower by 12 % as compared to car distance in Warsaw and more than 9 % in Vilnius.

Secondly, in cities with restricted traffic zones that prohibit cars from entering, forcing them to take longer routes, differences in average distances per mode were observed. In Florence, the average distance for bikes was almost 14 % lower as compared to cars. This distance was further reduced for ADRs, which can use pedestrian areas as opposed to bikes, lowering it by over 35 % compared to an LCV. As some pedestrian areas in Gothenburg are not available for cyclists the bicycle could not outperform a car, however the distance difference was not high (6 %). Moreover, as ADRs could enter pedestrian areas in traffic limited zones the distance covered by the system of robots was almost 17 % lower as compared to the LCV. It is also important to note that the Low Traffic Zones in various cities could follow different rules. ADRs and bicycles could outperform the LCVs as long as cars are not allowed in the areas or enough streets are one way or too narrow for a car to enter.

In smaller cities like Karlsruhe and Oulu, where the city centres are more compact and services are closely located, not only the average distances per mode of transportation were relatively shorter but also the differences between them. For instance, in Karlsruhe, the ADRs needed to cover 13 % less distance on average as compared to the cars, while in Oulu the distance covered by ADRs, and cars is practically identical. On the other hand, Ostrava, a small city with scattered points of interest, exhibited longer average distances per mode. This could be attributed to the need to enlarge the radius while searching for points of interest in the area. In fact, a radius of 250 m was not enough to locate 21 distinct POIs so a radius of 500 m was used. This resulted in higher distances for all modes and shows that there could be various types of small cities. This knowledge can guide decision-making in selecting the most appropriate mode of transportation for efficient and cost-effective deliveries in diverse urban contexts.

The average durations of delivery trips per mode of transportation

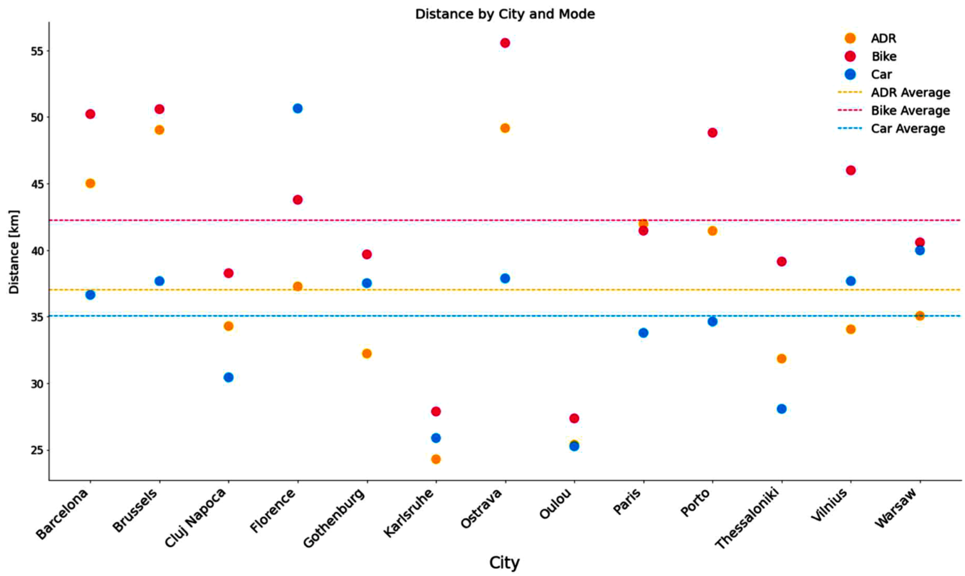

Fig. 4. Average distance travelled to deliver the 20 parcels by mode and city.

