

Home Delivery vs Parcel Lockers: an economic and environmental assessment

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Abstract: The past few years have been characterised by the emergence and the growth of B2C e-commerce in both developed and emerging countries (eMarketer, 2015). This phenomenon has highlighted the importance of conceiving new delivery strategies in order to deal with the increasing challenges of an internet-driven society. In this context, last mile logistics, i.e. the concluding distribution process to the end customer is particularly critical (Wang et al., 2014). One of its biggest problems is related to missed deliveries. The authors aim to analyse one of the solutions recently introduced to minimise missed deliveries, i.e. Parcel Lockers (PLs). More in detail, our objective is to develop an analytical model to assess the costs and the environmental impact of the distribution process based on the use of PLs and compare them with the ones of traditional Home Delivery (HD). The paper adopts a quantitative approach. The core of the research is represented by an Activity-based estimation model, which was developed and verified by following a three-step methodology: (i) Description of the last mile delivery phases in the two considered shipment options, (ii) Modelling of the environmental impact and costs produced by the two alternative processes, (iii) Application of the model to a base case, performance of sensitivity analyses and validation of results. We find that PLs generally cause less operational costs and carbon emissions than HD, although benefits are not homogeneously split among couriers and customers. The paper represents a starting point to bridge the gap found in the extant literature regarding the combined evaluation of e-commerce delivery processes from a financial and environmental perspective. The paper is also relevant for practice as it provides couriers with a reliable tool to support their decision-making activities and benchmark their environmental and economic performances.

Keywords: B2C e-commerce, Last mile logistics, Parcel Lockers, Costs, Environmental impacts

1. Introduction

The past few years have been characterised by the emergence and the growth of e-commerce in both developed and emerging countries (eMarketer, 2015). This phenomenon has highlighted the importance of conceiving new delivery strategies in order to deal with the increasing challenges of an internet-driven society. B2C e-commerce is indeed characterised by a demanding and granular approach to logistics, since transactions often consist of single-item orders, highly customised, which depend on impulse and are affected by seasonality, price and convenience (Bayles, 2002). This leads companies to strive for excellent supply chain performances in order to stay competitive and makes the last mile logistics, i.e. the concluding distribution process to the end customer, particularly critical (Wang et al., 2014). However, last mile delivery should be carefully considered not only for its effects on the service level, but also for its contribution to both total costs (Chopra and Peter, 2001) and pollution consequent to frequent missed deliveries (Gevaers et al., 2011).

In this context, the authors aim to analyse one of the solutions recently introduced to minimise missed deliveries, i.e. Parcel Lockers (PLs), by comparing its delivery costs and emission with the ones of traditional Home Delivery (HD). Despite last mile delivery is a

critical process anyways, its features and consequences may vary significantly according to the way the delivery itself is fulfilled. The mentioned solutions differ in the fact that while HD consists in basically shipping the item to the door of the client, the PL is a collection of cabinets where orders are delivered by the express courier and then autonomously picked up by the customer (Brummelman et al., 2003; McKinnon and Tallam, 2003).

2. Theoretical background and research questions

2.1 Theoretical background

B2C e-commerce has contributed to the diffusion of fragmented orders to be delivered to a high number of non-recurrent destinations, which can hardly be anticipated or planned. This makes it more complex to identify the most appropriate logistics strategy (Ghezzi et al., 2012) and may have negative impacts on the efficiency of the delivery process from the company's point of view.

Additional criticalities of the delivery process are linked to punctuality, i.e. the ability not to exceed the agreed delivery timing, the accuracy (i.e. integrity, security) of the delivered orders, the degree of flexibility achievable in terms of customisation of deliveries.

This has progressively led to the diffusion of alternative delivery methods, able to overcome some of the

limitations of traditional HD (e.g. missed deliveries, necessity to respect delivery windows).

Along with the creation of new delivery methods, multiple contributions have flourished with the main aim to compare them. For instance, McKinnon and Tallam provide an overview of five different methods of unattended delivery and compare their performances (2003) while Weltevreden empirically investigates the topic of collection and delivery points in the Netherlands assessing their impacts for retailers, shopping centres and mobility (2008).

