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Sustainable Urban Logistics in Milan: Train, Electric Vehicles and Cargo-Bicycles as alternatives to traditional deliveries

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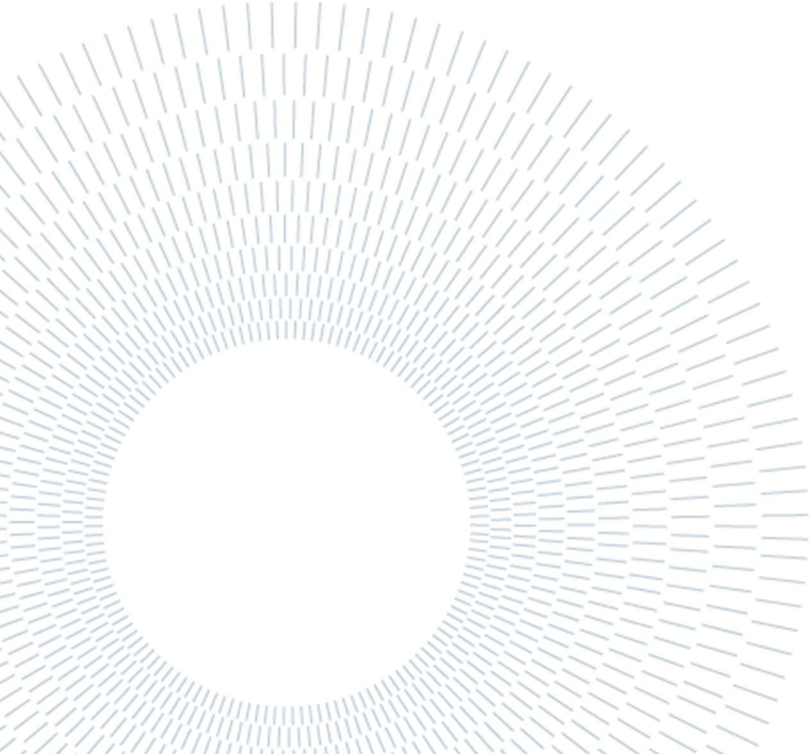


Abstract

Urban logistics operations are growing in volume at a very fast pace, mainly given by a significant increase year over year of e-Commerce penetration in almost every industry. Last-mile deliveries are the most inefficient activity in delivery networks impacting the costs and the environment, generating high pollution, and affecting people's quality of life, increasing congestion and noise pollution mainly. Therefore, there is a need to improve these processes and to design a much more sustainable network, for both companies and citizens, than traditional deliveries performed with traditional vans. In the present academic literature different solutions are proposed, like usage of alternative vehicles or collaboration among different stakeholders. However, only networks with one or two vehicle classes are proposed and the scope is usually limited to only the door-to-door deliveries, not considering the path for goods to reach the city center. This thesis work wants to fulfill these gaps developing a network covering from outside the city center capable of decreasing the environmental impact while also trying to get a solution that is not more expensive than traditional one. The proposed network exploits the usage of both EVs and Cargo-Bicycles for last mile deliveries, differentiated them according to the dimension of the parcels moved. Applying the study to the city of Milan, from a Courier Hub outside the City some EVs for deliveries directly start their delivery tours, while for the Cargo-Bicycles flow goods are moved into towards the City Center with the usage of a Truck and small Cargo Train and are then distributed by other EVs to some Micro-Hubs that as starting point for Cargo-Bicycles. To evaluate the to-be and as-is networks performances a simulation model on ArcGis was built, considering for emissions the ones generated for fuel production and during consumption, while for costs all operating costs, included renting of the vehicle. Comparing the performances of two networks very insightful results are obtained, with not only a drastic fall in emissions produced but also a decrease of the cost of the solution, proving Cargo-Bicycles to be the most efficient vehicle available for last-mile deliveries. Sensitivity analysis performed on some parameters suggests more insights, on how different penetration of Cargo-Bicycles usage affect the results, proving that the higher it is the best it is in terms of performance, with huge emission savings obtained even if with low percentages of adoption, while cost savings need higher adoption to be present.

Keywords: Last-mile delivery, Sustainable Urban Logistics, Cargo-Bicycles, e-Commerce

Abstract in italiano

La logistica nei centri urbani sta assumendo un ruolo sempre più importante data la veloce crescita dei volumi di pacchi spediti giornalmente dovuta principalmente alla sempre maggior penetrazione dell'e-commerce in quasi tutti i settori. L'attività più inefficiente è il last-mile delivery, che incide particolarmente su costi e ambiente, generando un elevato inquinamento e incidendo sulla qualità della vita delle persone, aumentando traffico e inquinamento acustico. Pertanto, è necessario progettare un sistema più sostenibile rispetto a quello tradizionale. In letteratura vengono proposte diverse soluzioni, come veicoli alternativi o collaborazioni tra diversi stakeholders. Tuttavia, queste proposte sono solo con uno o due diversi mezzi di trasporto e solitamente non considerano il percorso delle merci per raggiungere il centro città. Questo lavoro di tesi si propone di colmare i gap individuati in letteratura sviluppando una sistema in grado di diminuire l'impatto ambientale, garantendo l'efficienza del processo in modo che il costo della soluzione proposta non sia maggiore di quello del network tradizionale. La soluzione proposta utilizza per le consegne sia van elettrici che Cargo-Bike, differenziando i due in base alla dimensione dei pacchi consegnati. Lo studio è stato sviluppato sulla città di Milano, da un Hub fuori Città una flotta di van elettrici iniziano direttamente i loro tour di consegna, mentre le merci da trasportare con le Cargo-Bike vengono trasportate in Centro Città tramite un piccolo treno merci. Queste ultime sono distribuite da altri van elettrici in alcuni Micro-Hubs, punto di partenza dei tour delle Cargo-Bike. Per valutare le prestazioni delle soluzioni To-be e As-is è stato costruito un modello di simulazione su ArcGis, considerando per le emissioni quelle generate per la produzione di carburante e durante l'utilizzo dei mezzi, mentre per stimare il costo due network sono stati considerati i costi operativi, compreso il noleggio del veicolo. Confrontando le prestazioni, si nota, non solo un drastico calo delle emissioni prodotte ma anche una diminuzione del costo della soluzione, dimostrando che le Cargo-Bike sono un veicolo molto efficiente per le consegne last-mile. Inoltre, tramite una delle analisi di sensitività effettuate, emerge che, mentre per avere risparmi economici è necessaria un'adozione medio-alta, dal punto di vista ambientale si hanno enormi miglioramenti anche con percentuali molto basse di adozione.

Parole chiave: Last-mile delivery, Sustainable Urban Logistics, Cargo-Bicycles, e-Commerce

Contents

Executive Summary

1 Purpose of the study

The context on which this study focuses on is the one of last-mile deliveries and specifically deliveries related to e-commerce orders, which consist in the most of the last-mile deliveries performed and is a continuously growing phenomenon. Considering the Italian market, the value of e-commerce reached in 2021 an aggregate value of 39.4 billion with 578 million deliveries of products, growing in value and orders respectively 21% of 20% compared to 2020 (B2C eCommerce Observatory, Politecnico di Milano 2021). Last mile deliveries networks have some common aspects that effects their efficiency and make them expensive compared to aggregate deliveries. Indeed, customers need to be served singularly also demanding a high service level, making last-mile deliveries a complex and inefficient activity (Yu et al., 2016). Moreover, given the time needed for the actual delivery, the number of parcels delivered per tour is lower than its capacity and vehicles used are therefore unsaturated, which increases overall impact of deliveries activities.

Overall, inefficiencies bring to low optimization of emissions and costs, and it was proved how last-mile delivery is the most significant component of the whole parcel delivery costs, corresponding to 50% of it (Martin Joerss et al., 2016). Given the relevance that door-to-door deliveries have already and are always more obtaining, exploring more sustainable ways to perform them is quite a hot topic and need for metropolitan societies.

The purpose of this thesis work is therefore to propose an innovative solution to perform last-mile deliveries, capable of acting on both economic and environmental impact of urban logistics for the company's sake on one side and the environment and people health and life quality on the other.

2 Extant Literature

The first step of the study was to perform a systematic literature review in order to deepen, understand and classify the studies already performed on the topic of our interest and identify possible research gaps present that our study may aim to fulfil. The methodology of the literature review followed R. Mangiaracina et al. (2015), which, in turn, is based on Srivastava (2007). The first main phase consisted in the Papers selection, which were gathered through online libraries on the topic of "Urban logistics sustainability" and then selected in different steps according to their content and relevance, bringing from 668 initial papers to a research corpus analysed of 64 papers. The second phase was then the review itself.

The first step of the review was to analyse geographical and temporal distribution of the studies, highlighting how the contribution in the literature about this topic is something whose relevance increased a lot in the recent years and that is studied in developed countries much more than in developing one. Then the most spread research fields and methods were identified, realizing that most of the publications performed on Logistics & Supply Chain journals and using Analytical methods and Simulations, but also many Case studies. Given the practical topic we are investigating, indeed, many studies are related to real application case or else evaluation of potential implementations.

Going to the content and the classification of the papers, two classification axes have been used:

- Solution proposed: Regulations, Stakeholders' Collaboration, Non-Road Transportation, Alternatively Powered Vehicles, Cargo Bicycles, Autonomous Vehicles.
- Impact analysed: Economical/Operational, Environmental, Social.

On the first classification axes, what emerged was that many different networks can be set up, using different types of vehicles and strategies. The most common solution analysed is the usage of Cargo-Bicycles, given the very high emissions savings achieved and their affordable-price, while also maintaining good operational performances. The other most common solutions consider the usage of Alternative Powered Vehicles, which means Electric Vans (EVs) or hybrid ones, and Non-Road Transportation, which means tramways, railways, and waterways.

In general, three classes of vehicles used can be identified:

- Heavy Non-Road Vehicles, with high capacity and low costs and emissions per parcels but also low accessibility and flexibility, particularly suited for long movements without stops.
- Medium Road Vehicles, electric and hybrid vans, with medium capacity and huge accessibility and flexibility but also higher costs and emissions per parcel, particularly suited for medium-distance and weight moved tours.
- Small Road Vehicles, Cargo-Bicycles and Autonomous Vehicles as robots and drones, with lower capacity but huge accessibility and flexibility with however lower cost than vans, particularly suitable for the last-mile.

Networks with both only one vehicle type or more are presented, however, no solutions consider the possibility of using more than two vehicle classes assigning to each a piece of the supply chain and also no papers consider the whole path from outside of the city to the customers locations.

On the other side, considering the impacts studied, almost every paper in the corpus considered analyses the economical/operational dimension of the solution proposed, many the environmental one and only few the social one. Indeed, the first two are easier to be computed mathematically, which is harder instead in the case of social impact.

Our study wants to fulfil the gap identified, designing a network in which many vehicles are used, assigned to each the task that it can perform at best, to optimize cost generated and emissions produced for last-mile deliveries.

3 Methodology

Given the outcomes of the analysis performed on the academic literature and the purpose of the study, the research questions formulated are the following.

- RQ1: Is it possible to design an integrated network of different green vehicles from out-of-cities to customers' homes?
- RQ2: What is the Economic and Environmental savings that can be achieved in this way with respect to traditional networks?

To answer our research questions a Simulation model has been developed from the point of view of an express courier that exploits the benefits of using railways, EVs, and Cargo-Bicycles in a new and green integrated network simulated in the city of Milan.

The development and implementation of the model has been performed on ArcGIS, a geographical information system (GIS) that allows to perform geostatistical simulations. This choice allowed us to have different benefits given by the nature of simulation models such as being capable of randomizing customers on the real map of the city of Milan, to assess variability in different scenarios and to consider real time and distances needed and covered for performing each route.

Given some inputs, the model optimizes the routing of the different vehicles in order to serve all customers minimizing total distance covered and time needed. Then, through costs or emissions parameters, per unit of time or distance, total costs and emissions produced in a day of operations are computed. The same process is done also for the traditional deliveries network, which considers only Internal Combustion Engine Vans (ICEVs), and finally the economic and environmental performances of the two networks are compared to evaluate benefits and drawbacks.

At first, one case is analysed and compared to the traditional one, which is defined as Base Case, based on real volumes delivered in 2021 and some assumptions made in terms of network settings. Then, through a sensitivity analysis, the robustness of the model and the outcomes in different settings are evaluated, understanding if and how the results would change varying some of the inputs.

The activities considered for the assessment are the handling of parcels in the different infrastructures, the transportation of goods performed by vehicles and the delivery activities. Previous activities related to goods consolidation and sorting are not considered because not differential between the innovative and traditional networks, and also not significant on the overall costs and emissions produced.

For computation of Costs, we started from the framework used in R. Mangiaracina et al. (2019) adapting it a bit according to our goal. The final cost evaluation defined considers costs related to drivers and to vehicles, the last of which composed by

Feeding and Rental one, which also includes maintenance. Moreover, a daily toll for ICEVs assessing the city center of Milan is included. Different is the case of the Train in which the service is performed by a Railway Operator and therefore paid as a service on the base of distance and weight moved.

As regards emissions, similarly to most papers studied, as Carbon dioxide equivalent (CO2e) is adopted, in which all emissions coming from the different Greenhouse Gases produced are expressed in reference to CO2, using the Global Warming Potential (GWP) of each. For the method used the choice fell on the Well-To-Wheel analysis, in which emissions are computed considering the fuel production (Well-To-Tank) and the vehicle use (Tank-To-Wheel). What is therefore missing in this perspective is the emissions produced during the production of the vehicles, which is out of the scope of this thesis work, focused instead on operational results, costs and emissions.

4 Model Development

4.1. Model design

The network developed considers an express Courier that delivers through the innovative solution proposed the whole flow related to e-commerce delivers on the area inside the ring-road of Milan.

The starting point is a Courier Hub outside the city of Milan were the goods to be delivered are consolidated and sorted per delivery tour. From there two flows are delivered differently, according to the weight they have:

- Parcels over 2kg will be delivered by EVs directly from the Courier Hub.
- Parcel within the band 0-2kg will be delivered by Cargo-Bicycles starting from some Micro-Hubs located in the City Center.

The network related to Cargo-Bicycles deliveries is visualized in Figure 1.

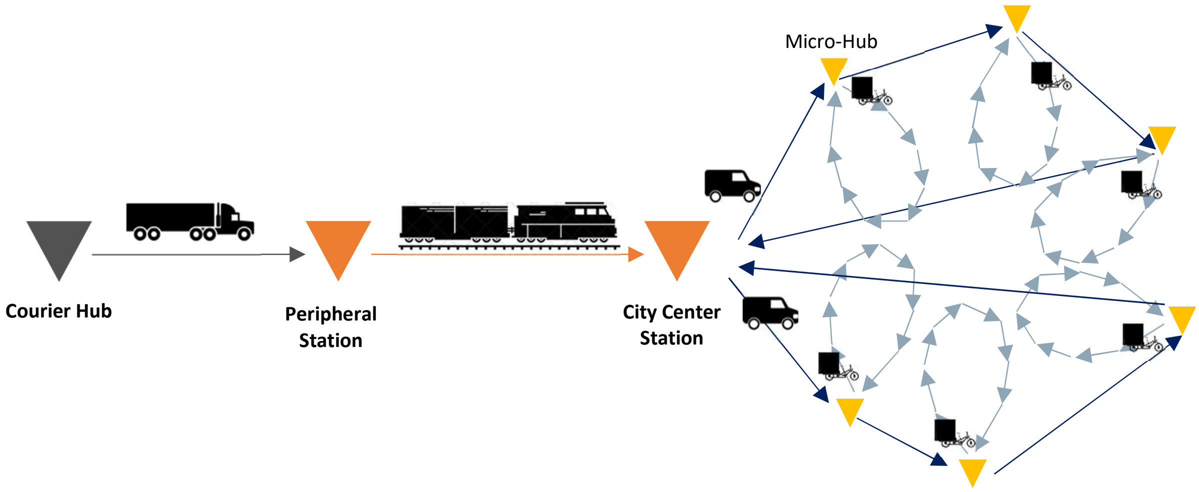


Figure 1 Cargo-Bicycles deliveries network

To move the goods from the Courier Hub to the Micro-Hubs, these are transported by a Truck to a nearby train station, and then by a Train towards a train station located into the city center. Here some other EVs, initially located in a parking spot near the City Center, collect the parcels and bring them to the Micro-Hubs from where the Cargo-Bicycles start their tour. At the end of their tour the Cargo-Bicycles leave the parcels related to failed deliveries and returns performed at the Micro-Hubs and an additional EV performs a tour to collect these parcels and bring them back to the Courier Hub.

4.2. Data

Considering the whole computational process, five different categories of data are involved:

- Input data: market data about deliveries and parcels dimensions inserted into the model.

- Context data: vehicles and activities data based on the application context of the study.
- First Output data: results of the simulation model in terms of distance travelled and total time required by each mean of transportation.
- Consumption data: costs and emissions factors needed to compute the total impacts starting from operational results.
- Final Output data: total costs and emission produced.

4.3. Simulation model design

As regards the actual definition of the network, after defining the activities included into the scope of the analysis, the model was built on ArcGis.

While the location of the Courier Hub and the train stations are consistent to the existing infrastructures, the Micro-Hubs locations, which are specifically 6, are obtained through a Location-Allocation problem resolution with the customers to be served as reference points and a group of 38 points as candidates for the hubs.

The final setting of the model on ArcGis is displayed in Figure 2.

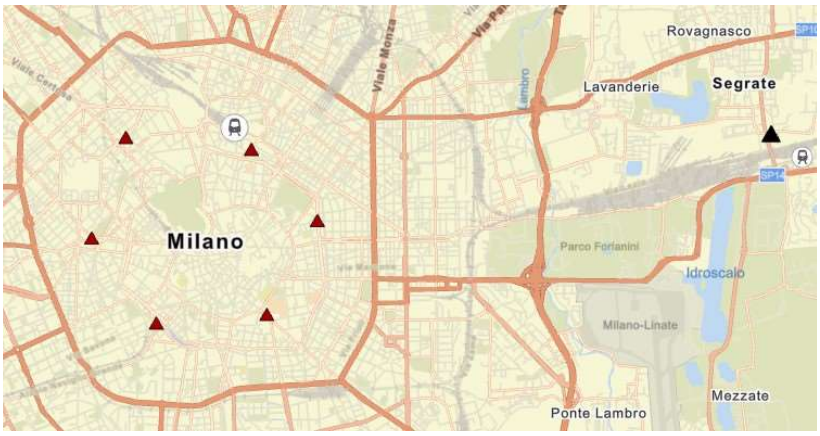


Figure 2 Problem Setting on ArcGis

The solution of the problem is based on different Vehicle Routing Problem, one per each mean of transportation and task performed, each considering the specific vehicle characteristics, infrastructures used, and points served. Solving the VRPs the routes are defined, and operational results obtained for all vehicles apart from the Train, for which instead the distance is obtained through a measurement tool and time spent is not relevant. In Figures 3, 4 and 5 are shown tour examples of respectively an EV that fulfills the Micro-Hubs, a Cargo-Bicycle and an EV that performs deliveries.