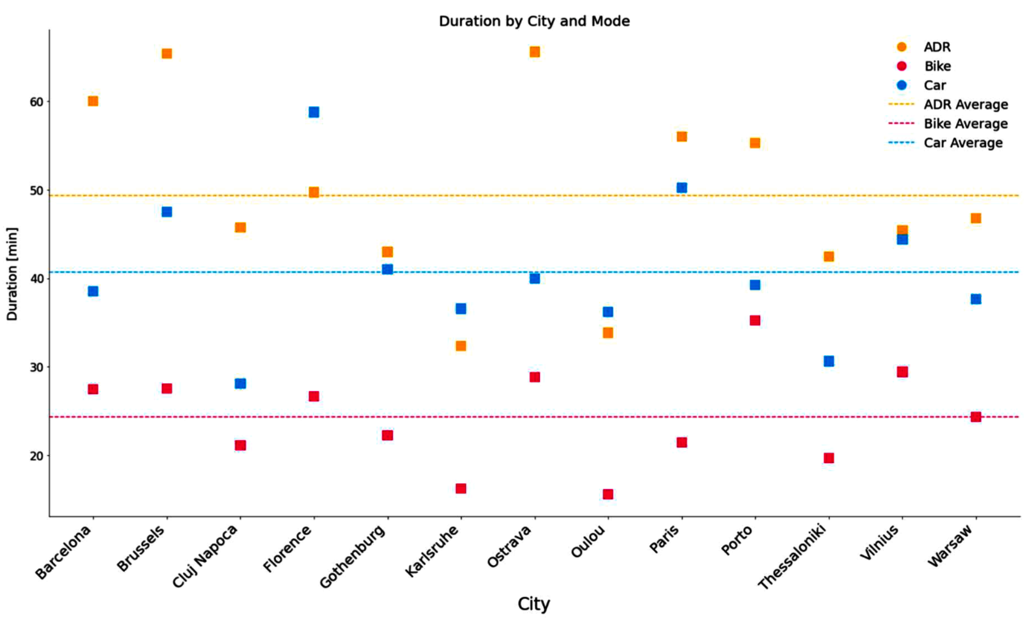

Fig. 5. Average duration of delivery of the 20 parcels by mode and city.

are as follows: for ADR, the average cumulative duration was approximately 8.7 h; for bikes, it was around 3 h, while for cars, it was about 41 min. However, the average duration considering the system of ADRs, and bikes was 58 min and 26 min respectively. It is noteworthy that ADR based system has a slightly longer average duration compared to cars, due to their lower maximum speeds (7.2 km/h for pavement frequenting ADRs). Meanwhile the delivery system using bicycles is in fact the fastest as the deliveries are distributed among the individuals who can cover the distance with a relatively high velocity (20–25 km/h, which is nearing a speed limit in central urban areas in Europe). Fig. 5 provides a visual representation of the average durations per mode and city. Again, the rural area of Ispra was omitted per readability of the graph. The values for the rural area were around 3 h for ADRs based system, 55 min for bike system and 47 min for the LCV.

The findings regarding delivery durations reveal interesting insights about the various modes of transportation. The bicycle-based system consistently proves to be the fastest option across the cities studied. However, it is important to consider that the advantage of bicycles in terms of speed is reduced in hilly areas such as Porto or when covering longer distances, as observed in Ostrava or Ispra.

On the other hand, the ADR-based systems present a more nuanced picture. In smaller cities like Karlsruhe and Oulu, they can deliver parcels with comparable or even faster durations than LCVs. For example, in Karlsruhe, ADRs have an average duration that is 11 % faster than LCVs, while in Oulu, ADRs are 6.6 % faster than LCVs. This further indicates that ADRs can be a viable alternative in these smaller cities.

In cities with low traffic zones or central areas such as Florence, Vilnius, and Gothenburg, the ADR-based systems also demonstrate competitive durations. In Florence, ADRs have an average duration that is 15 % faster than LCVs, while in Vilnius, ADRs are just 2 % faster than LCVs. This duration is a direct effect of a distance needed to be covered for deliveries, a proxy of city density. In central areas with lower density of POIs like in Warsaw the duration comparison between ADRs and LCVs is in favour of the LCV. While ADRs could be faster than or comparable