Delivery solutions can be compared along different variables ranging from lead times (e.g. Fernie et al., 2010) to security (e.g. McKinnon and Talam, 2003), from costs (e.g. Agatz et al., 2008) to environmental impacts (e.g. Mangiaracina et al., 2015; van Loon et al., 2015).

It is important to note the current predominance of qualitative methodologies used to describe these delivery processes. This is especially true when it comes to address their sustainability, which has currently been approached mainly through case studies (e.g. Smith, 2012) and literature reviews (e.g. Mangiaracina et al., 2015; Winter & Knemeyer, 2013). Therefore, despite the presence of some analytical contributions (e.g. Edwards et al., 2011; Mangiaracina et al., 2016; Mckinnon et al., 2015), the theme of sustainability of e-commerce processes still needs further investigation by means of quantitative methodologies.

Finally, papers trying to integrate the financial and environmental perspectives thus providing a more comprehensive tool for decision making, seem to generally be missing in the extant literature.

2.2 Research questions

Given the identified gaps, the present study aims to contribute to the extant literature on last mile delivery by proposing an analytical model to compare HD and the alternative delivery through PL. The analysis additionally aims to show how the environmental and economic costs of each alternative are split among the involved players (i.e. couriers and customers). The PL seems quite interesting to investigate because it is currently becoming very common in countries with a high e-commerce penetration rate such as UK, Germany, France (Morganti et al., 2014). Also, since one of the highest cost generators for online retailers is delivering orders to individual addresses, such a solution represents a positive innovation to reduce operational costs while sustaining customer value (Chaston, 2016).

In order to reach the mentioned goals the following research questions will be addressed:

RQ1 - How is the last mile delivery process structured in the two considered alternatives?

RQ2 -How can environmental impacts and operational costs be modelled and measured in the two processes?

RQ3 – What are the key drivers that influence the environmental impact and the operational costs of the

processes? What are the effects of a change of these parameters?

3. Methods

The paper has an empirical approach. The core of the research is represented by an Activity-based estimation model, which was developed and verified by following a three-step methodology:

- Phase I – Description of the last mile delivery phases in the two considered shipment options
- Phase II – Modelling of the environmental impact and costs produced by the two alternative processes. The environmental impact is expressed in terms of kgCO₂e. These are calculated as the weighted average of the Global Warming Potential (GWP) of CO₂, CH₄ and NO₂. Costs solely include items classifiable as operational costs. Refer to Appendix A for details on the model architecture and assumptions
- Phase III – Application of the model to a base case, performance of sensitivity analyses and validation of results.

The main methods adopted in the Research are:

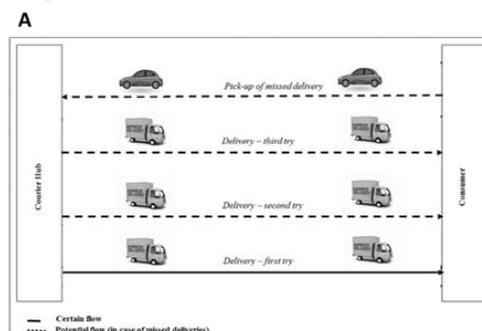
- Literature review to investigate how the environmental impact of a variety of processes is typically computed; this analysis confirmed that kgCO₂e is a commonly accepted indicator of the environmental footprint of a given process (e.g. Kellner and Igl, 2015; Pandey et al., 2011).
- 20 Interviews with specialised e-commerce operators and express couriers in order to (i) design the transportation flows of each delivery process, (ii) collect data for the model and (iii) receive feedback on its robustness.
- Analysis of secondary sources, such as logistics practitioners' journals, case studies, e-commerce websites, specific reports (e.g. Defra, 2015; FEFCO, 2015) and other trustworthy sources such as Automobile Club of Italy (ACI) to triangulate data coming from both the extant literature on the topic (e.g. Mangiaracina et al., 2016) and the interviews.