Given the complexity of the model, the many vehicles used and the interdependencies between their flows and activities, intermediate steps are performed between the different VRPs. For example, based the results of the Cargo-Bicycles the parcels to be moved to each Micro-Hub is defined, which is an input of the EV Fulfilling VRP. These computations are performed on Microsoft Excel where also the final outputs are computed.

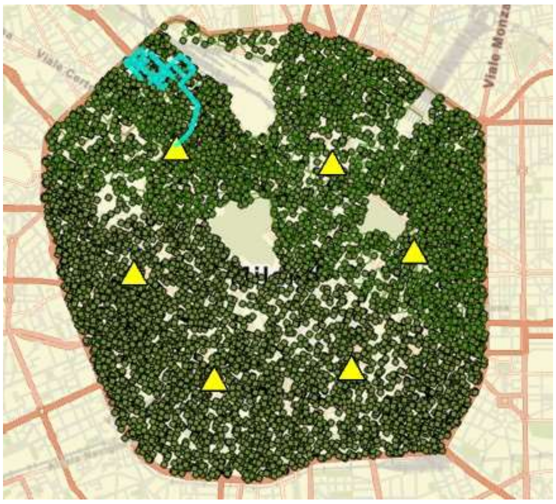


Figure 4 Example of Cargo-Bike network with tours

Figure 3 Example of EVs Fulfilling network with tours

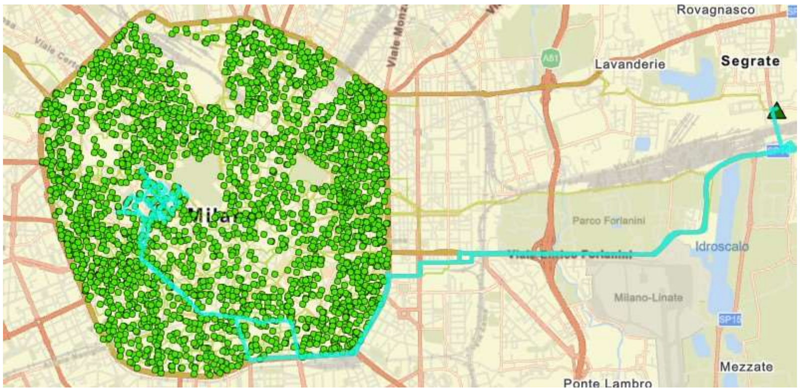


Figure 6 Example of EVs Deliveries network with tours

The model related to the Traditional Network is much simpler and consist in just one VRP with ICEVs delivering to customers directly starting from the Courier Hubs as displayed in Figure 6.

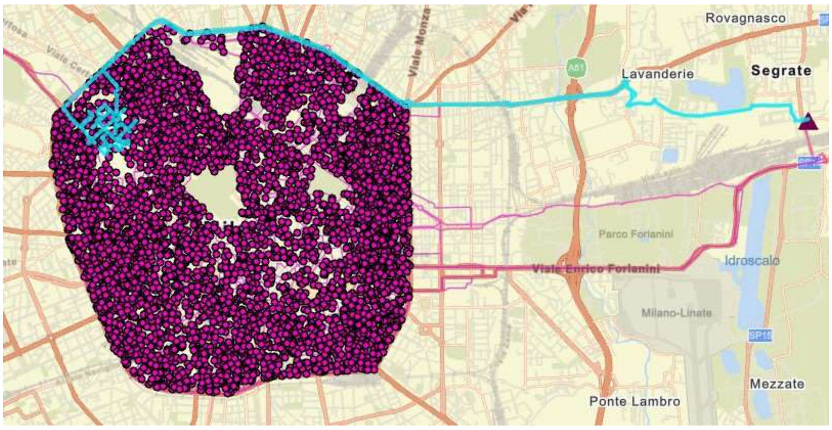


Figure 5 Example of traditional network with tours

5 Results

5.1. Base Case

According to the results of the model benefits can be achieved implementing the proposed solution in both emissions and costs.

On the emission side, it was expected, being the transition to green vehicles the basis of the network definition. Specifically, only 54.7 kgCO2e/day are produced with the innovative network, versus the 998.9 kgCO2e/day generated in the traditional network, with savings of 94.5%. The vehicles employed are indeed not comparable at all in terms of environmental sustainability, with 307.4 gCO2/km produced by ICEVs, 57.2 by EVs and 2.3 by Cargo-Bicycles. Therefore, even if the number of total vehicles is slightly higher, in the green network emissions are sensibly reduced.

Going on costs, instead, the solution proposed generates an overall cost of 21,589€/day versus the 23,146€/day produced by the traditional network, giving 6.7% of cost savings. Since our model also considers vehicle cost, this was not a certain outcome, being the EVs more expensive than ICEVs, not off-setting with lower fuelling and maintenance cost the higher vehicle cost. However, also in this case, Cargo-Bicycles, which are 84 out of the 110 vehicles used, play the fundamental role of decreasing vehicles cost so to offset the higher total driver cost of the network given by the increased number of total vehicles.

Deepening the contributions of the different transportation mean on emissions and costs, interesting outcome are obtained as well. On emissions, EVs Deliveries, even if are only the 16% of the vehicles, produce the 71.5% of the emissions, followed by the Train with the 11.3% and EVs Fulfilling with 8.9%. All the other vehicles account for around the 3% each, but what need to be noted is again how the Cargo-Bicycles, 76% of the vehicles, produce only the 3% of the emissions. Different is the role on costs, in which the main cost is given by the Driver cost, and therefore it is more aligned with the amount of vehicles per type. The 97.5% of the cost is therefore generated just by Cargo-Bicycles and EVs Deliveries, with the other EVs, the Train and the Truck being not significant.

5.2. Sensitivity Analysis

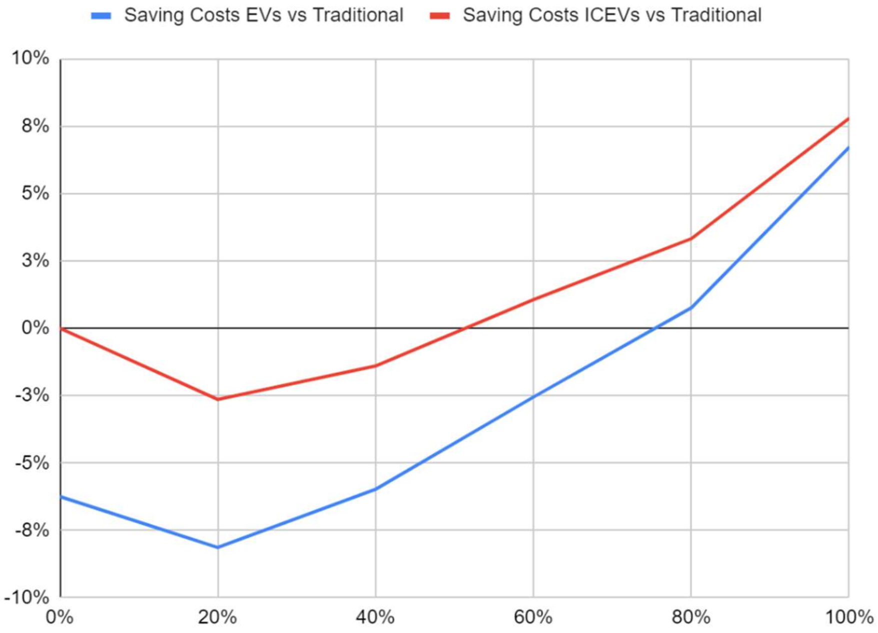
Different sensitivity analyses were performed to evaluate the robustness of the solutions obtained to the variability of some inputs and also to compute the performances of different scenarios.

5.2.1. Adoption rate

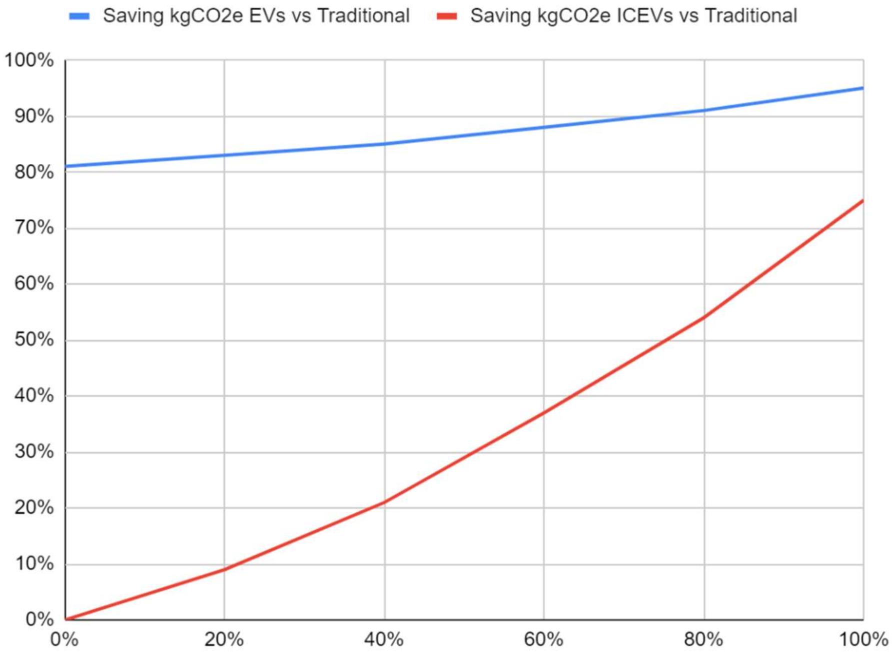
The first one is about the adoption rate of the innovative network, considering that initially there could be a partial adoption and what would be the effects. Rates considered are 20%, 40%, 60% and 80%, also compared with the Base Case as 100% and Vans only as 0%. Each scenario was evaluated considering as vans both EVs or ICEVs. Graph 1 and Graph 2 respectively present Costs and Emissions savings in all scenarios evaluated compared to the traditional network.

For low percentages of adoption, the network is not convenient from an economical point of view, and according to the usage of EVs or ICEVs, for the solution to become more convenient than traditional deliveries respectively 80% or 50%.

Emission savings increases in both EVs and ICEVs cases as the adoption increases, as expected but additional interesting outcomes are that even with 0% of Adoption EVs implementation would bring to more than 80% of emissions savings, while the 100% of adoption with ICEVs around the 75% of savings is achieved.



Graph 1 Adoption sensitivity - EVs vs ICEVs, cost savings



Graph 2 Adoption sensitivity - EVs vs ICEVs, emissions savings

5.2.2. Cargo-Bicycles weight range

The threshold considered for the assignment of parcels to Cargo-Bicycles choses was 2kg, however, it was worth to evaluate the effects and the feasibility of a higher threshold, which is specifically 10kg. Results in this case showed a halving of the emissions produced compared to the Base Case and a 3% decrease in cost generated, increasing its benefits compare to the traditional network.

5.2.3. Number of Micro-Hubs

The number of Micro-Hubs included in the network may vary and mainly depends on space availability. It was assumed to be 6, as a reasonable value given the area covered of around 30km^2. Effects of having between 2 and 6 Micro-Hubs, or 10 of them were studied and between 2 and 6 costs savings compared to traditional network increase from 6% to 6.7% while going to 10, no changes are present. On emissions side, the solution is all quite equal, with slight growth when increasing the Micro-Hubs to 10.

5.2.4. E-Commerce Volumes

The results obtained in terms of sustainability of the solution may be influenced by the relevant dimension of the deliveries volume considered. Therefore, scenarios with -20% and -40% of volumes were studied, to understand if the proposed network would still be worth. What emerged is that in both cases there is a contraction of the convenience of the network with respect to the traditional one, especially on cost going from 6.7% of savings to 5.8% in both reduced volume scenarios, while emissions savings are almost the same.

5.3. Discussion on the results

As regards the impacts generated, the solution designed and proposed in this study was proved to bring benefits in both costs and emissions, with respectively 6.7% and 94.5% of savings achieved compared to traditional deliveries network.

Cargo-Bicycles proved to be a very competitive vehicle for deliveries in city center given the very high proximity of customers and therefore no need of vans speed, while neither needing its capacity.

Performing some sensitivity analyses more insightful outcomes were obtained. Looking at the adoption rate results, it's clear that even low adoptions bring huge benefits in terms of emissions produced, while for cost savings certain threshold of adoption must be overcome. Considering the 0% and 100% cases as well, the main outcome is that using EVs instead of ICEVs in the traditional network or implementing the Cargo-Bicycles network at 100% without migrating to EVs, both can help in achieving around 80% of emission saving, while with their combination almost 95% is achievable.

The benefits achieved, both on monetary and environmental terms can be even increased if exploiting more the potential of Cargo-Bicycles, assigning to these not only parcels until 2kg but 10kg. Specifically, emissions would be halved, achieving 97% of savings compared to traditional network, while on costs savings would increase from 6.7% to 9.5%

The number of Micro-Hubs was then proved to bring some differences in the operational costs generated but considering that we are not including infrastructures costs and we are assuming their availability, a lower number of

Micro-Hubs may be considered without having significant decrease in performances.

Lastly, the solution proved to be very robust also to variations of the demand, with neither 1% of difference of savings in both costs and emissions compared to traditional network.

6 Conclusions

The main purpose of this thesis, correlated to the request questions formulated, was to design an integrated delivery network from out-of-cities to customers' homes through green vehicles. Once designed its performances needed to be assessed, in order to evaluate benefits and drawbacks with respect to traditional deliveries. The main benefit expected were significant reduction of environmental impact, which declined significantly, reaching almost 0 in case Cargo-Bicycles are exploited delivering parcels until 10kg. Moreover, the implementation of the innovative network deliveries proved to be, if at least 50% of adoption is set, also cheaper than traditional one.

This thesis work represents a step forward in the attempt to significantly reduce the impact of urban logistics on the environment in general and on the quality of life in cities more in detail, focusing on the networks preforming e-commerce deliveries.

The main originality is given by the number of vehicles considered and the fact that to each is assigned the activity in which it is one of the best vehicles to perform it. Truck and Train are used for high-volume movements, EVs for medium volumes and deliveries of big parcels and Cargo-Bicycles for most of the deliveries to customers.

Potential limitations on the model may be given by the assumption performed, even if most of these are coming from discussion with the couriers or other studies analysed. Moreover, each of the most relevant assumptions, for example the definition of the fixed delivery time, is affecting both the proposed innovative network and the traditional one. Being the comparison performed always comparing to the two networks, and given the sensitivities performed on the inputs, the results are therefore considered quite robust.

As last remarks, a very insightful study we consider could be performed with a view on the future could be based on autonomous vehicles. These indeed, drones or robots, not needing any driver, once regulated and operatively feasible, will bring a huge disruption in the field of last-mile deliveries.

1 Introduction

Urban Logistics regards all the mobilization of goods in urban areas and its fast developing and growing in volumes year after year. Consequently, the impact of this activity on transport system is increasing quickly and needs to be attentioned by both institutions, companies, and citizens. This phenomenon is mostly affected by parcel deliveries that generates the main part of urban freight traffic, given the increasing penetration that of e-commerce is reaching in the recent years in many industries and markets, both mature and emerging ones. A significant growth boost was also given in 2020 by the Covid-19 pandemic spread, which created conditions in which online shopping was the only way of shopping. Moreover, customers prefer always online shopping instead of physical channels given the continuously development of innovative solutions and customer experience, but also higher accessibility and lower prices. The service level is overall increased, and companies needs to adapt to changing customers' habits. This approach opens new challenges for companies that must manage additional problems, most of them related to higher complexity on logistics activities. Last-mile delivery, consisting in the delivery of parcels to the final customers, is the most crucial activity of logistic process since time spent and distance travelled is only attributed to one single customer, making it very inefficient. The issues generated by logistics activities regarding e-commerce purchases are not only linked to operational inefficiency but also to high environmental and social impacts that derives from unsustainable operations. To cope with these issues, various solutions have been developed trying to migrate traditional parcels delivery networks towards a more efficient and environmental-friendly one.

In this introductory Chapter is presented an overview of e-commerce, urban logistics and last-mile deliveries main characteristics, the impacts that these generates, and the solutions developed to mitigate them. Indeed, in Section 1.1 some data regarding B2C e-commerce are illustrated given the high influence of this market on increasing importance and impact of urban logistics, in particular last-mile delivery, for both enterprises and society. Then, in Section 1.2 characteristics and issues related to the logistics activities considered are shown and starting from them, Section 1.3 explores the possible alternative ways to mitigate the inefficiencies and reduce the impacts generated, partially or totally.

E-commerce trends

E-commerce is defined as sales of products and services through electronic devices (OECD,1999). In this thesis work, we focused on B2C product e-commerce, which means to deliver products from businesses to final customers. Looking at data regarding e-commerce, it's easy to understand how much this business is impacting the world nowadays. Estimates show that in 2021 online purchases reached 3,900 billions of euro worldwide, which means an increase of 18% respect to 2020 (B2C eCommerce Observatory, Politecnico di Milano 2021). This data includes both service and product e-commerce purchases, but the growth only derives from acquisition of goods online given by Covid-19 situation, indeed the other category of online purchases, the service one, shows a deep decline during last two years. In Europe, Italy registers a penetration rate of products e-commerce of 10%, that means the 10% of products are sold through an online channel. Even though, it is increasing along years, Italy doesn't present a very high e-commerce penetration compared to other European countries like United Kingdom (31%), Germany (15%), and France (13%) (B2C eCommerce Observatory, Politecnico di Milano 2021). Breaking down Italian data, e-commerce purchases reached 39.4 billion of euro in

2021, that means an increase of 21% compared to 2020, of which more than 30 billion derives from product purchases, with a total number of deliveries performed in 2021 of 578 million. (B2C eCommerce Observatory, Politecnico di Milano 2021). The industries that sell through online channels are varied, but the highest volumes are coming from (B2C eCommerce Observatory, Politecnico di Milano 2021):

- Informatics and Electronics (7.7 billion €)
- Apparel (5.1 billion €)
- Food and Grocery (4.1 billion €)
- Furniture and Home Living (3.3 billion €)
- Publishing (1.4 billion €)

The industry showing the highest growth respect to 2020 is Food and Grocery (+38%), followed by Apparel (+23%), Furniture and Home Living (+18%), Informatics and Electronics (+10%) and Publishing (+9%) (B2C eCommerce Observatory, Politecnico di Milano 2021). The very high increasing of Food and Grocery online purchases are due to Covid-19 situation, which was a huge booter for restaurants, supermarkets and shops deliveries, being often not allowed to go out because of curfew, quarantine or social distancing.