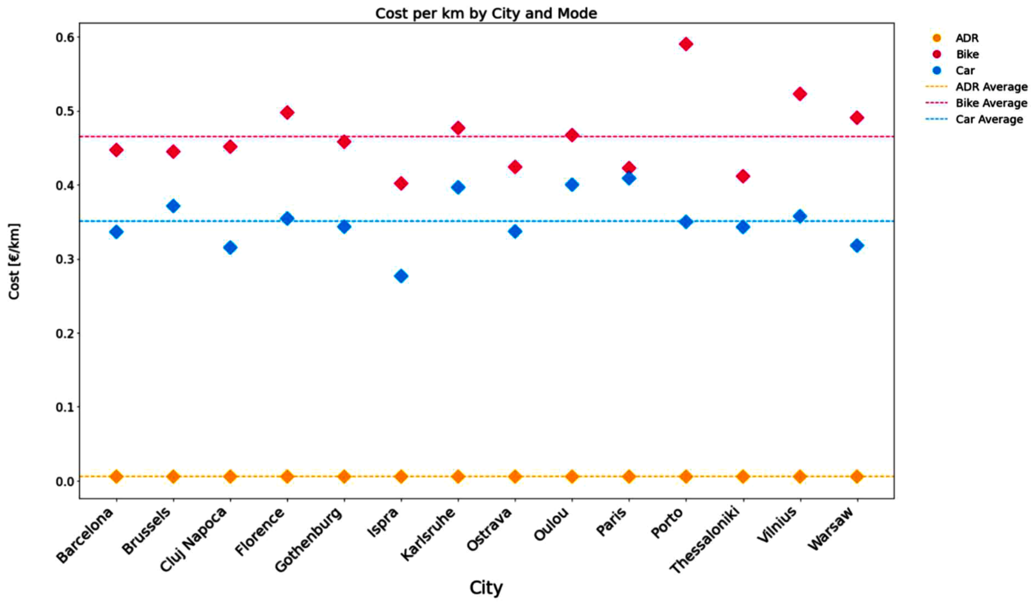

Fig. 6. Average cost per km per mode and city.

to LCVs in densely populated areas, the advantage decreases in less dense areas. These findings highlight the importance of considering the specific characteristics of each city when selecting the appropriate mode of transportation for efficient and timely deliveries.

4.2. Economic efficiency

Consideration of the cost per kilometre for delivery trips in each mode in all studied areas is presented on Fig. 6. The average cost per kilometre for each mode of transportation was as follows: for ADR, the average cost per kilometre was approximately €0.025; for bikes, it was around €0.445, and for the LCV, it was about €0.371.

Examining the data, it is evident that the ADR-based system has the lowest cost per kilometre, followed by cars and bicycles. However, it is worth noting that the costs included into the calculation are based on general prices for gas and electricity in Europe. Adding the real prices for those commodities per country could lead to different results. Moreover, these are simply operational costs that include courier labour as well as the energy consumed (either gasoline in case of LCV or electricity for the ADRs). To have more realistic results additional data on insurance and maintenance costs for all modes would be needed. Additionally, the labour costs of an LCV courier are understated as they only cover a cost of a singular delivery in terms of hourly rate. Meanwhile, the couriers are employed on fixed positions and paid for a monthly work. Moreover, the cost of the ADRs system does not include the cost of an external operator who would need to take care of the system in case of malfunction or in case there is a need to take over control of the robot. Nevertheless, in case the technology of ADRs is mature enough these costs could be accurate as the only borne costs would be energy consumption and maintenance.

4.3. Environmental efficiency

In the comprehensive analysis of the environmental impact of last-mile delivery options, the quantitative emissions data is considered alongside the specific urban contexts in which ADRs, LCVs, and bicycles operate. Bicycles, being human-powered, inherently have the least environmental impact and are especially effective in flat, compact urban areas with developed cycling infrastructure. However, their efficiency diminishes in cities with challenging terrains such as hills or spread-out geographies, where the physical exertion required makes them less viable.