Empirically collected data were inputted in the model and used as a basis to perform the calculations.

4. Results

4.1 Definition of the delivery processes

In modelling the main activities of the last mile logistics in the HD and PL cases, only the pure shipment actions have been considered. The output of this stage is pictured in Figure 1 and answers RQ1.



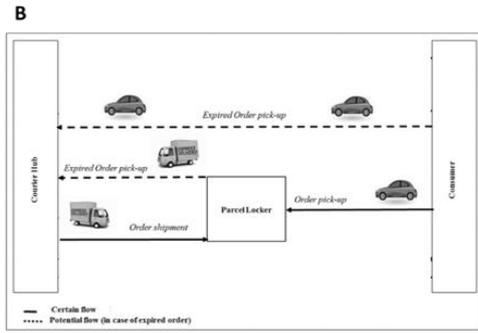


Figure 1: Configuration of delivery processes

As shown in the illustration above, HD (graph 1A) implies the company is in charge of the transportation of the order through courier services. If the customer is not home at the moment of the delivery, the shipment is repeated two more times. Only in case the customer is unreachable for the third time, the order is delivered back at the hub and stored there waiting for the customer pick-up. Conversely, when using a PL (graph 1B) both the courier and the customer are involved in the delivery. The former brings the ordered item to the PL, the latter has to go there and take it, after receiving a notification that the order is ready to be picked up. However, generally the customer has a limited time of 3 days before the order “expires” and is taken back to the hub. If that happens (1% of the cases) the customer will need to personally collect the item at the hub.

4.2 Operational costs and emissions in the base cases

Two base scenarios were considered in our model, as the customer location impacts on multiple parameters:

- (i) Customers living in an urban area;
- (ii) Customers living in an extra-urban area.

Figure 2 shows the environmental impact produced when customers live in an urban area for both HD and PL configurations.

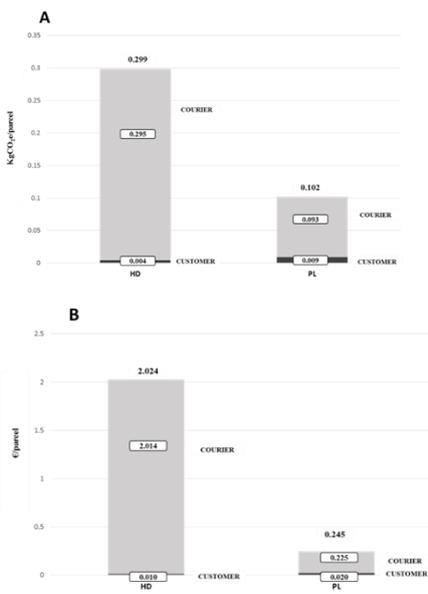


Figure 2: Costs and emissions – Urban case

As for the environmental impact, graph 2A reveals that PLs help reduce almost by two-thirds the emissions of HD. Moreover, regardless of the chosen delivery method, the emissions attributable to the customers are significantly lower than the ones produced by the courier, especially in the HD case where they reach a value of 0.004 KgCO₂e/parcel thus accounting for just nearly 1% of total emissions. This is because, in both configurations, the emissions due to the customer are linked to order recovery activities, which take place only if regular delivery fails. The higher incidence of the customer component in the PL case signals that a parcel “expiration” consequent to a non timely collection generally weights more than a triple HD failure. Much more important is the difference in the emissions produced by the courier in the two processes. The impact is indeed three times higher in traditional HD than in the PL. This is because the courier needs to travel more to reach every customer house rather than to unload the whole orders to the locations where the PLs are installed.

By summing up the components associated to the different actors an overall gap of 0.197 KgCO₂e per parcel is registered between the two examined methods, with the HD and the PL respectively producing and impact of 0.299 KgCO₂e/parcel and 0.102 KgCO₂e/parcel.