To understand what the trends could have been if there wasn't Covid-19, the Osservatorio B2C e-commerce of Politecnico of Milan applied the same growth rate registered from 2016 to 2019 also to years 2020 and 2021. Overall, the effect of pandemic is negative, with a decreasing of 4.1 billion euro in 2021 and 3.5 billion euro in 2021, and this is because of the significant fall of service online purchases. Indeed, looking at each category, product e-commerce purchases would be 4.0 billion euro less in 2020 and 3.3 billion euro less in 2021 without Covid-19, and it is mainly due to the huge rise of Food and Grocery e-commerce market, which looking at overall e-commerce doesn't offset the decrease in services purchase.

Logistic implications

Urban Logistics includes all the activities related with the movements of goods in urban area, consequently it is affected by the huge growth of e-commerce market, more precisely by B2C online purchases given their peculiarities. Indeed, online customers are demanding an always better service level, asking for a very short delivery time, considering it as the time interval that goes from the moment in which the online order is done to the physical delivery of the product ordered (Lu et al., 2016). In addition, they assume that the company must guarantee extra services, like possibility to return products or else to receive additional attempts of deliveries if not at home at the first, and customers don't presume to pay for these severe requirements (Borsenberger et al., 2016). In this context, to reach the service level required by customers companies must face different challenges to not be out of the game, resulting distribution of goods as a complex and inefficient activity (Yu, Wang, Zhong, & Huang, 2016).

Through the several activities included in the logistic process to deliver the parcels until customers home, by far the transportation is the one that faces most of the issues and by far the most expensive. Last-mile delivery, the transportation of goods from courier hub to final destination (Dolan, 2018), is the least efficient part of the delivery being it a door-to-door delivery. Indeed, last-mile routes are composed by many stops characterized by small order size in both terms of dimensions and quantity, resulting in a very low saturation of vehicle. Furthermore, the customers density can have a strong impact on costs generate by last-mile delivery, because if the order density of delivery points is low, vehicles need to drive more kilometers per tour generating a more inefficient process. Finally, the last big issue regarding last-mile delivery concerns the failed deliveries, which means extra costs due customers that are not at home when the delivery is performed and therefore the parcel needs to be sent back to the hub and be delivered the day after.

All the inefficiencies described, together with many other, make last-mile delivery the most significant component of parcel delivery costs, corresponding to 50% of the total cost (Martin Joerss et al., 2016).

The high service level required by e-commerce customers and the many and complex challenges faced by the companies, leads on one side to very high cost and complex network, and on the other to very low environmental and social sustainable one. Indeed, the higher demand of online purchasing the number of vehicles to perform all the required deliveries, and this has a huge impact on environmental and social sustainability, causing emissions, congestion, and noise pollution among the many. One of the main goals that companies and institutions should keep in mind is the reduction of greenhouse gas (GHG) emissions to improve the quality of life of people (Pieralice and Trepidi, 2016). Transport has a strong impact in these terms, given that it accounts for a quarter of EU GHG emissions and most of them, the 70% of which are generated by road transportation (European Commission, 2017), mainly deriving from fossil fuels. To invert this trend, the European Green Deal has placed a target of reducing GHG emissions generated by transportation of 90% by 2050 compared to 1990 (European Commission, 2020). Inside urban centers, the environmental and traffic congestion problems, and in urban freight vehicles contributes up to 25% of urban transport-related carbon footprint (EC, 2015). The objective of European White Paper (EC, 2011) is to reduce such impact, through a halving of the use of conventionally fueled vehicles in urban centers and achieving CO2-free logistics in major cities by 2030.

Given the importance and the vastity of this topic, there are many studies regarding not only economical sustainability of urban logistics but also focusing on social and environmental issues coming from last-mile delivery. In the next Section are presented the solutions available as mitigations of the main issues just described or of the effects from a sustainability point of view.

Possible solutions to last-mile delivery issues

Regarding cost, a large number of studies are published during last ten years, in the first period they concentrated on the optimization of traditional delivery mode, that means deliver the parcels to customers through diesel vans. The main topic is the developing of more or less advanced VRP, vehicle routing problem (Geetha et al., 2013), that is an optimization and integer programming problem aiming to service a number of customers with a fleet of vehicles. In this way, savings in term of cost can be achieved, but it is minimal and not doesn’t impact positively on environment or society. Then publications focused more on innovative solutions, based on the introduction or substation of elements in the traditional networks to increase the efficiency, trying to decrease not only the cost of last-mile delivery but also the environmental and social impacts generated by it. In this sense, the role of governments and municipalities can be crucial and determinant, incentivizing companies, and people to adopt more sustainable solutions, behavior, and choices, for example applying time-windows or tolls for fossil vehicles to enter the city center (G. Sanz et al., 2018).

Regarding solutions initiated by companies, one of the most developed and analyzed is the exploitation of parcel lockers or pick up points (R. Villa et al., 2021) in which the parcels are put in some small storage places around city center instead of going to final customer. This increases the drop quantity reducing dramatically the number of stops and therefore time needed, and distance covered. Moreover, failed deliveries being the delivery and the reception disconnected. As a consequence, not only costs but also emissions generated by parcel locker or pick-up point solutions are far less than traditional network because the savings of kilometers and the lower impact of customers reaching parcels instead of parcels reaching customers.

Other innovative solutions regard the collaboration between the different stakeholders involved in the e-commerce process, which can be critical for achieving very good results. These can be companies with institutions, companies with customers but also and especially companies with companies, going from a conception of competition to a one of coopetion, made of cooperation and competition. For example, in recent years Urban Consolidation Centers are tested in order to decrease the logistics costs related to handling of goods in the hubs and high inventory carrying costs. This is because through this hub, that is usually placed near city center, the sorting and consolidation of loads coming from different logistics companies take place in the same site that is most of times managed by a neutral third logistic provider, and consequently the costs per parcel processed are less (J. Leonardi et al., 2012). Another similar and stronger solution consists of sharing of hubs and vehicles among different companies, in this way not only the costs related to hubs but also the ones concerning the last-mile delivery decreases given the better exploitation of resources (Y. Li et al., 2019). Instead of having a collaboration between companies, another possibility to improve the efficiency of last-mile delivery is the crowdsourcing, that consists of employing citizens to deliver packages to other people while moving around the urban area for their own reasons through their routes. In this way, deliveries could be performed with very small costs (A. Giret et al., 2018 and A. Seghezzi and R. Mangiaracina, 2021). Regarding environmental and social impact, lower number of vehicles used means also less carbon footprint, noise pollution and less congestion, so definitely a better quality of life for citizens.

With respect to traditional network using only diesel vans used to deliver the parcels to final customers, using different means of transportation can be also a very effective solution for mitigating urban logistics impact, both as only vehicles and in combination with traditional vans. Most of studies and real implementation are focused on substitution of diesel vans with electric ones. This solution obviously decreases the environmental impact of urban logistics, but it is usually more expensive than traditional network given the higher costs of electric (R. Mangiaracina et al., 2020), which is not offset by lower feeding and maintenance cost. It is also becoming increasingly popular the usage of Cargo Bikes as only vehicle (Carlos Llorca et al., 2021), with stationary or mobile depots (Sara Verlinde et al., 2014), or else in combination with other delivery vehicles with whom cargo-bicycles share the flow, like traditional or electric vans (J. Leonardi, 2012). The main advantage of exploiting this solution is the very low emissions and noise pollution generated by this type of vehicle. In term of operational efficiency and cost, Cargo-Bicycles have lower capacity and drives at lower speed, which may or may not be a drawback for the tour performing, according to the instances studied. Another possibility is to equip vans with autonomous vehicles, like drones (C. Chase et al., 2020) and small robots (Simoni et al., 2020, Ostermeier et al., 2021), to increase the efficiency and to decrease the pollution generated by transportation to final customers given the possibility to deliver part of parcels through this type of vehicles that leave the van, perform the deliveries and then re-join it in other locations while the van performs its tour. Instead of using only road transportation, a sort of intermodal solution can be developed to serve the customers generating benefits as decreasing costs, not being affected by road congestion and most of times lower environmental impact. The main intermodal solution is based on railways, like cargo-tram (O. Pietrzak, 2021) or underground logistics system (D. Guo et al., 2021), however the parcels to reach the customers need to be moved by a last-mile delivery vehicle, like vans or maybe Cargo-Bikes. Finally, the public transportation systems, as sharing of infrastructures but also sharing the same vehicles and/or windows of time, can be exploited to saturate the spare capacity of public transportation means, using it for freight transportation without additional congestion, costs and emissions (R. Masson et al., 2015).

The goal of this thesis is to contribute to develop an innovative solution capable of performing the same service of traditional networks but with lower impact. The aim of the work performed is both to contribute to the literature on the topic and to provide an applicable network that can make the difference in city sustainability.

This study is structured as follows: the next Chapter presents the Literature Review performed on the topic and the Research Gap identified; then, Chapter 3 defines the research question and describes the methodology adopted for the study; following, Chapter 4 presents the network designed and the model developed to assess the performances of both innovate and traditional solutions; in Chapter 5 the results of the analyses performed are presented; finally, Chapter 6 illustrates the conclusions of the study.

2 Literature Review

2.1. Introduction

The aim of this chapter is to present the state of art of the academic literature about the impact that freight transportation has in the urban context, focusing on the possible ways to reduce it from one or more point of view among environmental, social, and economic/operational.

Urban logistics is a topic that has always received significant attention from academic research (A. Lagorio et al., 2016) because of the continuously growing role and impact that it has on the environment and on quality of life in cities, considering air pollution, noise, congestion, space conflicts and co-existence with passengers' mobility services. The most harmful activity in urban logistics is surely last-mile delivery (Martin Joerss et al., 2016), which is also the costliest, and the most part of the which is given by e-commerce logistics, having the customer expecting the package to be delivered at their location. It is therefore interesting to assess the state of advancement of the research in the topic of urban logistics sustainability, what kind of research are the most utilized, which are the solutions or innovations considered the most, if and which are the cases of implementation of some solutions around the world and what can be the outcomes so to also identify literature gaps and opportunities of further research.

In the next section the methodology of the literature research, structured following Mangiaracina et al. (2015), is presented and then in the subsequent sections, according to the steps of the review, the results are presented.

2.2. Methodology

The first phase of the literature review consists in the creation of the research corpus, which is the material that will be the base of the analysis. This phase is called *"Paper Selection"* and is made of different stages in line with Srivastava (2007):

- *Classification context:* identification of the research context and main topic.
- *Definition of the unit of analysis.*
- *Collection* of the publications through different library databases.
- *Delimitation of the field:* from all the publications collected, selection of the most relevant ones for in-depth investigation.

The second phase of the analysis consists in the review itself and is made of two different parts. The first one is a presentation of the main characteristics of the reviewed publications corpus, specifically pointing out:

1. *Geographical scope:* countries that mostly contributed and grouping in developed and developing countries.
2. *Year of publication.*
3. *Journal field:* focus of the journal in which the papers were published among logistics, operations, mathematics, social science, sustainability, and others.
4. *B2B/B2C:* if the papers focus on a specific case of deliveries to businesses or to customers.
5. *Methodology of the research:* different research methods implemented among literature reviews, conceptual framework, analytical methods, simulations, and case studies.

In the second step, papers are classified according to two different axes, the first according to the type of solution(s) addressed in the study and the second according to the kind of impact of urban logistics considered:

- *Solution/innovation fields:* Regulations, Stakeholders' Collaboration, Non-Road Transportation, Public Transport, Alternatively Powered Vehicles, Cargo-Bicycles, Autonomous Vehicles.
- *Impacts:* Economical/Operational, Environmental and Social.

Lastly, the research gap that this study aims to fill is highlighted.

2.2.1. Phase 1: Papers selection

The first step was to define the *classification context* of the review. The main scope of this research is to understand how urban logistics impacts on the three pillars of sustainability (3PL) and what has been studied and implemented all over the world for reducing those impacts. Specific relevance has been given to cases of e-commerce deliveries, or similar contexts of door-to-door deliveries of moderate-volume parcels, in which characteristics such as low saturations of vehicles and high density of delivery points are present (Macioszek, E. 2017). When it comes to differentiate between B2C and B2B last-mile delivery, being the volume/delivery of the last usually much higher, and therefore the number of stops lower, B2C deliveries and e-commerce benefits more from the improvements that in efficiency and sustainability can be achieved in this field.

The *unit of analysis* was then defined as a single article published in international research journals. However, in some cases the research has been extended also to conference papers, but the unit of analysis is also in this case the single paper.

The *collection of the publications* is the core step of this phase since creates the basis from which the research corpus is then extrapolated. To do this, different library databases and academic papers search engines have been utilized, giving high priority to Scopus, from which most of the articles were obtained, but also Science Direct, Research Gate, Emerald and Google Scholar have been useful to enlarge the collection results. The research has been in general performed with keywords and strings in combination, looking for correspondences in papers' titles, abstracts, or keywords. Specifically, given the scope of our analysis, the keywords used can be divided into two groups: a first group composed of expressions like "city logistics", "urban freight", "urban distribution", "last-mile delivery" and possible synonyms, and a second one composed by sustainability-related keywords like "sustainab*", "electric*", "green", "intermodal", "innovative" and synonyms. The research has been conducted through a query in which, through the Boolean operators AND and OR, at least one expression of the first group and a keyword of the second should be identified in a publication to be considered. Moreover, three more inclusion criteria have been used to filter the research:

- English as language
- Being the topic in continuous evolution according to technologic advancement of vehicles and the attention to sustainability deeply increased in the last years, selected papers had to be published after the year 2000
- Belonging to one of the following subject areas: Engineering, Environmental Science, Social Sciences, Mathematics, Business-Management-Accounting

This procedure led to the identification of a research basis of 668 publications.

To conclude the first phase and obtain the final research corpus some *further selection* was needed, to obtain a corpus of reasonable dimension to perform the analysis. The first selection has been based on the publication title, keeping those papers that were more related to the research scope, which means papers that dealt with urban logistics impact, issues, innovations, solutions and regulations. After this step, the papers were reduced at 341. Reading the abstracts and performing a skimming activity on the whole papers, some were discarded because were duplicates of others, some others because not strictly inherent to the research aim and some more because they were not giving any useful insights. On the other side, some other papers were added even if not article but conference papers because of their value. At the end of the delimitation of the field phase, *64 papers* were kept for the in-depth analysis, and it is on these that the systematic review has been performed.

The review process and its finding are presented in the following sections. The research corpus is firstly presented highlighting some main characteristics. Then, the content of the papers is explored, classifying the publications firstly according to the type of innovation or solution studied and secondly regarding the typology of impacts assessed. While presenting the categorization, the findings for each value of the axes are presented.

2.2.2. Phase 2: Review

Once the first phase is concluded, the final research corpus papers are ready to be classified and discussed. Firstly, the main characteristics of the articles are examined, and the different research methods used in the papers are analyzed. After that, the papers are classified according to their main characteristics and their content is presented, stressing two aspects: the assessed solution/innovation type and the impacts of urban logistics considered. Once the papers are presented and classified, general findings and considerations are presented.

2.3. Review

The 64 papers, obtained from the previous phase and composing the database for the literature review are presented in Table 1 which shows Authors, Country, Journal, Year, and Title of each.

No.	Authors	Country of the study	Journal	Year	Title
1	C. Chase et al.	USA	Transportation Research Part C: Emerging Technologies	2020	The multiple flying sidekicks traveling salesman problem. Parcel delivery with multiple drones.
2	A. Alessandrini et al.	Italy	European Transport Research Review	2012	Using rail to make the urban logistic more sustainable
3	A. Anderluh et al.	Austria	Central European Journal of Operations Research	2017	Synchronizing vans and cargo bikes in a city distribution network
4	A. Conwey et al.	USA	Research in Transportation Business & Management	2017	Cargo cycles for local delivery in New York City - Performance and impacts
5	A. Lagorio et al.	Italy	International Journal of Physical Distribution & Logistics Management	2016	Research in urban logistics - a systematic literature review
6	A. Seghezzi and R. Mangiaracina	Italy	International Journal of Logistics Research and Applications	2021	Investigating multi-parcel crowdsourcing logistics for B2C e-commerce last-mile deliveries
7	A.Seghezzi and R.Mangiaracina	Italy	International Journal of Logistics Research and Applications	2020	‘Pony express’ crowdsourcing logistics for last-mile delivery in B2C e-commerce: an economic analysis
8	Adriana Giret et al.	Spain	Sustainability	2018	A Crowdsourcing Approach for Sustainable Last Mile Delivery

9	Amy M. Moore	USA	Transportation Research Interdisciplinary Perspectives	2019	Innovative scenarios for modeling intra-city freight delivery
10	Bucchiarone A. et al.	Italy	IEEE Transactions on Intelligent Transportation Systems	2021	Autonomous Shuttle-as-a-Service (ASaaS): Challenges, Opportunities, and Social Implications
11	C. Altuntas¸ Vural and Ç. Aktepe	Turkey	Research in Transportation Business & Management	2021	Why do some sustainable urban logistics innovations fail - The case of collection and delivery points
12	C. Navarro et al.	Spain	Transportation Research Procedia	2016	Designing New Models for Energy Efficiency in Urban Freight Transport for Smart Cities and its Application to Spanish Case
13	Cardena I. D. et al.	Belgium	International Journal of Transport Economics	2017	The e-commerce parcel delivery market and the implications of home B2C deliveries vs Pick-Up Points
14	Cardenas I.D. et Beckers J.	Belgium	International Journal of Transport Economics	2018	A location analysis of pick-up points networks in Antwerp
15	Carlos Llorca et al.	Germany	European Transport Research Review	2021	Assesment of the potential of cargo bikes and electrification for last-mile parcel delivery by means of simulation of urban freight flows
16	D. Guo et al.	China	Tunnelling and Underground Space Technology	2021	Planning and application of underground logistics systems in new cities and districts in China
17	D. L. J. U. Enthoven et al.	Netherlands	Computers and Operations Research	2020	The two-echelon vehicle routing problem with covering options: City logistics with cargo bikes and parcel lockers
18	D. Patier et al.	France	Procedia - Social and Behavioral Sciences	2010	A methodology for the evaluation of urban logistics innovations

19	David Swanson	USA	IEEE Engineering Management Review	2019	A Simulation-Based Process Model for Managing Drone Deployment to Minimize Total Delivery Time
20	Diana Diziain et al.	France	Procedia - Social and Behavioral Sciences	2014	Urban Logistics by Rail and Waterways in France and Japan
21	Divieso E. et al	Brazil	Theoretical and Empirical Researches in Urban Management	2021	The use of Waterways for urban logistics: The case of Brazil
22	F. Bruzzone et al.	Italy	Transport Policy	2021	The integration of passenger and freight transport for first-last mile operations
23	J. Fraselle et al.	Belgium	Sustainability	2021	Cost and Environmental Impacts of a Mixed Fleet of Vehicles.
24	G. Sanz et al.	Spain	International Journal of Transport Economics	2018	Evaluating urban freight transport policies within complex urban environments
25	G. Schiliwa et al.	UK	Research in Transportation Business & Management	2015	Sustainable city logistics — Making cargo cycles viable for urban freight transport
26	J. Allen et al.	UK	Transportation Research Part D: Transport and Environment	2018	Understanding the impact of e-commerce on last-mile light goods vehicle activity in urban areas: The case of London
27	J. H. R. Van Duin	Netherlands	Transportation Research Procedia	2019	Evaluating new participative city logistics concepts, the case of cargo hitching
28	J.H.R. van Duin et al.	Netherlands	European Transport	2013	Towards E(lectric)- urban freight: first promising steps in the electric vehicle revolution

29	Jacques Leonardi et al.	UK	Procedia - Social and Behavioral Sciences	2012	Before-After Assessment of a Logistics Trial with Clean Urban Freight Vehicles_ A Case Study in London
30	Jane Lina and Wei Zhoub	USA	International Journal of Sustainable Transportation	2020	Important Factors to Daily Vehicle Routing Cost of Battery Electric Delivery Trucks
31	Jay R. Brown & Alfred L. Guiffrida	USA	International Journal of Logistics Research and Applications	2014	Carbon emissions comparison of last mile delivery versus customer pickup
32	Jesus Gonzalez-Feliu	France	Expert meeting in urban rail freight	2014	Costs and benefits of railway urban logistics
33	K. Fossheim et J. Andersen	Norway	European Transport Research Review	2017	Article Plan For Sustainable Urban Logistic – comparing between Scandinavian and UK practices
34	K. Lee et al.	Korea	Sustainability	2019	A courier service with electric bicycle in an urban area: The Case in Seoul
35	K. Mommens et al.	Belgium	Journal of Transport Geography	2021	Delivery to homes or collection points? A sustainability analysis for urban, urbanised and rural areas in Belgium
36	K. Pietrzak et al.	Poland	Sustainable Cities and Society	2021	Light Freight Railway (LFR) as an innovative solution for Sustainable Urban Freight Transport
37	Lebeau P. et al.	Belgium	The Scientific World Journal	2015	Conventional, Hybrid, or Electric Vehicles: Which Technology for an Urban Distribution Centre?