LCVs present a contrasting environmental profile. Their fuel reliance results in an average consumption of 5.6 litres per trip and higher GHG emissions of 14.91 kg per trip. Additionally, they contribute to urban air pollution with PM10 and NOx emissions averaging 0.0012 g and 0.0141 g per trip, respectively. These emissions, mainly from fuel combustion and mechanical aspects of the vehicle, pose significant concerns in densely populated areas where air quality is paramount. The effectiveness of LCVs is influenced by urban factors such as traffic density and delivery volume; they remain crucial for larger or urgent deliveries but require careful consideration in urban planning, especially in cities focused on reducing air pollution.

ADRs, which rely on electric power with an average consumption of 7.3 kWh per trip, offer a more sustainable alternative in certain urban settings. Their zero-fuel consumption and significantly lower GHG emissions (2.1 kg per trip) compared to LCVs highlight their potential for reducing urban environmental footprints. This is particularly true when their electricity is sourced from renewable energy, greatly enhancing their environmental efficiency. The way in which the electricity mix impacts the environmental performance of ADRs could be represented by an outlining value of high NO_x emissions from trips in Porto, as the electricity production in Portugal is highly emissive in NO_x. ADRs are especially suited for modern, high-tech cities with robust infrastructure that can support their operational needs. In contrast, their performance may be less environmentally efficient in older cities with complex layouts and limited technological support.

In summary, the environmental effectiveness of bicycles, ADRs, and LCVs is intricately linked to both their emission profiles and the specific characteristics of the urban environments in which they operate. The choice of mode for last-mile delivery should therefore be informed by a thorough understanding of these factors, ensuring that urban logistics are optimized for both operational efficiency and minimal environmental impact. This balanced approach is vital for cities aiming to enhance sustainability in their logistics and delivery systems. The results of GHG and NO_x emissions per city study could be seen in more detail on Figs. 7 and 8 hereunder respectively.

4.4. Policy implications

In the context of fostering sustainable urban environments, the deployment of ADRs presents a unique intersection of technological

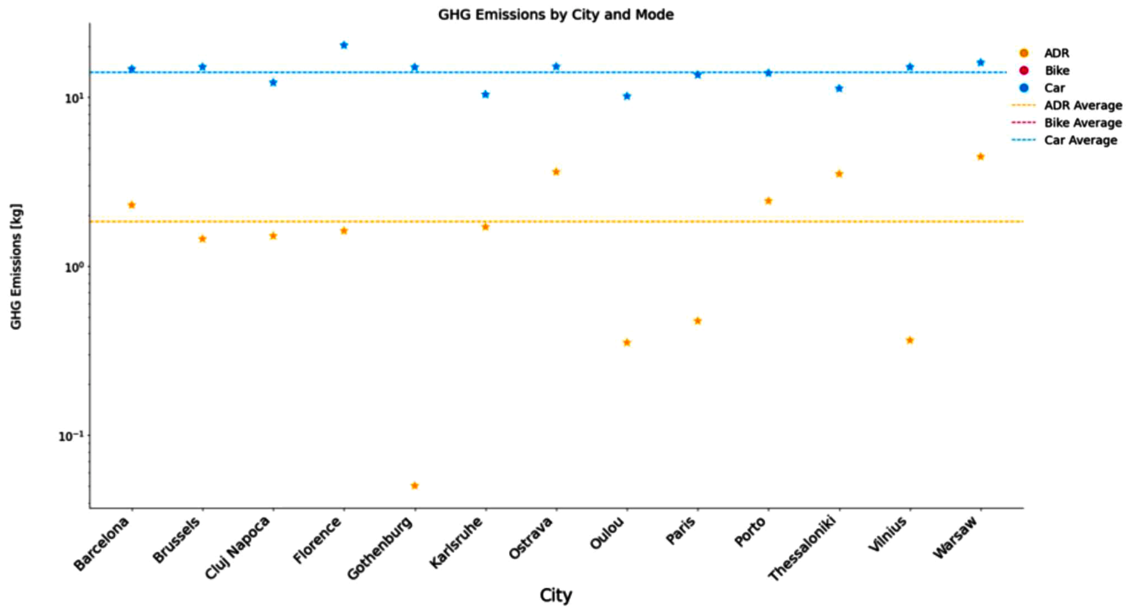

Fig. 7. Average GHG emissions per mode and city.