Coming to the costs (graph 2B), a similar path can be observed. The part of costs sustained by the customers is negligible in the HD process, while representing around 8% of the total (i.e. 0.02 €/parcel out of the overall 0.245 €/parcel) when using PL. The majority of costs is again associated to the courier. In total (by considering both costs of the courier and the customers) using PLs allows to overall save 1.779 €/parcel.

Figure 3 reports the environmental impact and the costs associated to the extra-urban scenario

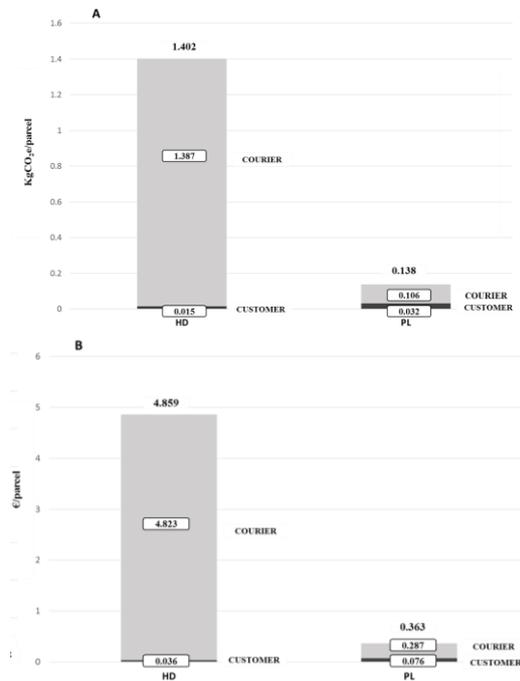


Figure 3: Costs and emissions – Extra-urban case

CO₂e emissions linked to the customer activities are marginal in the HD process while they account for 23% of total emissions in the PL alternative. However, the greatest contributor is again the courier that produces a 13 times higher impact in HD than in the PL case. The difference between the two configurations is significantly more marked here than in the urban setting. This happens mainly because deliveries to customer houses in peripheral zones are extremely onerous (44 deliveries/day are generally executed in extra-urban areas, vs. 88 in urban areas). By summing up all the emissions produced in the extra-urban scenario (i.e. 1.402 KgCO₂e/parcel in the HD case and 0.138 KgCO₂e/parcel in the PL case) a gap of 1.264 KgCO₂e/parcel is registered between the HD and PL processes. Accordingly, the HD alternative happens to be more costly than the PL with a total cost per parcel highly exceeding 4 €, mainly due to the courier's activities again. The courier indeed needs to travel definitely higher distances to deliver the parcels with respect to the urban case. The costs to be sustained by the customers only account for 1% in this scenario.

4.3 Sensitivity analysis

In the static scenarios we have noticed how generally PLs are less costly and more sustainable solutions than HD. However, such results were mainly providing benefits to couriers rather than customers. By means of sensitivity analysis the authors aim at measuring the actual convenience of the solution for both customers and couriers by varying:

- (i) the "deviation": we assume the customers need to deviate of x km from their habitual route in order to reach the PL, with $x \in [0 \text{ to } 10]$.
- (ii) the "density": we assume the average distance between two PLs can be "high", "medium" or "low". The lower the distance, the higher the density.

The specific scenarios considered for the sensitivity analysis are displayed in Appendix B, while this section only discusses results.

Let us start with the urban case. We changed the parameters one at a time. Results reveal that when changing the deviation (and leaving the density at the default value) the emissions produced by the PL alternative range from a minimum of 0.102 KgCO₂e/parcel to a maximum of 0.95 KgCO₂e/parcel. The breakeven in terms of carbon emissions between the two alternatives is reached for a deviation slightly lower than 1 km (i.e., 0.94 km). For any distance higher than this one, the PL alternative produces higher emissions than HD. A specular analysis is conducted by considering operational costs. In this case the PL alternative is less costly than HD for any deviation smaller than 3.5 km. When exceeding such distance, the transportation costs that each individual has to bear in order to collect the item are so high that PL becomes less convenient than traditional HD. The costs of delivering through PLs range from 0.245 €/parcel to 2.3 €/parcel.