38	M. D. Simoni et al.	USA	Transportation Research Part E: Logistics and Transportation Review	2020	Optimization and analysis of a robot-assisted last mile delivery system
39	M. Koning et al.	France	Case Studies on Transport Policy	2016	The good impacts of biking for goods - Lessons from Paris city
40	M. Morfoulaki et al.	Greece	Transportation Research Procedia	2016	Evaluation of specific policy measures to promote sustainable urban logistics in small-medium sized cities: the case of Serres, Greece
41	M. Ostermeier et al.	Germany	Networks	2021	Cost-optimal truck-and-robot routing for last-mile delivery
42	Maria Giuffrida, Mangiaracina et al.	Italy	XXI Summer School "Francesco Turco" - Industrial Systems Engineering	2016	Home Delivery vs Parcel Lockers: an economic and environmental assessment
43	Michael Browne et al.	UK	Procedia - Social and Behavioral Sciences	2014	The potential for non-road modes to support environmentally friendly urban logistics
44	Monika Singh et al.	India	Transportation Research Procedia	2020	Urban rail system for freight distribution in a mega city, case study of Delhi,India
45	N. Boysen et al.	Germany	European Journal of Operational Research	2018	Scheduling last-mile deliveries with truck-based autonomous robots
46	N. Nesterova et H. Quak	Netherlands	Transport and Sustainability	2014	Towards Zero Emission Urban Logistics, Challenges and Issues for Implementation of Electric Freight Vehicles in City Logistics

47	Niklas Arvidsson, Michael Browne	Sweden	European Transport	2013	A review of the success and failure of tram systems to carry urban freight: the implications for a low emission intermodal solution using electric vehicles on trams
48	O. Pietrzak et al.	Poland	Sustainable Cities and Society	2021	Cargo tram in freight handling in urban areas in Poland
49	Oliveira, C.M et al.	Brazil	Sustainability	2017	Sustainable Vehicles-Based Alternatives in Last Mile Distribution of Urban Freight Transport: A Systematic Literature Review
50	P. Menga et al.	Italy	World Electric Vehicle Journal	2013	Promotion of Freight Mobility in Milan: Environmental, Energy and Economical Aspects
51	Quak and de Koster	Netherlands	Transportation Science	2008	Delivering Goods in Urban Areas: How to Deal with Urban Policy Restrictions and the Environment
52	R. A. de Mello Bandeira et al.	Brazil	Transportation Research Part D: Transport and Environment	2019	Electric vehicles in the last mile of urban freight transportation - A sustainability assessment of postal deliveries in Rio de Janeiro-Brazil
53	R. Gervaers et al.	Belgium	Procedia - Social and Behavioral Sciences	2014	Cost Modelling and Simulation of Last-mile Characteristics in an Innovative B2C Supply Chain Environment with Implications on Urban Areas and Cities
54	R. Mangiaracina et al.	Italy	International Journal of Sustainable Transportation	2020	Electric vehicles performing last-mile delivery in B2C e-commerce: An economic and environmental assessment
55	R. Masson et al.	France	EURO Journal on Transportation and Logistics	2015	Optimization of a city logistics transportation system with mixed passengers and goods

56	Rafael Villa et al.	Spain	Sustainability	2021	A Metro-Based System as Sustainable Alternative for Urban Logistics in the Era of E-Commerce
57	Rosenberg, L.N. et al.	Israel	Sustainability	2021	Introducing the Shared Micro-Depot Network for Last-Mile Logistics
58	S. Beherends	Sweden	Procedia - Social and Behavioral Sciences	2012	The urban context of intermodal road-rail transport – Threat or opportunity for modal shift
59	S. Melo et al.	Portugal	European Transport Research Review	2017	Evaluating the impacts of using cargo cycles on urban logistics: integrating traffic, environmental and operational boundaries
60	S.Nocera, F.Cavallaro	Italy	Research in Transportation Economics	2017	A two-step method to evaluate theWell-To-Wheel carbon efficiency of Urban Consolidation Centres
61	Sara Verlinde et al.	Belgium	Transportation Research Procedia	2014	Does a Mobile Depot Make Urban Deliveries Faster, More Sustainable and More Economically Viable Results of a Pilot Test in Brussels
62	Simoni et al.	Italy	Transportation	2019	Potential lastmile impacts of crowdshipping services: a simulationbased evaluation
63	V. Naumov et al.	Poland	Energies	2021	Identifying the Optimal Packing and Routing to Improve Last-Mile Delivery Using Cargo Bicycles
64	Y. Li et al.	China	Resources, Conservation & Recycling	2019	Sharing economy to improve routing for urban logistics distribution using electric vehicles

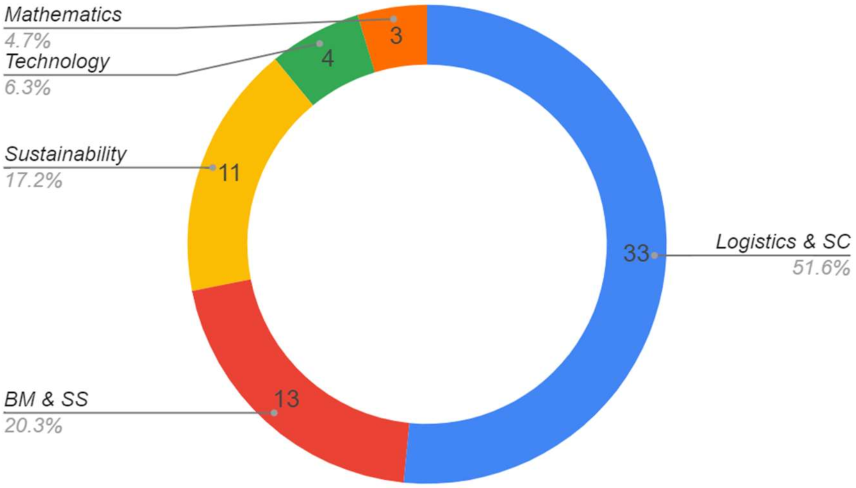
Table 1 Scientific articles classification

2.3.1. Main characteristics

Looking the different papers examined, they are published in 37 different ***journals***. A clustering can be performed to divide them into five main areas:

- *Logistics and Supply Chain:* this area includes publications on the logistic process. Most of the journals are concentrated in a specific type of activity of the logistic process: the transportation. This is because the literature review is based on the different solution to manage and improve urban logistic, in which the most onerous activity is the last-mile delivery, that consists in the transportation of goods into the cities until the final customer.
- *Mathematics:* it contains contributions on journals mainly oriented to operational research and optimization. Even though several articles develop models to solve the problems, few papers are in inside this area, because papers usually, given the topic that they deal with, such studies are published on Logistics or Sustainability journals.
- *Business Management & Social Science:* approximately half of the journals of this area discusses on business management and economic research in the field of transportation. The others focus on the involvement of social and behavioral sciences in urban logistic activities.
- *Technology:* in this area the contributions are focused on emerging technologies and innovative solutions for transportation of goods.
- *Sustainability*: journals on sustainable management and transformation processes involved in a transition towards a more sustainable world, impacting industries and cities. Even though there are a lot of papers talking about sustainability, the publications of this field are few because most of the papers belong to journals related to last mile city logistics and consequently to Logistics and Supply Chain area.

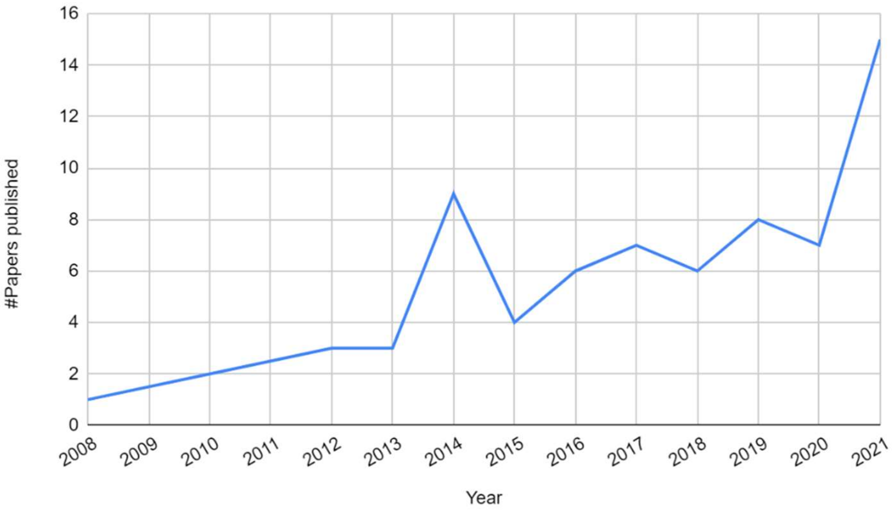
As expected once defined the research and as shown in Graph 3, most of the publication that deal belong to journals that come from Logistics and Supply Chain area. Sustainability and Business Management & Social Science have slightly more than 10 papers each while Mathematics and Technology are represented by less than 5 each.



Graph 3 Number of papers per Journal Area

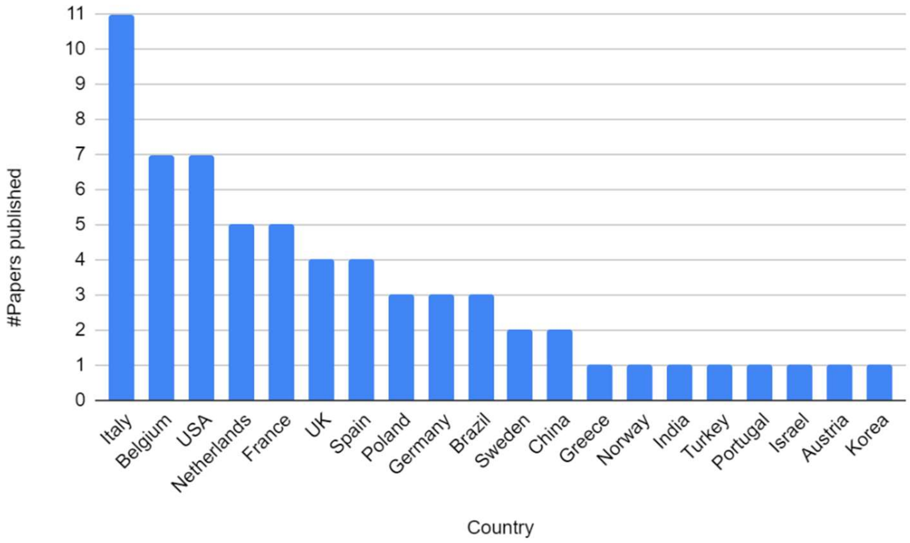
Going on with the analysis of the main characteristics of the scientific papers, some considerations can be developed on ***publication dates*** and ***geographical scope***.

The period of reference of the analysis was from 2000 to 2021, but as the graph shows, the interesting publications on alternative solution to develop urban logistics seems to start later, in this analysis the year of reference is 2008. Moreover, the number of papers increases year after year with a linear trend and in 2021 the number of articles is doubled respect to the previous year. This is a result of the exponential increasing of the last-mile logistic in these years, which caused a continuous increasing interest in city logistics, especially in its impact on sustainability and innovative solutions to improve urban transportation. Indeed, the main aim is to transform last mile delivery in a less expensive activity with zero emissions and positive social impact.



Graph 4 Number of papers published per Year

Regarding the geographical area, the selected papers come from three different continents: Europe, Asia and America (from North America and 3 papers from Brazil). Graph 5 displays the contribution and effort of each country in the literature about the alternative solutions to develop urban logistics towards a more sustainable direction. The distribution of the articles per country shows that half of the articles are concentrated in few countries: Italy, that is the nation with most papers (11 papers), followed by Belgium and USA (7 papers each), Netherlands and France (5 papers). From this result, it can be immediately noticed that Europe seems to be really involved in sustainable urban logistic theme rather than the other continents. This result is common with the other literature reviews that are present in our corpus of papers.

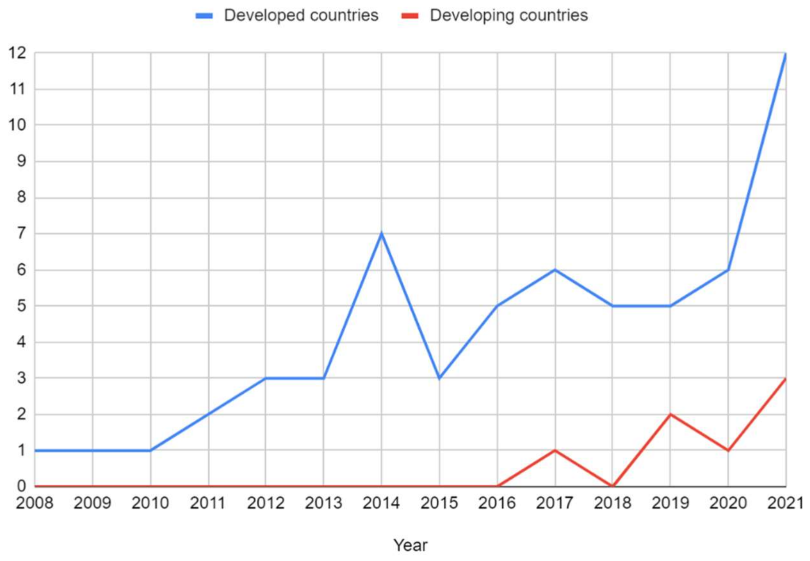


Graph 5 Number of papers published per Country

Deepening the most contributive countries, Italian researchers started to concentrate their effort on sustainable urban logistics from 2012 increasingly the interest on it year by year. Moreover, they are more focused on collaboration between the different stakeholders to minimize costs and impacts on environment, looking also to potentiality of policies and green vehicles like electric vans. Instead, researchers from Belgium and USA seem to have been interested on the theme later than Italy, focusing mainly on innovative solution like parcel lockers in Belgium and drones in USA to decrease in both the situation the impact of the pollutions coming from the last mile delivery process in cities. In Belgium, also the impact on society is quite taken into consideration, while it is not in studies from USA. The Netherlands and France started earlier than all the others, respectively in 2008 and 2010, with no specific interest in a topic, looking at almost all different solutions.

The countries can also be divided in developed and developing countries, following the GDP metric and the 2020 UN classification, in which the developed countries are the ones of North America, Europe and the developed part of Asia and Pacific.

Following this classification only few papers are from developing countries that are Brazil, China, India, Korea, and Turkey. Moreover, they started to be interested on the topic only in 2017, instead the developed countries, mainly concentrated in Europe, started before with a constant increase of interest over the years.



Graph 6 Number of papers published per countries development

Another interesting analysis to perform is to identify how the different ***research methods*** are employed in the study context of urban logistics sustainability.

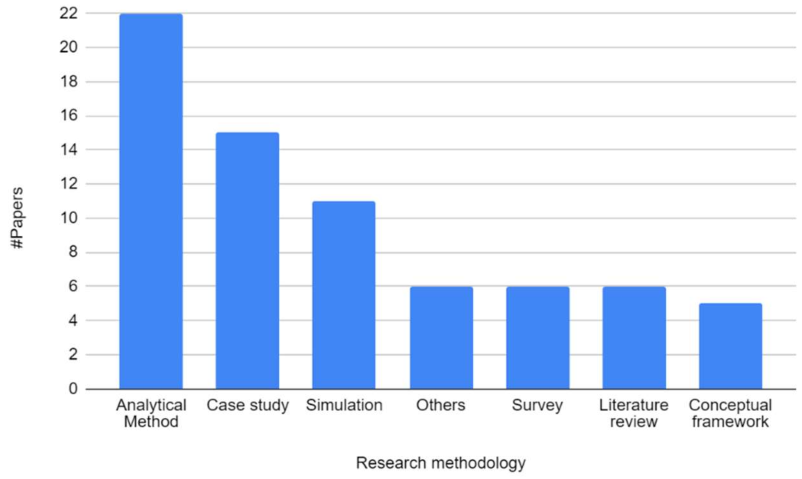
The research methods that were considered in this analysis are the following:

- Literature review – Analysis of the literature related to a specific topic, to identify main characteristics of the research field, common features among papers and research gaps.
- Analytical Method – Universal quantitative model designed in detail to assess effects of some solutions, choices, or settings.
- Conceptual Framework – Model capable of dealing with a problem with the use of qualitative tools like causal relationship and diagrams.