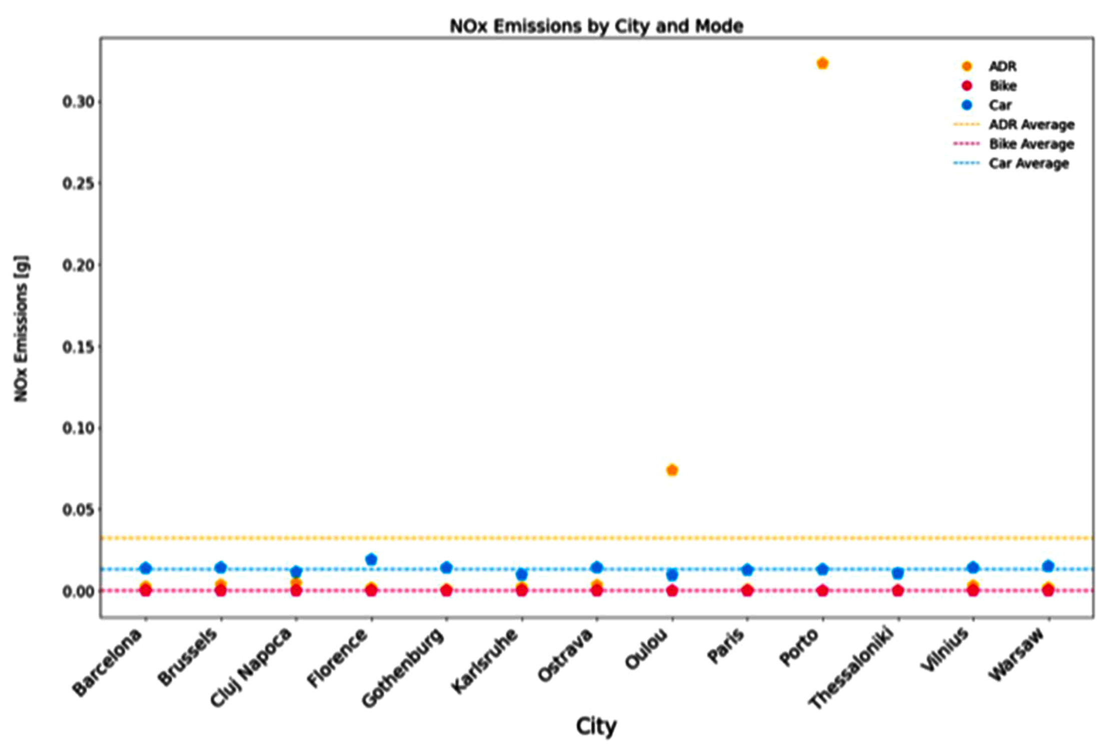

Fig. 8. Average NO_x emissions per mode and city.

innovation and regulatory challenges. ADRs, particularly when coupled with low or no-traffic zones, offer the potential to reduce vehicular congestion and emissions, thus aligning with sustainability goals. However, their efficiency and effectiveness are intricately tied to the regulatory frameworks in place.

To harness the benefits of ADRs while ensuring urban sustainability, it is imperative for European or national regulators to establish and enact comprehensive regulations. These regulators should specify the types of ADRs, their maximum speeds, and autonomous features, ensuring that they meet safety and efficiency standards for operation on sidewalks and bike lanes.

At the local level, policymakers play a crucial role in implementing and enforcing these regulations. They should govern what types of vehicles can access specific zones, including sidewalks and bike lanes, and impose caps on their numbers to assure safety and maintain pedestrian-friendly environments. Urban planners must also consider the creation of low traffic zones to facilitate the integration of ADR-based deliveries, an approach that can significantly enhance last-mile efficiency and sustainability.

Additionally, policymakers can incentivize businesses to adopt sustainable last-mile delivery solutions through various policy instruments, including tax reliefs and grants aimed at fostering innovation within the industry. These incentives can be contingent upon businesses acquiring renewable energy source certificates, thereby ensuring that ADR operations align with eco-efficient practices.