By changing the density of lockers (i.e. high, medium, low) in the urban case, minimal differences occur with respect

to the base case both from an environmental and an economic perspective. The density has an impact mainly on the courier that needs to lengthen its journey to refill the lockers thus increasing carbon emissions and costs. However, the possibility to travel full load softens the impact of this phenomenon so that density can be considered a less critical parameter than the deviation operated by the customers to reach the cabinets. This in turn means that the main objective of a successful PL strategy should be to minimise the extra-distance travelled by customers but also that this objective is not necessarily to be reached by increasing the number of the lockers. It could rather be more beneficial to detect their most effective and strategic positioning.

Moving to the case of extra-urban customer location, the PL produces emissions ranging from 0.138 to 2.67 KgCO₂e/parcel and costs of 0.363 to 5.35 €/parcel. The distance making the two alternatives indifferent is around 6 km with reference to emissions and 9.135 km with reference to operational costs, all further distances resulting in higher convenience of HD. These values are significantly higher than the ones registered in the urban setting because in this case couriers travel much longer distances to fulfil a delivery at home. It is therefore "harder" for HD to become preferable to PL. Once again the analysis is repeated by setting the density feature on a "high" and "low" level. As already observed in the urban scenario, these additional sensitivity analyses show little difference with the base scenario and confirm that the most critical parameter is the deviation rather than the density. However, it is interesting to note that the gap in the emissions and costs of HD and PL configurations is larger in an extra-urban context than it is in an urban one. This means that being able to turn traditional HD into PL when customers live outside the city can bring significant environmental and cost benefits for the community as a whole.

The results delivered by the model have undergone a validation process. A second round of interviews with major logistics operators has been conducted. These experts have confirmed the entity of operational costs is coherent with reality while no opinion could be expressed with reference to carbon emissions since interviews have shown no proper carbon footprint tracking system is in place at any of the interviewees. This part of the model will then need to be validated by future research.

5. Conclusions

Given the main purpose of this paper – i.e. to perform an analysis of traditional HD and the delivery through PLs in a B2C e-commerce environment – a quantitative Activity-based model has been developed to assess the kgCO₂e and the operational costs of the mentioned processes.

The main evidences from this study are:

- (i) PLs can be considered a valid alternative to HD since they are more sustainable from both an economic and environmental point of view. Benefits related to this solution mainly derive from the possibility, for the logistics provider, to execute deliveries more efficiently.

(ii) From an environmental point of view, the convenience of the PL keeps valid for the whole community (in our case, the couriers and the customers) as long as the distance the customer needs to purposely travel by car to reach the PL does not exceed 0.94 km in a urban context and 6 km in an extra-urban one. From an economic point of view, the convenience of the PL is present also for customers as long as the distance they need to travel by car to reach the PL does not exceed 3.5 km in a urban context and 9 km in an extra-urban one. Beyond these thresholds the PL will only be convenient for the logistics operators

(iii) The split of costs and emissions between customers and couriers significantly varies in the two configurations. More specifically, the use of the PL implies – by definition - a more active involvement of the customers

(iv) The location of the customer house is a key parameter in determining the entity of benefits associated to PL due to a significant difference in the density of urban and extra urban areas affecting costs and emissions of a traditional delivery route. Also the identification of the best location for positioning the PLs is a key issue.

(v) the density of PLs does not seem to influence the processes significantly. However, density plays a role too. Despite their promising features, PLs are indeed beneficial mainly when they reach a sufficiently critical dimension. This is hard to achieve in a short time, especially if merchants have to build their PLs network from scratch. This is the main reason why PLs are not largely diffused yet.

To conclude, one potential limitation of the paper is highlighted: the focus was only on cost items which can objectively be quantified. Other types of cost which can vary according to the subject (e.g. opportunity cost for the time the customer spends to pick-up the parcel) were excluded from the analysis.