- Survey – Statistical assessment to collect opinions, preferences or behavioral aspects with a specific goal related to a topic. This is performed on a sample of subjects, who can be any kind of the topic/problem stakeholders.
- Simulation – Model that attempts to evaluate/predict effects of solutions, choices, or settings trough a dynamic assessment of a reality-like environment based on computation. This is usually performed through the definition and assessment of different scenarios.
- Case Study – Description and analysis of a real case in its own real context.
- Others – Everything that was not included in the 6 methods above.

In our research corpus there are 64 papers, but in 7 cases it was not possible to enclose the papers in only one method and so two different methods were assigned to each of those 7 papers. These are mainly cases in which there is a preliminary analysis that may be a Literature Review, a Survey, an Analytical Method, or a Conceptual Framework and then a Case Study is assessed applying that universal method presented before.

Because of the double-method papers, 71 "values" of research method are present.



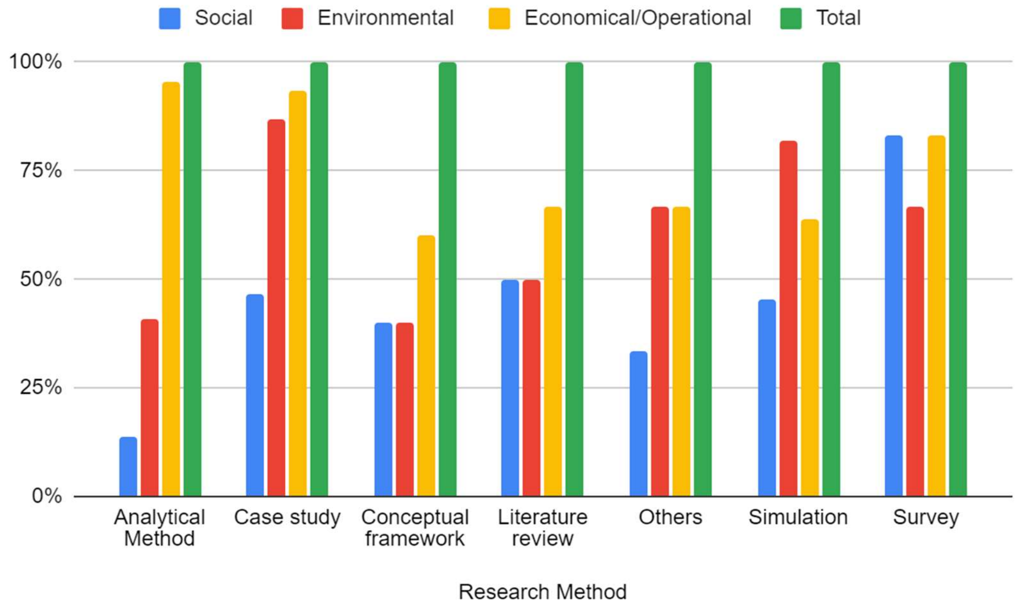
Graph 7 Number of papers per research methodology

This first categorization suggests that most of the collected literature is based on the development of models capable of giving results on the effects, benefits, and drawbacks that some solution or implementation may have. These models can be universal, as for Analytical Methods (31%) and Conceptual frameworks (7%), or case-specific, as for Case Studies (21%) and Simulation (16%). Most explorative methods, Literature Reviews and Surveys account both for just the 8% of the total; the same applies to "Others" category, in which are mainly included papers that were talking about different cases of innovations and solutions implemented to improve urban logistics sustainability, but without providing any qualitative or quantitative results in addition to giving a picture of the cases.

Further in the literature analysis, when it comes to the content of the research corpus, we focus on two different main classification axes:

- Different solutions that were studied/presented/described by the different papers.
- Different impacts of urban logistics that were considered in the paper referring to the three pillars of sustainability.

While as regards the presence of solutions there are not particular differences among the different research methods, it is worth to show how differently in %Papers/Total the 3 impacts, i.e., social, environmental, and economical/operational, are assessed according to the research method.



Graph 8 Social, Environmental, Economical/Operational and Total percentages of papers per research method

It is evident from Graph 8 that:

- Social impact is much easier to be assessed in a qualitative way like research carried out trough surveys, reviews and conceptual frameworks. It is instead less common to assess social impact of urban logistics when using quantitative methods like analytical methods or simulations.
- Economical/Operational impact assessment is the most widespread because it is the one linked to what companies' usually focus on: decreasing costs. For this reason, many authors mainly put a lot of attention on this, not always caring about impact on environment and people.
- Environmental impact assessment is very present in Simulation and Case Studies, since it is fundamental to consider it to truly evaluate a real urban logistic solution implementation, but it's much less present in case of other research methods in which, excluding the "Others", effects of logistics on environment are assessed in more than 50% of papers.

The outcome of this Impact-assessment vs Research methods analysis, point out how considerable improvements and changes are needed in how the problem of urban logistics is treated, still too much linked to money and profits and not giving enough weight to the long-term effects on the environment and on society.

Lastly, it is analyzed if there is a focus on ***B2B*** or ***B2C*** cases and what eventually is its extension. Different aspects characterize logistics in the two different cases, which may influence the efficiency of innovative applications to reduce the impact of urban logistics:

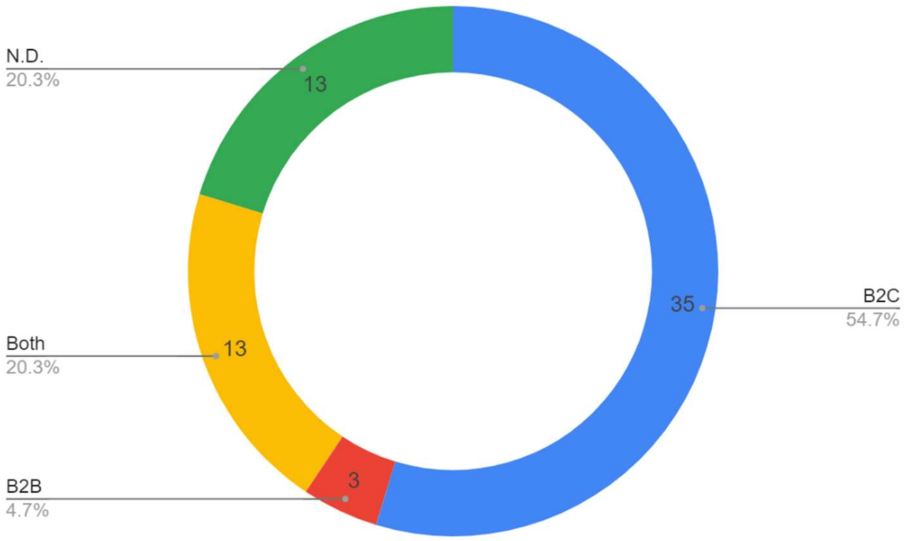
1. Volume per delivery - In B2B deliveries usually the volume/delivery is much higher than B2C deliveries in which instead the order dimension is made of few parcels at most.
2. Delivery points density – As a consequence of the volume/shipment, B2B deliveries tours are usually characterized by a much lower delivery points density, given that for the same area fewer deliveries of bigger dimension are performed with respect to the B2C case.
3. Signature requirement – Most B2B deliveries require to be attended by someone for a signature to confirm the delivery, while in the B2C cases this almost never happens.

It is relevant to see if there is any prevalence of one kind of logistics systems in the literature or if both cases have been equally studied and analyzed. To do this we consider 4 different classifications of the B2B/B2C for a single paper:

- B2B – if there is a clear focus on B2B deliveries, due to a case study presented, the scope of the study or the technology used.
- B2C – if there is a clear focus on B2C deliveries, due to a case study presented, the scope of the study or the technology used.

- Both – if both cases of B2B and B2C are presented, or the study clearly specify the fit both types of systems.
- N.D. – if there is not any distinction between B2B and B2C, both in cases of study or of practical case presented.

In results of these classification are displayed in Graph 9.



Graph 9 Number of papers per business focus

The results show a huge prevalence of B2C only cases, with a representation of 35 papers out of 64, the cases of Both and N.D. are equally present with 13 papers each, and lastly B2B only with 3 cases.

This was quite expected because of the different characteristics of the two different businesses presented at the beginning of this analysis. Being B2C logistics characterized by a much higher number of smaller deliveries with respect to the B2B, these are characterized by a huge amount of delivery stops and unsaturated capacity of vehicles, which are the most relevant causes of urban logistics inefficiency. Consequently, B2C deliveries are the ones that mostly can benefit from impact reduction policies, studies, and delivery technologies. It is sufficient to think at examples like usage of cargo-bikes or small autonomous vehicles such as drones and robots, which would not make sense for performing few deliveries of considerable dimensions and that instead get increasing benefits as the deliveries becomes more, with higher customer density and smaller volumes/customer.

It’s interesting to point out anyway how the 3 cases of B2B only are all papers in which a case study was presented, specifically about the usage of light freight railway, railways, no diesel vans or sharing customers’ and freight movements on public transport.

When it comes to studies, without application cases, it would not make sense to be only B2B-related since any benefits the B2B may have can be obtained more significantly in B2C, and for this reasons studies consider both or B2C only. When it comes to the real applications, instead, given the higher decisional power that companies can have in B2B logistics, it is not difficult to find applications that had success in that field, both internal cases, moving goods from one facility to another, or external like delivering goods to another company.

2.3.2. Classification dimensions

After describing the main characteristics of the collected papers in terms of time, geography, research field and method used, we decided to classify and analyze the studied literature on the base of two main axes: the type of solution/innovation proposed by the study and the impacts evaluated (economical/operational, environmental, social). The idea of axes coming from a literature review analysing possible innovative solutions to increase last-mile delivery efficiency by Mangiaracina et al. (2019).

The whole paper selection process was based on the goal of understanding in what extent the impact of urban logistics is topic of interest in the academic world and what kind of solutions were studied and/or tested with the aim of reducing it. However, every study can have a different perspective or interest and therefore it is worth also to track how many and which of the 3 conventionally defined impacts (economical, environmental, social) are more commonly object of study. The following research questions can be then formulated, according to the dimensions just defined:

- RQ1: What solutions does the academic world consider for reducing urban logistics impact?
- RQ2: How much and how each impact of urban logistics is considered in the actual literature?

2.3.3. Type of solution proposed

As presented in the research method analysis, very different kind of papers have been selected in our literature research: literature analysis, analytical/mathematical models, case studies, surveys, qualitative models.

Given the heterogeneity of the research methods it was already expected a great heterogeneity of problems and solutions proposed by the different papers, since not all types of solutions can be analyzed with the same method having good quality outcomes.

The number of solutions presented by each paper is highly variable. There are studies that given their nature deals with just one solution type, for example case studies or mathematical models focused on a single network. There are papers, on the other side, presenting different solutions, which can be few, as in case studies with different innovations were combined in a single context, or many, as in literature reviews dealing with wide urban explorative researches and presenting different cases.

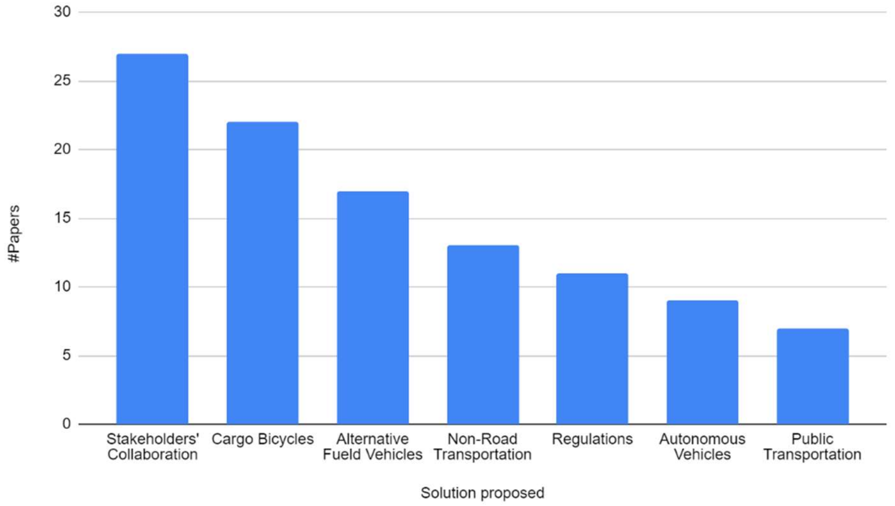
Given the vast diversity of all the possible actions, solutions and innovations proposed, we decided to group them according to the similarity they share in the following characteristics:

- Technology or impact mitigation means used. There can be different types of vehicles, network restructuring or organizational changes.
- Barriers to implementation. The obstacles to the implementation of the solutions may be of different types, some may be too expensive or need heavy infrastructures, others may not be safe enough yet or else not well perceived by customers.
- Stakeholders involved. Different solutions may include and need the coordination and agreement of different types of stakeholders with different roles in the supply chain: suppliers, express couriers, retailers, customers, municipalities, and governments to name a few.

Based on the features above presented, the following dimensions were identified:

- Regulations
- Stakeholders’ Collaboration
- Non-Road Transportation
- Alternatively Powered Vehicles
- Cargo-Bicycles
- Autonomous Vehicles

The number of papers that deal with each type of solution is displayed in Graph 10.



Graph 10 Number of papers per solution proposed

The leading category in number of papers is “Stakeholders’ Collaboration”, theme present in 27 out of 64 papers, which means that almost the 50% of the literature analyzed considers stakeholders’ collaboration as fundamental part of impact reduction actions and solutions that can be put in place. This clearly states how important coordination among different actors is in reducing the impact of urban logistics without losing service level. In the perspective of increasing efficiency, the competition moves towards a different concept: coopetition, a mix of cooperation and competition. In this category we find all the papers in which the whole or part of the network is shared among different actors or else in which there are direct or indirect agreement between different supply chain components, as in the case of parcel lockers utilization.

The second category in this ranking is “Cargo Bicycles”, present in 22 out of 64 papers. Once the research was defined as “solutions and innovations for reducing urban logistics impact”, it was expected that the cargo-bicycles would have played a dominant role as alternative vehicle. Delivery vehicles in urban areas usually reach the capacity limit in time available and not in weight or volume capacity of the truck, therefore, smaller vehicles are seen as a good solution for reducing the impact of heavy vehicles without significant losses in customers served, also because given the city traffic, it is not so easy that vans can benefit of their higher speed power. Cargo-bicycles are basically bicycles equipped with a trailer or a small wagon, which makes it a not innovative technology. However, the exploitation of cargo bicycles in efficient ways was made possible only in the last years thanks to the evolution of pedal assisted electric bikes in both regular and cargo usage.

With 17 papers the third most analyzed solution type is "Alternative Fueled Vehicles", in which we grouped all the papers that consider traditional delivery networks but with vans or trucks alternatively fueled with respect to Internal Combustion Engine Vehicles (ICEVs) consider. These are mainly full electric vans or hybrid ones of which operability, limits, barriers to implementation and costs are quite studied in the academic literature in this field.

Going on in the presentation of the different solution categories by number of papers, the next is "Non-road transportation", including 12 papers. This group is composed of intermodal solution in which the "mile before last" is performed with a waterway or railway-based transportation, after which there can be traditional deliveries or else other innovative solutions. What these two smaller groups (waterways and railways) share is mainly on the barrier to implementation side, given the need of authorities or third parties permissions and heavy infrastructures and vehicles, which makes going towards these systems not as easy as changing the vehicles fleet of a courier from ICEVs to EVs or Cargo-Bicycles. In the railways solutions are considered both trains and trams, that can play very different role in urban distribution.

The fifth category in order is instead "Regulations", with 11 papers out of 64. This is composed by all the studies that consider the effects on urban logistics impact that be achieved with governments or municipalities decisions, bans, limitations, and charges on one side, but also benefits and incentives on the other. Some examples are Limited Traffic Zones, taxation benefits for electric vehicles or else disincentives for high-emissions vehicles, limitations to number of commercial vehicles/days allowed in a city and fees that ICEVs need to pay for entering the city center.

In sixth position there is "Autonomous Vehicles", with 9 papers out of 64. This result was quite expected because of the developed technology needed to implement such solutions and also that in most of the countries worldwide the regulation of autonomous vehicles, also small delivery vehicles, is still not developed. Therefore, the cases of autonomous vehicles usage, as small wheeled-robots or drones, are mainly studies in which costs and/or emissions of the designed solution are considered, but no case studies based on real applications are present.

Lastly, there is the least wide category, which is "Public Transportation", with only 7 papers out of 64. These studies are considering the integration of public transportation for passengers with deliveries through different solutions. Some researches are related to passengers and cargo sharing the same vehicles, others about passengers performing deliveries in a crowd-participated delivery network (crowd-shipping).

In the following sections, the different categories are deepened, and the main studies and topics presented.

2.3.3.1. Stakeholders' collaboration

The environment of urban logistics is supposed to keep being very challenging, with customers requiring astonishing delivery performances that at the same time increase inefficiency in both environmental and economical sustainability of last-mile deliveries, which directly brings to poorer quality of life in cities. Single players in this setting are therefore usually not enough for changing the direction of how far impacts of urban logistics are going. Trough the coordination and collaboration of different actors, instead, it is much easier to move towards a more sustainable future since each player can take care of what it does in the most efficient way.

More in detail we find different kind of collaborations that are deepened:

- Integration of the flow/network
- Crowdsourcing
- Different companies collaborating on one flow line
- Decoupled deliveries

Given the fragmentation of the delivery flows of different companies last-mile delivery is always composed by unsaturated vehicles, that travel inside the city in much higher number than already needed and for much more kilometers. If the companies were able to consolidate the flows and deliver "together" then both the number of vehicles and the kilometers travelled would decrease. A first solution in this perspective is the creation of Urban Consolidation Centers: logistics facility in proximity to urban areas where sorting and consolidation of loads dropped off by different logistics companies takes place and deliveries are launched. J. Leonardi et al. (2012) present a case study analysis in which a UCC is combined with the usage of cargo-tricycles vehicles for last-mile deliveries. Nocera et Cavallaro (2012), instead, are also worth to be mentioned for the detailed Well-To-Wheel analysis prepared and then applied to assess the potentiality of a new UCC in the city of Lucca. Y. Li et al. (2019), instead, assessed how the sharing of hubs and vehicles among different delivery companies can significantly reduce the impacts of urban logistics. Other types of shared hubs are presented to name few also by A. Bucchiarone et al. (2021), designing a shared delivery platform making use of autonomous shuttle for deliveries, and by L N. Rosemberg et al. (2021), in which shared Micro-Depots can function both as consolidation centers and collect points for customers.