By embracing these multi-tiered policy measures, European cities can navigate the dynamic landscape of urban logistics prudently, promoting ADRs as sustainable solutions while upholding safety, efficiency, and environmental responsibility as paramount considerations in shaping the future of last-mile delivery.

5. Conclusions and future research

In summarizing our findings, this study offers a comparative analysis of last-mile delivery methods across diverse European contexts, highlighting the variable efficiencies of LCVs, cargo bicycles, and ADRs. The investigation reveals distinct operational and environmental implications, underpinning the decision-making process for optimal transportation mode selection in different urban scenarios. Despite its comprehensive approach, the study acknowledges inherent limitations such as the selection of a limited number of European cities, reliance on simulations, and the rapidly evolving nature of ADR technology. These factors may influence the generalizability and future applicability of our results.

The findings delineate the nuanced efficiencies of ADRs in last-mile delivery within varied urban landscapes. Across the studied European cities, ADRs demonstrated economic efficiency with consistently lower operational costs per kilometre when compared to bicycles and cars. However, this cost advantage is juxtaposed with increased delivery durations, which could impact timeliness. The environmental analysis further reveals ADRs as a sustainable choice, particularly when powered by renewable sources. This underscores their potential role in future-focused, eco-efficient urban delivery systems, where cost-effectiveness and sustainability are paramount considerations.

Aligned with the literature, the results of this study emphasize that there is not a one-solution miracle to last-mile delivery, and that different solutions apply to both delivery system specificity and external factors. Indeed, the findings highlighted notable variations among different city scenarios, with bikes and ADRs showing advantages in cities characterized by one-way streets and restricted traffic zones. Particularly in smaller cities with compact centres, ADRs emerged as a suitable solution due to the relatively shorter distances for all modes of transportation. The environmental efficiency study underscored bicycles as the most environmentally friendly option in flat, compact cities with developed cycling infrastructure. However, their effectiveness is limited in challenging terrains. LCVs, necessary for larger deliveries, have higher fuel consumption and GHG emissions, presenting concerns in densely populated areas where air quality is paramount. In contrast, ADRs offer a sustainable alternative with lower GHG emissions, especially when powered by renewable energy, though their effectiveness depends on the supporting urban infrastructure. The specific characteristics of each city significantly influence the environmental performance of these modes, emphasizing the need for a tailored approach to last-mile delivery that balances operational efficiency with environmental considerations. Moreover, the study's exploration of ADRs highlights their potential in enhancing last-mile delivery efficiencies in urban settings, particularly in pedestrian-centric and traffic-restricted areas, demonstrating their viability as a sustainable alternative in urban delivery systems.

Overall, this study provides valuable insights into optimizing delivery services by comparing different transportation modes, assessments criteria, and urban settings, providing a more holistic approach compared to the current literature. Indeed, although articles investigated and compared different transport modes, they are missing layers of understanding and complexity to provide the adequate decisional tool. It could aid decision-makers in selecting the most appropriate mode of transportation based on specific urban contexts, considering factors such as distance, duration, cost and potential environmental impacts.

While our simulations provide insightful comparisons of last-mile delivery modes, it is important to acknowledge the limitation regarding weather conditions. During our experiments with ADRs, rain did not significantly impact their operations. However, the study did not extensively investigate the effects of various adverse weather conditions, such as heavy rain or snow. Future research could benefit from incorporating detailed simulations of these conditions to better understand their impact on delivery system efficiency. Moreover, it is crucial to include labour prices specific to each country in the study. This would allow for a more accurate assessment of the advantages of a given transportation mode in a particular city context. By incorporating these factors, decision-makers can make informed choices based on the total costs associated with each mode of transportation, including maintenance and total labour costs of ADR-based systems. Moreover, the environmental study compares deliveries made with a combustion engine LCV Euro 6 LCV, which nowadays is a vehicle typically used for deliveries. However, the environmental impact of such vehicles is subject to change, particularly as companies increasingly adopt electric vehicles. The transition to electric or alternative fuel vehicles could significantly alter the environmental footprint of these delivery modes. Further research could strive to include electric LCVs as an alternative car-based system as well as other new mobility solutions that could be used in the last mile context such as drones. Moreover, once further last-mile delivery options are included a multivariate logit model is planned to be used to deepen the analysis of last-mile e-commerce modes. This approach will allow for a detailed examination of how various factors interact and influence delivery choices.