References

- Agatz, N.A.H., Fleischmann, M., and Van Nunen, J.A.E.E. (2008), "E-fulfillment and multichannel distribution -A review", *European Journal of Operational Research*, Vol. 187 No. 2, pp.339-356.
- Bayles, D. E-logistics & e-fulfillment: Beyond the "buy" button (2002). Paper Presented At UNCTAD Workshop 2002 Curaçao.
- Brummelman, H.J., Kuipers, B. and Vale, N. (2003), *Effecten van Packstations op Verkeersbewegingen (Impacts of Locker Points on Mobility)*, TNO Inro, Delft.
- Chaston, I. (2016). *Entrepreneurial Marketing. Sustaining growth in all organisations*, New York, NY: Palgrave.
- Chopra, S., and Peter M, (2001). *Supply Chain Management: Strategy, Planning, and Operations*, Upper Saddle River, NJ: Prentice-Hall, P. 28–34.
- DEFRA (2015), "2015 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors" [online], available at: www.ukconversionfactorscarbonsmart.co.uk/ (accessed 20 July 2015).
- Edwards, J.B., McKinnon, A.C. and Cullinane, S.L. (2011), "Comparative carbon auditing of conventional and online retail supply chains: a review of methodological issues", *Supply Chain Management: An International Journal*, Vol. 16 No. 1, pp. 57-63.
- eMarketer (2015). *China Ecommerce: 2015 Market Update*. [report].
- FEFCO (2015), "European Database for Corrugated Board Lifecycle Studies", European Federation of Corrugated Board Manufacturers [online], available at: <http://www.fefco.org> (accessed 20 July 2015).
- Fernie, J., Sparks, L., and McKinnon, A.C. (2010) "Retail logistics in the UK: past, present and future", *International Journal of Retail & Distribution Management*, Vol. 38, No. 11/12, pp.894 – 914.
- Gevaers, R., Van de Voorde, E., and Vanelander, T. (2011). "Characteristics and typology of last-mile logistics from an innovation perspective in an urban context" in Macharis, C. and Melo, S. (Ed.), *City Distribution and Urban Freight Transport – Multiple Perspectives*, Edward Elgar Publishing Limited, Cheltenham, UK, chapter 3, pp. 56-74.
- Ghezzi, A., Mangiaracina, R. and Perego, A. (2012) "Shaping the e-commerce logistics strategy: a decision framework", *International Journal of Engineering Business Management*, Vol. 4, No. 13, pp.1–13.
- Kellner, F., and Igl, J. (2015) "Greenhouse gas reduction in transport: Analysing the carbon dioxide performance of different freight forwarder networks", *Journal of Cleaner Production*, Vol.99, pp.177-191.
- Mangiaracina, R., Marchet, A., Perotti, S., and Tumino, A. (2015), "A review of the Environmental Implications of B2C eCommerce: A Logistics Perspective", *International Journal of Physical Distribution and Logistics Management*, Vol. 45, No.6, pp.565 – 591.
- Mangiaracina, R., Perego, A., Perotti, S. and Tumino, A. (2016), "Assessing the environmental impact of logistics in online and offline B2C purchasing processes in the apparel industry", *International Journal of Logistics Systems and Management*, Vol. 23, No.1, pp. 98-124.
- McKinnon, A.C., and Tallam, D. (2003) "Unattended delivery to the home: an assessment of the security implications", *International Journal of Retail & Distribution Management*, Vol. 31 No: 1, pp. 30 - 41.
- Morganti, E., Seidel, S., Blanquart, C., Dablanc, L. and Lenz, B. (2014). "The impact of e-commerce on final deliveries: Alternative parcel delivery services in France and Germany", *Transportation Research Procedia*, Vol. 4, pp. 178–190.

Pandey, D., Agrawal, M., and Pandey, J.S. (2011), "Carbon footprint: current methods of estimation", *Environmental Monitoring and Assessment*, Vol. 178 No. 1-4, pp.135-160.