Another relevant theme treated is the Crowdsourcing: a system in which citizens deliver packages to other people while moving around the urban area for their own reasons through their routes. In these ways, deliveries could be performed with no or very small emissions and costs. A relevant study has been performed in A. Giret et al. (2018), in which a complex network-based algorithm is developed for the definition of the routings, given the customers and the citizens available to perform this service. An important role is played also by A. Seghezzi and R. Mangiaracina (2021) in which the possibility and impact of having multi-parcel deliveries in a crowdsourcing logistics system. Lastly, Simoni et al. (2019) developed different simulation scenarios for crowd shipping, car-based or else public transportation-based.

Another type of collaborations is the one that can take place between actors of the supply chain, each one performing different parts of it. An example is the study developed by J. H. R. Van Duin (2019), in which different integration possibilities between a delivery company and a passenger-transportation one were assessed. Other examples are the development of a parcel locker system in metro stations simulated in R. Villa et al. (2021) or else cases in which private companies collaborates with municipalities sharing investments and/or responsibilities, as a tramway-based project in Paris described by J. Gonzalez-Feliu (2014).

Lastly, the remaining main topic treated in the “Stakeholders’ collaboration” section, is related to "Decoupled deliveries”. Two significant issues of B2C last mile deliveries are demand fragmentation, that brings to having many delivery points, and unattended deliveries, factors that are among the most challenging for actual and future urban logistics. In this perspective decoupling courier and customers in the moment of the delivery is of significant help, and to do this some collection-delivery points (CDP) are needed. They can be of different types, attended as postal offices or unattended as parcel lockers, but what is common is that the courier delivers large quantities there and then the customers go to pick-up their parcel. In the ecommerce environment, in which returns are significant and affecting the overall performances of the delivery services, collection points could be used also to try the item, for example combining it with a dressing room in case of apparel deliveries, and eventually return it through the same system of collection points. Studies related to decoupled deliveries are many, the usage of CDPs can be stand alone or else combined with other solutions, innovations, or vehicles, like the case of D. L. J. U. Enthoven et al (2020) in which both cargo-bicycles and parcel lockers are used. Some are trying to evaluate the difference between traditional deliveries and CDPs, as Cardenas I. D. et al (2017), J. R. Brown and A. L. Giuffrida (2014) or M. Giuffrida et al. (2016), others show the reasons of success or failure of some real cases, as C. Altunas et al. (2021). Worthy of mention is also the work performed by Cardenas I. D. et Beckers J. (2018) about the development of a framework for the evaluation of the actual state of pick-up points network in a Belgian city, considering the population reasonably covered by those points, their availability in terms of opening days and hours, applying the framework to different couriers that have pick-up networks in that city.

2.3.3.2. Cargo Bicycles

Cargo Bicycles are the technology-based solution that is most represented in our research corpus, with 22 out of 64 papers using cargo bicycles in their proposal or talking about them as alternative delivery mean for urban logistics. Into this category we find mainly electric assisted cargo bicycles or tricycles whose technological evolution is making always easier and more convenient the migration towards this transportation mean for freight transportation.

We find in this group very different solutions, cargo-bicycles as standalone solution, with stationary or mobile depots, sometimes also with depots and distribution shared among different delivery companies, or else in combination with other delivery vehicles with whom cargo-bicycles share the flow. The most relevant contributions are presented below.

A first relevant study is performed in V. Naumov et al. (2021) which present different types of cargo bicycle, in terms of dimension and capacity and evaluates the different performances. Similar is the case of R. Gervaers et al. (2014) with a development of a cost model to evaluate the last-mile delivery considering many different features that can have an influent role, such as time windows or collection points. Carlos Llorca et al. (2021) performs a simulation of a distribution network using micro-depots and cargo bikes in Munich, in which deliveries can be performed by a van or by cargo bikes passing through urban hubs, in different scenarios according to the percentages of volumes dedicated to cargo bikes are tested. Same sensitivity analysis on the split between cargo bikes and vans is performed also in S. Melo et al.(2017) in which, moreover, not only economic costs but also the ones related to emissions and congestions are considered.

Sometimes, instead of stationary depots, mobile ones are used. In this perspective a first interesting case is studied in Sara Verlinde et al. (2014) presenting a case study on the introduction of a mobile depot and four cargo bicycles in a small and density populated area in Brussels, performing an evaluation of the solution through a Multi Actor Multi Criteria analysis considering as many stakeholders involved as possible. Analogous is the case presented in A. Anderluh et al. (2017) which studies a two-echelon routing problem application in Vienna using vans to serve the customers outside the city center while the bikes the ones in. It is also interesting to notice that this network is tested with both depots for the feeding of the cargo bikes and with vans acting as mobile depot for them. A singular comparison is performed in R. A. de Mello Bandeira et al. (2019) in which distribution through electric tricycles in Rio is compared to a traditional approach using a bus and walking to reach customers.

It is quite common also to be in front of cases in which shared depots and distribution network are used in solutions with cargo bicycles so to exploit even more the efficiency and environmental sustainability increase that such solutions can bring in urban logistics. We can find this in J. Leonardi (2012) in which an Urban Consolidation Center in the city center of London is used to deliver using cargo tricycles while EVs are used for larger parcels. Another example is C. Navarro et al. (2016) presenting two different pilot cases in Spain, one in Barcelona and the other in Valencia, using cargo tricycles departing from containers used as micro depots paying attention to the impact of cargo bikes in avoiding problems given by time windows or limitation imposed in cities to vans. A case in which cargo-bikes are combined with parcel lockers is presented instead in L. N. Rosenberg et al. (2021) in which a shared micro depot can work also as collection/pick-up point for customers to receive in this point their deliveries and collect them when it is more comfortable.

Lastly, it is worth to mention Fraselle J. et al. (2021) that compares electric bicycles and tricycles with both electric and combustion engines vehicles assessing both costs and environmental impact

2.3.3.3. Alternative Fueled Vehicles

Using delivery vehicles powered by different technologies than fossil fuels, is one of the most common solutions for decreasing the environmental impact of urban logistics. These are mainly electric and hybrid vehicles, which are not “new released” technologies but are facing many improvements in the last years, becoming operationally and economically more attractive than how they used to be in the past.

Therefore, out of 64 papers reviewed, 17 of them consider the implementation of alternative fueled vehicles, which may be used both as standalone solution and in combination with other transportation means for feeding them or for performing door-to-door deliveries.

A first possibility is composed by hybrid vehicles, that in A. Alessandrini et al. (2012) are presented as choice for last mile delivery after a railway transportation in a Multi-modal Urban Distribution Center in Rome.

The main and most studied technology is instead related to electric vehicles, more specifically vans. The first study worth to mention is R. Mangiaracina et al. (2020), in which a comparison between Electric Vehicles and Internal Combustion Engine Vehicles is performed through a Total Cost of Ownership analysis for the economical side and a Life-Cycle Assessment on the environmental emissions one. Among the papers focused entirely on EVs, there is also N. Nesterova et H. Quark (2014) in which instead, through a SWOT analysis, are presented the main issues and challenges, but also benefits and opportunities, of implementing electric freight vehicles in city logistics. Y. Li et al. (2019) and S. Nocera et F. Cavallaro (2017), instead, present the possibility of using EVs in shared networks, paying attention to both the increasing economic affordability and the decreased emissions of the shared solutions with respect to the traditional ones.

In other cases, electric vans can be used in multi-modal solutions, and the possibilities are many. J. Leonardi (2012) presents a case in London in which EVs are used in combination electric bicycles or tricycles starting from a shared Urban

Consolidation Center and diving the deliveries to the different vehicles according to the size of it: bigger ones to vans and smaller ones to bicycles/tricycles. Another common use is to have EVs performing last mile deliveries after a railway transportation, to fill the low capillarity that railways, needing specific infrastructure can have. In this sense, N. Arvidsson et M. Browne (2013) presents a case in Amsterdam in which EVs are used for door-to-door deliveries after a tramway transportation, while J. Gonzalez-Feliu (2014) performs a socio-economic cost/benefit analysis of a network in which, after a train transportation, small electric vehicles are used for final deliveries, considering both economic and social impacts, monetary and non-monetary costs.

Lastly, we have cases in which different technologies are considered in the same papers and the performances of mixed fleet analyzed, comparing the different vehicles. An interesting Life-Cycle Assessment is performed in J. Fraselle et al. (2021), in which both economic cost and environmental impact of mixed fleets of electric bikes, electric vans, combustion engine vans and light truck are considered. Similar analysis is performed in P. Lebeau et al. (2015), in which alternative vehicles technologies, dimension and power source in different fleet compositions, mono vehicle or mixed are used.

2.3.3.4. Non-road Transportation

The main benefit of road transportation is its high capillarity and accessibility given the very dense road network that every developed country has all over its territory. However, non-road transportation can sometimes bring huge benefits to network that were used to be road-only, decreasing costs and/or environmental impact and not being affected by road congestion. There are therefore studies about green urban logistics solutions that take advantage of what non-road transportation modes have to offer. In our research corpus, 13 out of 64 papers consider non-road transportation related solution. Sometimes traditional or electric vans are used to feed the alternative mean and/or to perform the last mile.

The main non-road solutions are based on railways, that, as stressed in S. Beherands (2012), allows to exploit both accessibility and efficiency. Different implementation cases are presented in M. Browne (2014), in which also the barriers preventing the success of the failed cases are explored. In the urban logistics environment, the most common railways-based solutions are the usage of cargo-trams or metropolitan systems for the movement of goods. As regards the first, O. Pietrzak (2021) evaluates the development and success of cargo-tram freight transportation in Poland and applies an evaluation framework to the city of Szczecin, considering different ways of integrating freight and public transport in terms of division in wagons and/or vehicles. Considering the metro systems instead, two different papers are worth of mentions. D. Guo et al (2021) studies an underground logistics system in China, from the planning to the implementation phase, highlighting the challenges that during the implementation most commonly will be faced. In R. Villa et al. (2021), instead, is discussed a solution in which light-duty vehicles work as feeder to some metro-stations from where the goods will be moved through rails to different metro stations and there put into parcel lockers for customers to retrieve their parcels.

Besides railways-based solutions, also waterways-based solutions are studied in literature and some cases presented. Of relevant interest is the case present in F. Bruzzoni (2021) about Venice Lagoon and specifically a way to integrate passengers and freight transportation in waterbuses during a low saturation timeframe for the public transportation mean. Similar is the analysis in E. Divieso et al. (2021) in which it is evaluated the potential of a project in Brazil about a cargo and passengers transportation network between different cities through rivers.

Lastly, it’s worth to mention D. Diziain et al. (2014) that comperes the development of railways and waterways in France and Japan for urban logistics, deepening benefits and challenges of both.

2.3.3.5. Public regulations

The role of governments and municipalities in fostering innovations in general can be crucial and determinant, incentivizing companies and people to adopt decisions or behaviors that are expected to have long-term benefits for city livability and people well-being. In case of urban logistics, the role of policies should be to incentivize those kinds of modernizations of technologies and/or methods that can help in reducing the impact of urban logistics. Even if not all papers in this category focus on public regulations to mitigate economic, environmental, and social sustainability of freight transportation in urban areas, it is relevant how the definition by regulators of benefits and/or restrictions regarding urban logistics can be a great incentive to make companies and researchers start thinking to alternative solutions to the actual system. Consequently, 11 papers out of 64 specifically present regulations as determinant components of the network, being the cause of the new solution implementation or else being studied as a direct game-changer.

Looking at the papers that present a general overview of the most common public policies enforced for reducing urban logistics impacts, different papers are worth to be mentioned. G. Sanz et al. (2018) evaluates different urban freight transportation policies through a process of surveys and interviews to Urban Freight Transport experts. Relevant is also the contribution of K. Fossheim et J. Andersen (2017) that, before comparing UK and Scandinavia implementation and results of regulations for urban logistics, deepens and differentiate the European guidelines plans regarding urban sustainability, namely SUTP (Sustainable Urban Transport Plan), SUMP (Sustainable Urban Mobility Plan), and SULP (Sustainable Urban Logistics

Plan). Lastly, N. Nesterova et H. Quak (2014) focuses on local policies that can push towards the implementation of electric freight vehicles, diving them in 4 groups according to the nature of the policy effect, financial/non-financial, and the goal of the policy, incentivizing electric vehicles or disincentivizing combustion engines ones.

Other papers instead are more case-specific, deepening the regulatory policies implemented in some cities and their effects or else their potential. M. Morfulaki et al. (2016) presents an application case in a Greek city named Serres in which the implementations of different regulatory policies are evaluated through different indicators such as cost, time for implementation, social reaction, effectiveness for the specific city and others. M. Koning et al. (2016) while presenting the transport situation in Paris, names different freight policies that may have had effects on deliveries efficiency and urban sustainability, considering both disincentives to traditional vehicles and incentives to the usage of cargo bikes. H. Quak et R. B. M. De Koster (2008) evaluates the performances, financial and environmental, of two retailers delivering to stores after the implementation of two different policies: time windows for entering the city and vehicle dimensions-restriction. Interesting is also how in R. Mangiaracina et al. (2020) regulations specific of the city of Milan are considered for the TCO of both EVs and ICEVs, in terms of differences in tolls for entering the city, cost of insurance, registration fee and benefits allocated by governments to incentivize migration towards EVs. Lastly, still regarding Milan, P. Menga et al. (2013) performs an evaluation of electric vehicles usage pushed by the definition by the municipality of a central area into the city called Area C, in which traditional fueled vehicles are subject to many restrictions to which instead electric ones are not.

2.3.3.6. Autonomous vehicles

The solutions with autonomous vehicles have been grouped because of their similarity in novelty and barriers to implementation. We have here 9 papers out of 64 which means that it is a quite studied phenomenon in literature but not the same as cargo bicycles in which many papers about application cases make the core of the class. Indeed, apart from the three literature reviews we can observe that there are four "Analytical Methods" and two "Simulations", no case studies were found, making the literature on this topic more modeling and optimization oriented. Two main technologies are presented: Drones and Small Robots, but also an interesting Autonomous Shuttle usage proposal has been reviewed.

As regards robots, 3 interesting optimization models are present, with different network designs or optimization targets. Simoni et al (2020) analyzes a delivery system based on a truck and a large size robot with the capacity of serving more than one customer per launch, rejoining the truck after some stops. In Boyesen et al. (2018) a delivery truck contains several robots, and a network of depots is used for robots to go back after delivering to a customer and from where the truck replenishes robots. Ostermeier et al. (2021) performs the same study case of Boysen et al. (2018) but with different optimization objective: instead of the minimization of late deliveries, minimization of cost.

Similar models are developed also with drones, for example in C. Chase et al. (2020) in which a truck drops off several drones to serve customers autonomously and then re-joining it in other locations while it is performing its path serving other customers. Different case is studied in D. Swanson et al. (2019) presenting a simulation model of store-to-customers deliveries using drones compared to using surface vehicles, evaluating differences in delivery distance and time. Both also highlight the differences between drones and autonomous robots and the aspects that should be regulated.

Lastly, it is relevant the study of Bucchiarone et al. (2021), in which it is designed what has the name of Autonomous Shuttle as a Service (ASaaS), a shared and flexible, delivery system of people and goods in the field of last-mile mobility, highlighting benefits and challenges of autonomous shuttles.

2.3.3.7. Public transportation

In this category were grouped the papers that shared the integration with the public transportation systems, not only sharing the same infrastructures but also sharing the same vehicles and/or windows of time. It is the class with fewer papers, but still 7 papers consider this as a solution for decreasing the impact of urban logistics.

A first typology of studies gets their initial idea from the unsaturation of some public transportation means and evaluates the possibility to exploit it for freight transportation without additional emissions and congestion. It is the case of R. Masson et al. (2015) presenting a case study in which buses spare capacity is used for freight movements in the city of La Rochelle, France, into the city center with narrow streets where deliveries with traditional vehicles are difficult. Another case is F. Bruzzone et al. (2021) that studies a case of integration in the Northern Venice Lagoon of public waterbuses and freight delivery in different islands of the lagoon. Lastly, J. H. R. Van Duin (2019) proposes a cargo hitching network analysis in which public bus is used for movements of freight, delivering to collection points and then bikes performing last-mile deliveries.

In other cases, not only the unsaturated space is considered but also the possibility of using same infrastructures but separate wagons or vehicles for passenger and freight transportation services. O. Pietrzak et al. (2021) studies different integration solutions of freight deliveries and tramways, with freight and passengers on the same wagons, in different wagons of the same vehicle or different vehicles on the same rails. With the same logic is the study of D. Guo et al. (2021) in which underground logistics systems are exploited for freight movements in separate wagons.

Lastly, few solutions are focused on the exploitation of metro-systems capillarity and accessibility such as in R. Villa et al. (2021) in which it is developed a network of smart lockers in subway stops using metro lines for the movement of goods or Simoni et al. (2019) that hypothesizes a crowd-shipping network in which the "crowd" transportation is performed only by tram or subway.

2.3.4. Type of impact considered

The second axes according to which out research corpus has been classified, as already anticipated, is related to the types of impact of urban logistics that are considered in the single papers. Indeed, sustainability of delivery activities inside city areas follow quite precisely the 3 pillars conception, in which sustainability is composed by economic viability, environmental protection and social equity, with the main aim of guaranteeing planet's integrity and improving quality of life, while also maintaining economic practicability. Following this reasoning, the values of this classification axes are:

- Economical/Operational impact.
- Environmental impact.
- Social impact.

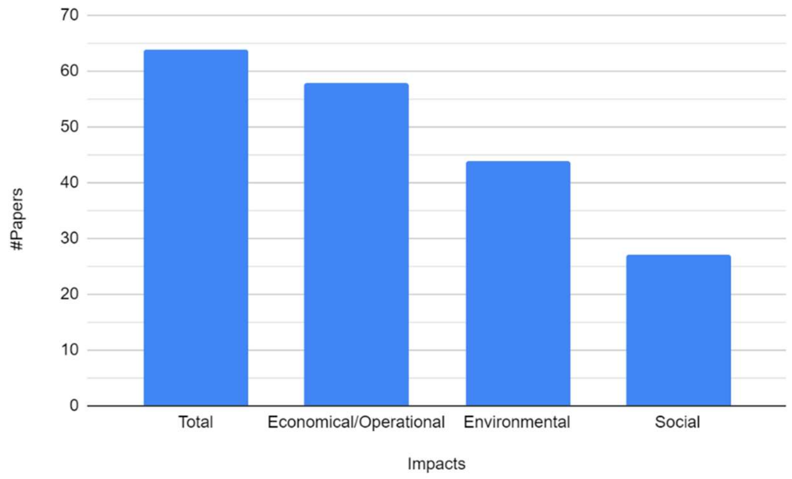
While for Environmental and Social impacts no further explanations are needed, as regards the Economical we decided to expand in into Economical/Operational. This because there were some papers that were not considering costs as impact but efficiency measures like time or distance, which anyway have impact into cost and that is why operational efficiency has been grouped with economical.