Furthermore, it is important to note that this study's findings are specific to European cities, and the same analysis could be replicated on other continents. The cities in different regions often have unique characteristics and challenges, and evaluating the performance of delivery systems in diverse urban contexts would provide a more comprehensive understanding of the topic.

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Author statement

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Annex 1

City	Mode	Distance	Duration	Cost [€/km]	Fuel consumption [l]	GHG [kg]	NOx [g]
Brussels	ADR	49,03	65,37	0,02	0	1,45	0,003579
Brussels	Bike	50,59	27,55	0,44	0	0	0
Brussels	Car	37,67	47,52	0,37	5,65	5,27	0,0141423
Barcelona	ADR	45,02	60,02	0,02	0	2,31	0,002376
Barcelona	Bike	50,22	27,48	0,45	0	0	0
Barcelona	Car	36,64	38,53	0,34	5,50	5,13	0,013756
Florence	ADR	37,28	49,70	0,02	0	1,62	0,001628
Florence	Bike	43,78	26,67	0,50	0	0	0
Florence	Car	50,65	58,75	0,35	7,60	7,09	0,01901284
Warsaw	ADR	35,06	46,75	0,02	0	4,46	0,00177433
Warsaw	Bike	40,58	24,38	0,49	0	0	0
Warsaw	Car	39,98	37,62	0,32	6,00	5,60	0,0150096
Paris	ADR	41,98	55,97	0,02	0	0,48	0,000628
Paris	Bike	41,46	21,45	0,42	0	0	0
Paris	Car	33,78	50,22	0,41	5,07	5,07	0,0126827
Gothenburg	ADR	32,23	42,97	0,02	0	0,05	0,000767
Gothenburg	Bike	39,68	22,25	0,46	0	0	0
Gothenburg	Car	37,52	41,03	0,34	5,63	5,63	0,014085
Vilnius	ADR	34,05	45,40	0,02	0	0,37	0,002963
Vilnius	Bike	45,99	29,44	0,52	0	0	0
Vilnius	Car	37,67	44,39	0,36	5,65	5,65	0,0141433
Thessaloniki	ADR	31,85	42,46	0,02	0	3,52	0,000114
Thessaloniki	Bike	39,14	19,72	0,41	0	0	0
Thessaloniki	Car	28,07	30,64	0,34	4,21	4,21	0,010539
Karlsruhe	ADR	24,29	32,39	0,02	0	1,71	0,00201012
Karlsruhe	Bike	27,88	16,27	0,48	0	0	0
Karlsruhe	Car	25,88	36,57	0,40	3,88	3,88	0,0097165
Cluj Napoca	ADR	34,29	45,72	0,02	0	1,52	0,0046
Cluj Napoca	Bike	38,26	21,15	0,45	0	0	0
Cluj Napoca	Car	30,44	28,15	0,32	4,57	4,57	0,0114274
Porto	ADR	41,45	55,26	0,02	0	2,44	0,323131
Porto	Bike	48,82	35,28	0,59	0	0	0
Porto	Car	34,64	39,24	0,35	5,20	5,20	0,0130028
Oulou	ADR	25,38	33,84	0,02	0	0,35	0,073835
Oulou	Bike	27,36	15,65	0,47	0	0	0
Oulou	Car	25,26	36,23	0,40	3,79	3,79	0,0094836
Ostrava	ADR	49,16	65,55	0,02	0	3,62	0,003309
Ostrava	Bike	55,56	28,85	0,42	0	0	0
Ostrava	Car	37,88	39,97	0,34	5,68	5,68	0,0142188
Ispra	ADR	129,82	173,10	0,02	0	5,66	0,0056688
Ispra	Bike	113,36	55,77	0,40	0	0	0
Ispra	Car	68,08	47,22	0,28	10,21	10,21	0,025559

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