Smith, A.D. (2012) 'Green manufacturing in the packaging and materials industry: case study of small-to-medium sized corporate eco-friendly initiatives', *International Journal of Logistics Systems and Management*, Vol. 11, No. 4, pp.429–449.

van Loon, P., Deketele, L., Dewaele, J., McKinnon, A., and Rutherford, C., (2015), "A comparative analysis of carbon emissions from online retailing of fast moving consumer goods", *Journal of Cleaner Production*, Vol. 106, pp. 478-486.

Wang, X., Zhan, L., Ruan, J. and Zhang, J. (2014). "How to Choose "Last Mile" Delivery Modes for E-Fulfillment," *Mathematical Problems in Engineering*, vol. 1, pp. 1-11.

Weltevreden, J.W.J. (2008) "B2c e-commerce logistics: the rise of collection-and-delivery points in The Netherlands", *International Journal of Retail and Distribution Management*, Vol. 36, No. 8, pp.638 - 660

Winter, M. and Knemeyer, A. M. (2013), "Exploring the integration of sustainability and supply chain management: Current state and opportunities for future inquiry", *International Journal of Physical Distribution & Logistics Management*, Vol.43 No.1, pp.18–38.

Appendix A. Model assumptions and architecture

Model assumptions

The main underlying hypotheses used to build the model are listed below:

- (i) Traditional deliveries that are unsuccessful at the third try and the orders in the cabinet which are uncollected after three days are assumed to be picked up at the sorting center exclusively by car;
- (ii) Every customer orders a single parcel;
- (iii) "Standard PLs" are used. They consist of 47 boxes of uneven dimensions so that items of various sizes can be easily stored.
- (iv) The average saturation coefficient for each locker is 60%.

Model architecture

The model architecture consists of three main components, i.e. an inputs section displaying the information required to run the model, hidden spreadsheets for data computation (containing contextual data, and the mathematical formulas to calculate the environmental impact and the costs of each delivery process), and an interface allowing the user to visualise the output graphs and tables. More in detail, the input section contains data related to the four categories listed below:

- (i) Customer location, i.e. specification of the positioning of the customer's house (urban or extra-urban area);
- (ii) Deviation needed to reach the PL, i.e. average extra distance (in km) the customers need to purposely travel towards the locker;

- (iii) Density of PLs, expressed as the average distance between two PLs.

Apart from the listed inputs, the model elaborates results based on a set of context data, grouped into the following main clusters:

- (i) CO₂ emissions [kgCO₂e/parcel], deriving from the transportation and dependent on both the type of vehicle and its saturation.
- (ii) Costs [€/parcel], including all transportation related costs (i.e. costs of employees involved in the process, costs proportional to the use of transportation means such as fuel consumption, wear and maintenance, costs not proportional to the use of transport vehicles such as insurance premium and vehicles taxes (ACI, 2014).
- (iii) Delivery route [km], referred to the length of the delivery course;
- (iv) Shipment features, which present various data mainly related to the delivered flows and the characteristics of the load;
- (v) PL features, e.g. average number of compartments, their dimensions and average energy consumption, average permanence of the item in the cabinet;

The core element of the model is the one containing the computation algorithms, able to return a measure of the CO₂e per order delivered [kgCO₂e/order], where an order corresponds to a single parcel, and associated operational costs.

Last, the model outputs are listed into a spreadsheet. They can be selected by the user and visualised through tables and graphs. More in detail the outputs returned by the model are the total unitary emissions [KgCo₂e/parcel] and costs [€/parcel] related to the HD and PL processes. All values are obtained by summing up the operational costs related to the courier and the ones related to the consumer.

Appendix B. Sensitivity analysis - Scenarios

A total of six scenarios were simulated in the study in addition to the base cases, whose features are summed up below:

Scenario	Customer location	Density of PL	Deviation to reach the PL
Scenario 1	Urban	High	0 km
Scenario 2	Urban	Medium	Up to 10 km
Scenario 3	Urban	Low	Up to 10 km
Scenario 4	Extra-urban	High	0 km
Scenario 5	Extra-urban	Medium	Up to 10 km
Scenario 6	Extra-urban	Low	Up to 10 km