Different papers, however, focusing on different topics and analyzing the problems in their own way, can have different point of view and interest into the field of urban logistics sustainability. A study can consider only if a solution can help in decreasing cost for a delivery company or may focus on the environmental impact of urban logistics, with particular attention to the emissions due to the activities performed, or lastly can be more interested on presenting the point of view of people that see the quality of their own life and health influenced by the huge growth of urban logistics. Not only papers can have a specific focus of course, but consider also more impact at the same time, taking care of both economical affordability/benefits and emissions improvement, or maybe of both economical/operational sustainability and effects on society and how to reduce them or else do not consider the cost/operability of something but only its effects on the planet and on people. Lastly, of course, there are also cases in which all the three different impacts are considered all simultaneously.

However, not all the impacts can be estimated and analyzed with the same methods and precision, and that is why for each impact we present if it is usually assessed qualitatively or quantitatively and what tools and methods are the most used.

Strictly related to this last consideration, there is how much each impact is included in each group of studies of the same research method, analysis already performed in the first part of this literature analysis, in which it was clear that while Economical/Operational and Environmental impacts are quite easy to be assessed analytically but also qualitatively when needed, Social impact is usually only qualitatively analyzed, given its subjective nature.

In Graph 11 are displayed the number of papers that consider each of the impact considered.



Graph 11 Number of papers per Impact

Looking at the whole research corpus under the scope of our literature review, it is clear how the Economical/Operational impact is the most considered and studied impact, 58 out of 64 papers, which was quite expected because, no matter the topic and the solution, economical and operational efficiency has always been the first thing that is evaluated when new ways of doing things. As already said, this is related to costs, time and distance efficiency that can be achieved with different solutions.

In the second place we find the Environmental impact, with 44 papers out of 64, which even if quite commonly studied, makes sustainability for our planet not the first goal of the research. This difference is given by papers that even if assessing innovative and green solutions, do not consider the environmental impact in their goals and achievements, but only a reduction in cost or improvement in efficiency. As environmental impact what is usually assessed are the emissions that are consequence of the activities performed, considering different perspectives and different pollutants.

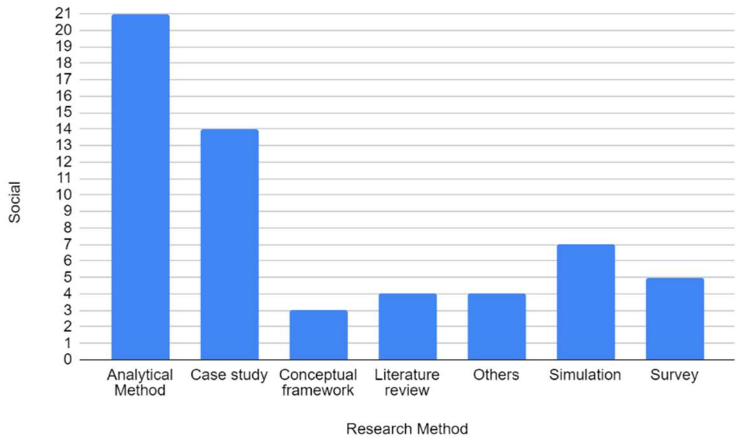
Social impact, instead, is the one that in most cases is not considered by the authors of the papers, only 26 out of 64 consider it, both because not always interested and because in many cases it is quite difficult to consider it, given the qualitative nature of the effects on social sustainability of urban logistics.

In the following paragraphs we present a deepening of how each urban logistic impact is studied in literature, in general and pointing out also the main contributions. For each impact it is highlighted:

- Research methods that mostly populate each different impact group.
- Methods used.
- Variables evaluated.
- Point of view considered out of all the stakeholders (e.g., delivery companies, logistics players, institutions, or citizens).

2.3.4.1. Economical/Operational Impact

Economical/Operational impact is considered in almost all the papers analyzed and, therefore, the distribution of research methods used in the papers concerning Economical/Operational impact (Graph 12) is almost the same of the whole research corpus.



Graph 12 Economical/operational vs Research Method

The first main topic into the bigger one of Economical/Operational impact is Cost. What in the most cases the models or the research performed try to assess is cost difference that a different technology, vehicles, or organization can bring in costs, in terms of savings or additional costs, according to the cases. In this perspective different variables and components are considered. On the operational side, the most common cost contributions considered are maintenance, amortization, carbon taxes, insurance, fuel, driver's wage, but also penalty costs for late deliveries, parking fees, registration fees and fines received. On the investment side, instead, money spent for vehicles and/or infrastructures, such as depots, charging stations and ways for transportation. In optimization model for a last mile delivery network with truck-based autonomous cargo robots developed in M. Ostermeier et al. (2021), the objective function includes all the operating and investment costs related to all vehicles used and to late deliveries. Also, in Sara Verlinde et al. (2014) all the operating and investment costs are taken into consideration to evaluate the performances of using mobile depots and cargo bikes in a case in Brussels using a Multi actor-Multi criteria analysis (MAMCA), that includes the points of view of different stakeholders like logistics service providers, shippers, receivers, citizens, and local authorities. In J. Fraselle et al. (2021) and in R. Mangiaracina et al. (2020) a Life-Cycle Assessment (LCA) of alternatively fueled vehicles is performed, comparing them with traditional diesel van including feeding, maintenance, and repair costs but also road tolls, insurance, registration fee and others.

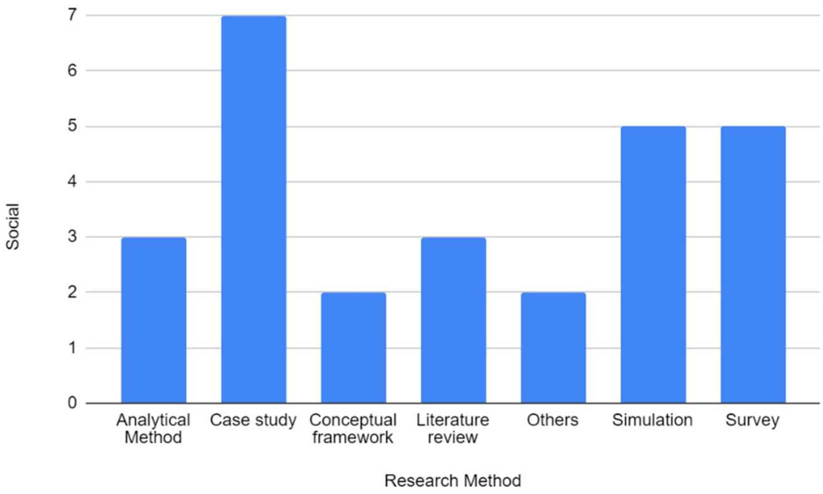
In some cases, are considered also costs related to emissions, which may be more difficult to define and estimate, but that can give an even more complete view of the total economic value that an innovation or solution can bring. In Alessandrini et al. (2012) the cost savings given by the usage of a train and low pollution trucks instead of traditional vehicles are evaluated looking firstly the costs related to operator's point of view like maintenance, amortization, taxes, insurance, fuel, driver's wage.

Moreover, the cost of emissions is analyzed, using emissions cost factor from the European Commission's handbook, to understand the society's point of view. A social cost-benefit analysis (SCBA) is developed instead by Jesus Gonzalez-Feliu (2014) to evaluate an innovative solution exploiting railway urban logistics and for last mile small electric vehicles, considering both monetary, like investments costs for infrastructures, and non-monetary costs, like emissions and social impact.

Apart from costs, another way to consider efficiency of urban logistics and the benefits that different solutions and innovation can bring in this field is to look at different cost- or service-related aspects. Particular attention is given to impacts in traffic congestion, distance driven, delivery time, number of late deliveries and IT support complexity. Regarding this purpose, S. Verlinde et al. (2014) in its MAMCA, apart from costs, also considers the negative impact that mobile depot can have on punctuality as operational figure. S. Melo et al. (2017) with its microscopic traffic simulation comparing traditional vans with cargo bicycles, evaluates the impact on congestion of considering different market penetration of cargo bikes. M. Morfoulaki et al. (2016) assess operational impact of its solution, together with the other impacts, in a qualitative way with a survey directed to a multi-criteria analysis. Specifically, for the operational one, it considers aspects as the implementation time, IT support needed and exploitation of existing infrastructures.

2.3.4.2. Environmental Impact

Environmental impact is the second most considered impact in our research corpus, present in almost 70% of papers analyzed.



Graph 13 Environmental vs Research Method

Observing the distribution of the Research Methods used in papers concerning environmental impact (Graph 13), this is very similar in most of the classes to the one of Economical/Operational impact with as main difference the loss for Environmental impact of the half of the papers based on Analytical methods. These are cases in which analytical model are developed with the only aim of studying cost and operational efficiency of some innovation or solution.

Different pollutants are considered in the papers analyzed, with specific focus on Greenhouse Gas Emissions and micro-pollutants such as CO_2, CH_4, NO_2, NO_x and PM10. An indicator born with the aim of aggregating the impact of all the GHG pollutants is the $kgCO_2e$, which consist in the weighted average of the Global Warming Potential of CO_2, CH_4 and NO_2.

As regards the method instead, mainly two different approaches are used:

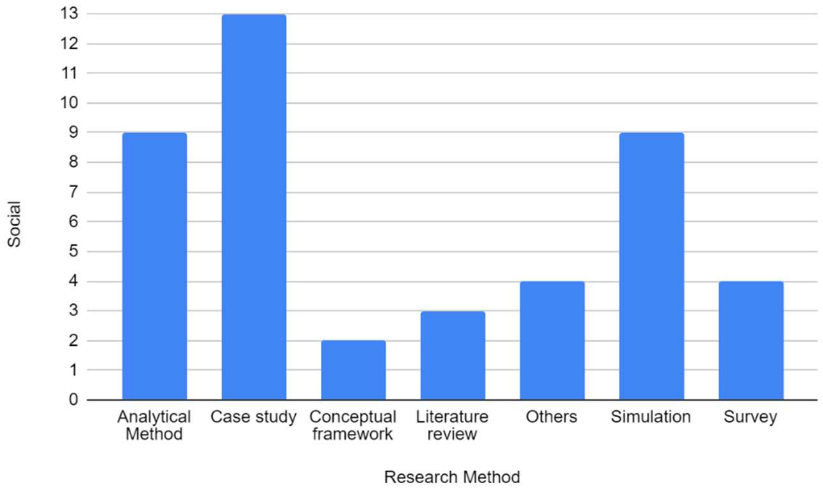
- Well-To-Wheel: evaluating not only the emissions produced during the usage of the vehicle but also the ones needed to produce the source of energy (fuel or electricity).

- Life-Cycle Assessment: considering besides the emissions related to the transportation activities also the ones generated during vehicles production and disposal.

Many interesting studies in terms of environmental impact analysis are present in our research corpus, considering different perspectives and emission factors. In Maria Giuffrida et al. (2016) is developed an activity-based model to compare home delivery with parcel lockers evaluating the KgCO2e produced by both networks. Both R. Mangiaracina et al. (2020) and Nocera et Cavallaro (2017) consider for the environmental impact analysis not only the emissions generated by the usage of vehicles but also the impact of upstream process. In particular, the first paper performs a Life Cycle Assessment of EVs and ICEVs in Milan, considering GHG emission from energy production, which means for fuel or electricity, the ones produced while travelling, applicable only to ICEV, and the ones related to the so-called vehicle cycle, which means production, maintenance, and disposal of the vehicle. Instead, S.Nocera and F.Cavallaro (2017) performs a CO2 quantification through a Well to Wheel approach with a model that computes the emissions in different conditions of traffic flow, road slope, congestion and vehicle load. In this second case, the reduction of CO2 emission is then also monetized. In some cases, the emissions considered are not only coming from Carbon Footprint but also by other type of pollutants like in Sara Verlinde et al. (2014) that considers also SO2, PM2.5, and PM10 to evaluate the performances of using mobile depots and cargo bikes, given the impact of these contaminants on the quality of air inside cities. The same happens in Simoni et al. (2019), in which the emission analysis to evaluate the impact of crowd shipping consider not only CO2 but also CO, NOx and PM10 as function of travel speed and distance covered.

2.3.4.3. Social Impact

The last and least considered impact is the Social one, included in only around the 40% of the papers studied.



Graph 14 Social vs Research Method

The main reason of this is that while for Economical/Operational and Environmental impacts is quite easy to define some algorithms to compute them, it is not the same for social impact, which is quite difficult to estimate quantitively. Consequently, as displayed in Graph 14, analytical methods and case studies or simulation, that are remarkably quantitative, struggle when trying to assess the impact on social sustainability that innovations and solution in urban logistics can have.

The main aspects considered in understanding the impact that city logistics has into the quality of people's life are congestion, road safety and noise. K. Pietrzak et al. (2021) with interviews to experts assesses expected benefits that a railway-based solution may have for society such as reduction of traffic, improvement of road safety, level of service and quality of life. Almost the same attributes are considered by G. Sanz et al. (2018), in which a multi-attribute decision making process based on surveys and interviews with experts in urban freight transport noise is developed to understand the impact of the innovative solution on traffic and road safety. Instead, K. Mommens et al. (2021) considers not only the qualitative impact of using and collection-points instead of home delivery on congestion, accidents, air pollution, climate change emissions, infrastructural damages, and noise, but also the paper convert them into external costs to evaluate the possible monetary savings. Also, the solution acceptance from the society and employee's satisfaction are considered in some papers like C. Navarro et al. (2016), in which the proposed solution is assessed looking at social impact as the society and employee satisfaction, public welfare, space occupancy, business attractive and visual nuisance. As shown in the graph above, when it comes to the methods mostly used, the main are interviews and survey, presented to field experts, or to relevant stakeholders.

2.4. Conclusion and future research

In the Sections 3.1 and 3.2 it was presented analysis of the papers composing the literature review performed. At first the main characteristics were highlighted and then the two classification dimensions introduced, grouping papers according to the classes and presenting the main topics analyzed for each. In this Sections we will present a summary of the research main findings, to finally identify research gaps in the literature studied, that this thesis work partially aims to cover.

2.4.1. Summary of main findings

The research corpus selected and analyzed is composed of a total of 64 papers about solutions and innovations to decrease impact of urban logistics towards a more sustainable view of city freight transportation.

Most of the papers selected are scientific journal articles published in a total of 37 different journals, divided in 5 different field of research, among the which more than 50% is related to "Logistics & Supply Chain", while around the 20% each is related to "Sustainability" and to "Business Management & Social Science". This highlights how, even if Engineering and Operations journals have a dominant role, also less analytical journals present relevant analysis in the field of urban logistics sustainability.

While from the research field point of view we can see a relevant heterogeneity, we can't say the same about the countries that the most study these topics. Indeed, less than 10% of the selected papers have been published in developing countries, from where moreover no publications have been selected before 2017. It is clear from this discrepancy that interest and projects about green options, sustainability of logistics and effects on quality of life into urban areas are still perceived as a luxury that only developed countries can enjoy, while it is something that influences all communities.

Looking at the structure and research methods of the studies analyzed, most of the publications are analytical methods, case studies or simulations in which different technologies, vehicles, policies, or infrastructures are evaluated or tested, presenting therefore many interesting cases all around the globe. A less relevant role is played by qualitative analysis and frameworks, surveys or literature reviews that may present different solutions and cases but if not assessing the performances properly may lose relevance for our goal.

However, not all the sustainability impacts can be equally evaluated with the same research and resolution methods. Indeed, while analytical methods and simulations are almost in all cases considering Economical/Operational and Environmental impact of urban logistics, not the same can be said about the Social impact. In this case, given its subjective and uncountable nature it is much easier to be assessed in qualitative analysis like conceptual frameworks and surveys than in very quantitative ones.

With the performed analysis what we wanted to assess and outline were mainly could have been divided in two main classification axes: the type of solutions or innovations proposed by the different papers and the type of impact considered on sustainability. As regards the first one it was interesting to have a complete overview of the different proposals, how much each was studied and what are application cases that were developed in real world and how they performed. As regards the impact we wanted to understand what aspects were mostly evaluated, given the vastity of the topic of urban logistics sustainability, and how these were treated, with what methods and taking into consideration what variables.

Talking about the solutions identified, there are many ways to deal with urban logistics impact and sustainability, which can be related to usage of different vehicles than traditional ones, collaboration with other actors of the industry or with customers. The dominant role as strategy for improving city logistics is played by "Stakeholders' Collaboration", because thanks to coordination and collaboration between actors of the same environment it is possible to deal with the biggest issues identified for urban logistics efficiency, which are the low saturation of vehicles and the low drop size per stop.

Thanks to collaboration between companies more couriers can share infrastructures and/or vehicles, integrating their flows and exploiting the efficiency benefits coming from the bigger scale of the resulting network (e.g., J. Leonardi et al., 2012; Nocera et Cavallaro, 2012; Y. Li et al, 2019; A. Bucchiarone et al, 2021; L. N. Rosemberg et al, 2021). The power of this kind of coordination is independent from the type of vehicles used and it is presented in many different cases such as ICEVs, EVs, Cargo-

Bikes and Autonomous-Shuttle, in which Urban Consolidation Centers (UCC) and shared depots or vehicles can play a significant role in cost, emissions or social impact reduction. The main barrier for implementation is in this case the integration that would be needed at both operational and IT level between the systems of the different couriers.

Huge role can be played not only by delivery companies but also by customers and citizens, who moved by the understanding the impact the service produces or by benefits they can get in exchange, may participate in two main different ways. The first one is the usage of parcel lockers or collection points instead of home deliveries, solving the drop size and number of stops problems of last-mile deliveries but also the issue of failed deliveries that creates huge wastes of time and emissions. Sometimes this can be a standalone solution (e.g., Cardenas I. D. et al., 2017; J. R. Brown and A. L. Giuffrida, 2014; C. Altunas et al, 2021) or in combination with other vehicles like in D. L. J. U. Enthoven et al., 2020, in which a collection-delivery points are used in combination with cargo-bicycles. The main limitations in analyzing the effect of parcel lockers introduction is the understanding of customers' behavior in choosing both the decoupled deliveries as delivery-method instead of home delivery and also how reach the collection point and therefore the emission generated for which usually assumptions are made by the authors or in few cases interviews are performed.

Another interesting solution is Crowdsourcing: a system in which citizens deliver packages to other people while moving around the urban area for their own reasons through their route (A. Giret et al., 2018; A. Seghezzi and R. Mangiaracina, 2021; Simoni et al., 2019). Studies in this field are mainly focused on understanding the assignment of riders to parcels and customers, evaluating effect of different transportation means used by riders and of possibilities of bundling deliveries to decrease the number of riders needed.

Without leaving the field of organizational solutions, another instrument for managing urban logistics impact is the imposition of regulations and/or handing out of benefits from public institutions with the aim of incentivizing the adoption of greener vehicles or behaviors. Apart from the European guidelines (SUTP, SUMP and SULM), different papers present real cases of regulations implementation (M. Koning et al., 2016; H. Quak et R. B. M. De Koster, 2008; K. Fossheim et J. Andersen, 2017; Menga et al., 2013) or else present different possible regulations and their potential effects (G. Sanz et al., 2018; M. Morfulaki et al., 2016). The main policies identified are related to Limited Traffic Zones, limitations in how many vans can enter the city or else in the hours in which they can, tolls for entering the city, benefits for electric vehicles purchase and/or usage, carbon taxes and others. Even if useful and necessary to push companies and citizens towards a greener behavior, usually public regulations are not enough for achieving urban logistics sustainability, which instead needs a decisive commitment from the operators' side.

Before talking about the exploitation of different vehicles with respect to traditional delivery vans, a last organizational solution, is based on the idea that it is possible to exploit the unsaturated space capacity inside many public transportations means to move freight through the city without performing any additional transportation and gaining therefore huge benefits in terms of sustainability. Different solutions are studied in this sense, with buses (R. Masson et al., 2015), waterbuses (F. Bruzzone et al., 2021), tramways (O. Pietrzak et al., 2021) or railways (D. Guo et al., 2021). Moreover, not only it is possible to use unsaturated capacity of already used vehicles but also there could be different wagons and/or vehicles for freight and passenger transportation sharing anyway the same infrastructure. The integration with passenger services so that freight doesn't interfere with it is the most reported issue public-transportation based solutions.

The remaining solutions presented are all related to the usage of alternative vehicles with respect to ICEVs and, in a descending order of number of papers that present the specific solution, specifically are Cargo-Bicycles, Alternative-Fueled Vehicles, Non-Road Transportation and Autonomous Vehicles.

The most studied solution based on different vehicles than traditional ones is based on the usage of Cargo-bicycles, in which not only 2-wheeled bicycles are considered but also tricycles and sometimes quadricycles, in almost all cases with electrically assisted pedaling.

Given the nature and the reduced capacity of a cargo-bike with respect to a van, these vehicles always need urban depots in which the parcels are loaded on the trailer of the cargo-bike and the tour starts. The way in which these hubs are supplied is usually with vans, which can be traditional (D. L. J. U. Enthoven et al., 2020; Rosenberg, L.N. et al., 2021) or else electric/hybrid (J. Leonardi et al., 2021). However, in most cases the analysis performed starts from the urban depot and concern only the cargo-bikes tours compared to what would have been the economical/environmental/social impact of the same services with ICEVs or EVs (J. Freselle et al., 2021; C. Navarro et al., 2016; K. Lee et al., 2019). In other cases, instead, cargo-bikes activities follow a non-road transportation, like railways or waterways (Divieso E. et al., 2021).

There are papers that present cargo-bicycles only last-mile delivery (A. Conwey et al., 2017; S. Melo et al., 2017) and others that instead consider that vans can perform part of them, usually the larger parcels and/or the furthest ones from the urban depots (J. Leonardi et al., 2012; Carlos Llorca et al., 2021; J. Freselle et al., 2021).

Some last cases, instead, give an additional role to the vans, that is being mobile-depots for the cargo-bikes (S. Verlinde et al., 2014; A. Anderluh et al., 2017).

The benefits identified of cargo-bike usage are plenty and the most relevant can be identified in significant reductions of environmental impact, operational costs, urban space occupied for logistics-reasons, traffic, noise pollution, time wasted for parking.

On the other side, at least remaining on the portion of the delivery flow lower than a certain weight threshold, there are no aspects of cargo-bicycles that are presented as barriers to implementation, apart from the organizational and operational changes needed. Indeed, cargo-bicycles are lower-performing than traditional vans in two points: maximum speed and maximum capacity. Both points, when dealing with last-mile deliveries into urban areas are lose relevance because of traffic that doesn't allow to reach high speeds and because delivery tours are always saturated in time dedicated to the deliveries and not saturating the vans capacity, which therefore is not all needed for delivery tours.

The second most studied vehicle-based solution is to still use traditional vehicles but alternatively fueled. These are mainly electric and hybrid vehicles that in the last years are becoming always more operationally and economically attractive than how they used to be in the past.

Indeed, the usage of vans gives the huge flexibility and capillarity that road infrastructures give, while at the same time being able to maintain high speeds when not in traffic and high cargo capacity. If it is possible to be, as it is the case of alternative-fueled vehicles, also sustainable, it can be a very interesting solution for having greener urban logistics without loss of the benefits from usage of vans.

In the literature, considering this topic, the focus is mainly on fully electric vehicles, but also hybrid vehicles are considered in some cases. Moreover, there are also cases in which a mixed fleet with different shares of vehicles per power-source are studied.

These vehicles, as the traditional vans, can be used as only-vehicle of the network (R. Mangiaracina et al., 2020; Y. Li et al., 2019; S. Nocera et F. Cavallaro, 2017) or else in a mixed-vehicles network in which EVs play only a part of the delivery. In this last case vans can be used for two different reasons:

- Supply activity for urban hubs from where other vehicles perform the deliveries to customers (J. Leonardi, 2012; J. Fraselle et al., 2021).
- Last-mile delivery after other vehicles supply an urban/semi-urban hub (N. Arvidsson et M. Browne, 2013; J. Gonzalez-Feliu, 2014; A. M. Moore, 2019).

The main concerns identified when companies and researchers are analyzing the possibility to electrify a fleet are two and from two different points of view:

- Financial – Purchasing prices of electric or hybrid vehicles are in general quite higher than traditional vehicles, making the difference in initial investment and amortization relevant.
- Operational – Fully electric vehicles have a limited range and need to be charged when they run out of battery. The same regards hybrid vehicles, not to be operative but to be greener than electric ones.

As regards the financial concern, the higher purchasing prices are usually offset by a lower maintenance and feeding cost that makes operative costs lower. Moreover, the more kilometers are travelled, the higher will be the savings. In last-mile delivery operations the number of kms travelled is usually much lower than middle- or long-mile logistics, therefore attention to cost is also higher in this case, because the benefits will be lower. On the operational side, for the same reasoning about the kilometers travelled in last-mile delivery networks, in the cases we studied and analyzed the battery recharge issue is not present, because the range achievable without charging is already enough and vans can therefore charge overnight.

In third place considering vehicle-based solution, we find Non-Road Transportation. These are usually used combined with road-transportation so to exploit strengths of both: high capillarity of road network that allows to reach every destination point and high efficiency and reduced costs and emissions of non-road transportation for longer paths without stops. The main vehicles and infrastructures used in this sense are related to railways, with trains (R. Villa et al., 2021; D. Guo et al., 2021) and trams (O. Pietrzak, 2021, M. Browne, 2013) and waterways (F. Bruzzoni, 2021; E. Divieso et al., 2021; D. Diziain et al., 2014). What is common in these solutions, apart from the inter-modal nature of the resulting network is the requirement of infrastructures that are less accessible than road, e.g., rivers, tram rails and train railways, are, in some cases, also more expensive and not easily extendable, requiring consequently huge coordination with regulators and public/semi-public infrastructures companies like railway operators.

Autonomous Vehicles are the least represented alternative vehicle typology in this literature research and that is not unmotivated. They are usually small electric vehicles like robots or drones capable of autonomously deliver parcels to customers and continuously be supplied by vans that can work as mobile depots or in stationary ones. Different solutions are studied and analyzed, mostly in terms of decrease in costs or increase in service time (Simoni et al., 2020; Boyesen et al., 2018; Ostermeier et al., 2021; C. Chase et al., 2020; D. Swanson et al., 2019; Bucchiarone et al., 2021). However, all these papers are about models developed for the evaluation and never assessment of real cases. The reason is that regulations of autonomous vehicles is still not very much developed and many barriers to implementation are present, therefore even if studied it is hard to find an implementation of autonomous robots for last-mile delivery.

The second classification axes used in this literature review is considering instead what kind of impacts of urban logistics are studied with the aim of reducing them with one or more network changes. The main impacts are three, specifically Economical/Operational, Environmental and Social, and are very different each other in the way in which these are analyzed in terms of methods and variables used.

The first and most common impact, considered in almost every paper, is the Economical/Operational one: no matter the solution implemented, costs and/or operational efficiency are always taken into consideration when evaluating an alternative network to the traditional one. Considering monetary costs, the main variables studied are:

- Maintenance
- Amortization
- Feeding (Fuel/Electricity)
- Drivers' wage
- Carbon tax
- Incentives
- Road tolls
- Registration fees

Moreover, sometimes also non-monetary costs are considered (J. Gonzalez-Feliu, 2014). Emissions generate costs on businesses, families, governments and taxpayers through rising health care costs, destruction of property, increased food prices, and more. To express the economic harm coming from those impacts, a value of €/tonCO2 is considered to translate CO2 emission into costs.

As regards the method, there is also some heterogeneity. The main methods are summarized in following Table 2.

Method	Papers
Life-Cycle Assessment	J. Fraselle et al., 2021; R. Mangiaracina et al., 2020; S. Nocera et F. Cavallaro, 2017
Social Cost-Benefit Analysis	J. Gonzalez Feliu, 2014
Multi-Actor/Multi-Criteria Analysis	S. Verlinde et al., 2014
VRP Problem solution	Y. Li et al., 2019; K. Lee et al., 2019; D. L. J. U. Enthoven et al., 2020
Real-case data collection	A. Conwey et al., 2017; A. M. Moore, 2019
TSP Problem solution	V. Naumov et al., 2021
Survey	C. Altuntas et al., 2021
Activity-Based model	M. Giuffrida et al., 2016

Table 2 Type of method used

The other side of the Economical/Operational impact is operational efficiency, sometimes considered together with the cost evaluation, sometimes as only objective of the analysis.

The most considered variables or performances are:

- Total distance travelled.
- Total time spent.

- Late deliveries.
- Effect on traffic.
- Rate of failed deliveries.
- Implementation difficulties (IT support, infrastructures need etc.).

The impact that is second as number of papers that consider it, is the environmental one related to pollution coming from urban logistics activities and the possibilities to reduce it with innovations or different solutions. Also in this case, what is worth to take as main outcomes from the literature review are the ways in which environmental impact is computed, analyzing both methods and variables considered. Generally, as the economical/operational one, also environmental impact is assessed analytically, and the main perspectives covered are two:

- Well-To-Wheel (S. Nocera et F. Cavallaro, 2017; A. Alessandrini et al., 2012, M. Singh et al., 2020) – Evaluating not only the emissions produced during the usage of the vehicle but also the ones needed to produce the source of energy. This approach can be divided in two steps: Well-To-Tank, related to all activities to have the used fuel suitable for transport powertrains and Tank-To-Wheel, in which the emissions generated by the vehicle during the driving cycle are computed.
- Life-Cycle Assessment (R. Mangiaracina et al., 2020, S. Melo, 2017; J. Freselle et al., 2021) – Considering the emissions related to the entire lifecycle of the product, process, or activity, that means a Well-to-Wheel analysis adding also the vehicle production, maintenance and disposal.

The main ways to compute the emissions considered in the Tank-To-Wheel phase uses real-life experiments, national or international annual statistics like INSPRA or DEFRA, direct measurements, or computer program like Handbook Emission Factors for Road Transport. Regarding the Well-To-Tank analysis, the authors start from the energy consumption related to extraction, refinement, transportation, and distribution if they refer to fuel, instead they look at the generation, considering the country-based electricity mix, transmission and distribution for electricity production. The value obtained is transformed into emissions using appropriate transformation coefficients, obtaining measures like gCO2/kWh or gCO2/MJ. Then according to the efficiency of the vehicle, expressed in term of kWh/Km or l/km, the value can be transformed in gCO2/km. Specifically, the pollutants considered focus on Greenhouse Gas Emissions and micro-pollutants such as CO2, CH4, NO2, NOx and PM10. To aggregate the impact of all the GHG pollutants, the CO2e is usually used, which consist in the weighted average of the Global Warming Potential of CO2, CH4 and NO2.

Lastly, there is the social impact: the effect that having urban logistics activities inside a city has on people, reducing the quality of their life. It is the most subjective one since it is not easy to identify objective measures capable of identifying this impact and the mitigation that may be achieved. Therefore, it is much more common to find qualitative analysis than quantitative ones, differently than Economical/Operational and Environmental that, instead, are possible to be computed based on figures like time, distance, type and number of vehicles and correlated ones. The most studied effects on society are related to:

- Congestion
- Road safety
- Space occupancy
- Visual nuisance
- Noise pollution
- Accidents

Also, some papers consider a different kind of social sustainability, with focus on the employees and not on citizens, assessing employee satisfaction or in a case some health parameters.

As regards the methods employed to study the social impact, as already said these are almost all qualitative and specifically, we can find:

- Interviews to experts (K. Pietrzak et al.; 2021, G. Sanz et al., 2018).
- Survey to citizens (C. Navarro et al., 2016).
- Survey to experts (G. Sanz et al., 2018).
- Traffic analysis (K. Mommens et al., 2021; Rafael Villa et al., 2021).
- Employees' health monitoring (R. A. de Mello Bandeira et al., 2019).

2.4.2. Research gaps identification

In the performed literature review 64 different papers have been examined, with different scope, aim, point of view, solution implemented, impacts analyzed and methods.

A first differentiating characteristics among the papers is if and which way the studies are related to real context. Some papers are presenting real solutions implementation, their sustainability, effects, success or failure (J. Leonardi et al., 2012; C. Altuntas et al., 2021; S. Verlinde et al., 2014; C. Llorca et al., 2021), others are evaluating the potentiality of some solution applying models to real context (A. Alessandrini et al., 2012; M. Singh et al., 2020; C. Navarro et al., 2016; S. Melo et al., 2017; Simoni et al., 2019) and lastly there are sum that just evaluate a network without being based on the reality (A. Giret et al., 2018; R. Gervaers et al., 2014; D. Swanson, 2019).

Another factor according to which papers can be divided in two classes is if the studied solutions consider one vehicle type only or else more than to exploit different characteristics of different vehicle types. When having only one vehicle type, the network analyzed is limited to the tours starting from the last hub and delivering door-to-door (A. Conway et al., 2017; J. H. R. Van Duin, 2019; R. Gervaers et al., 2014; L. N. Rosenberg et al., 2021). In case of multiple vehicles, a first solution is to use both for deliveries, differentiating customers to serve according to the position or the size of the delivery, which is mainly studied with Vans and Cargo-Bicycles (C. LLorca et al., 2021; S. Melo et al., 2017; J. Leonardi et al., 2021) but also with Vans and Autonomous vehicles (M. Ostermeier et al., 2021; M. D. Simoni et al., 2020; N. Boysen et al., 2018). The last alternative is that have vehicle type(s) that perform deliveries and type(s) that are used for feeding. The most relevant solution in this perspective is the usage of Railway for feeding and Van (ICEVs or EVs) for delivering to customers (N. Arvidsson et M. Browne, 2013; J. Gonzalez-Feliu, 2014; S. Beherends, 2012) but also some solutions are present with waterway integration with cargo-bicycles (Divieso E. et al., 2021) or EVs (D. Diziain et al., 2014).

The identified gap in the literature analyzed is that there are no solutions considering the possibility of using more than two vehicle types assigning to each a piece of the supply chain: the part in which it can be the best performing in terms of cost, environmental impact or effects on quality of life inside the city. If we analyze the type of vehicles considered in the review, these can be grouped in 3 classes:

- Heavy non-road vehicles (Railways and Waterways): higher capacity than road-vehicles and lower costs and emissions for equal distance covered and weight moved, but much lower accessibility and flexibility as well. Particularly suited for moving high volumes for long distances without stops.

- Medium-dimension Road vehicles (Electric and Hybrid Vans): huge accessibility and flexibility given by road capillarity, lower capacity than non-road vehicles, and usually higher costs and emissions per distance covered and weight moved as well. It is the mid-way suitable for many different cases of volumes and distances, but top performances are obtained with medium distances with not too many stops and when the capacity can be exploited.
- Small dimension Road vehicles (Cargo-Bicycles, Autonomous Robots, Drones): same accessibility and flexibility of Vans with lower costs and almost null emissions per distance covered and weight moved, but at the same time much lower capacity. Particularly suited for moving low volumes for not too long distances and with many stops.

The solutions studied never consider one vehicle of each class, so to exploit its own characteristics, but two at the most, even if, apart from the organizational complexity that must be faced, there are no specific reason to limit the vehicles differentiation in the same network.

2.4.3. Limitations of the review

The performed literature review has been carried out with systematic research following the stages defined in Srivastava (2007), whose first step in which the whole review lays its foundation is the selection of the papers. Even if the first selection through keywords was as objective as possible, in the next steps our subjective beliefs in what was relevant had a role and may have influenced the results. The main limitation identified in this literature is that there may be some solutions or combinations of them that did not come out in this review or else ways of considering the different impacts of urban logistics that reason differently from the methods we identified. An indication of this bias in choosing the papers is displayed in the geographical distribution of the countries in which the paper analyzed were written. Indeed, 11 out of 64 studied papers were published in Italy, with 4 of gap over Belgium and USA in second place, and it is reasonable to think that the share of contribution of papers published in Italy should be lower, given the dimension and the research extension of other countries. However, the corpus is still very heterogeneous, with papers published in 20 different countries located in Europe, Asia, North America, and South America. Consequently, the possible bias had during the paper selection towards papers written in the same country is not considered to be influencing and misleading.

3 Research Goal and Methodology

The aim of this chapter is to present the objectives, methodology, and context of the research performed in this thesis work. Indeed, in Section 3.1 the research gap identified in the literature review is re-presented and the research goal defined on the base of it; in Section 3.2 instead, the methodology used to reach the goal.

3.1. Research Goal

The literature review performed and described in the previous chapter pointed out the topic of interest, solutions, analysis scope and methods used in the main field of "Decreasing the impact of urban logistics".

We highlighted the presence of many different solutions, mainly based on different vehicles with respect to traditional ones, in order to chase a new conception and definition of city logistics capable of being less expensive, greener, and/or sustainable for citizens' quality of life. The main outcome of the review is that there is a huge possibility of improvement based on many different implementations that are available each one that could help in facing an issue typical of last-mile deliveries or in mitigating an effect typical of traditional vehicles. Some papers in the literature consider combining more solutions in the same network acting on different parts of the delivery network.

The three sections of the network with related best practices are listed above:

- Aggregated flow of goods towards the city – Use of alternative lower impact vehicles, typically railways, capable of moving high volumes of goods all together, with low impact for parcel.

- Flow inside the city – Use of lower impact vehicles, typically EVs but also tramways, to move the goods inside the city, trying to aggregate flows as much as possible to increase vehicles saturation.
- Door-to-door deliveries – Use lower impact vehicles, typically electric. Moreover, given the much lower number of customers that can be served in a tour with respect to the number of parcels that can fit in a van, small vehicles like bicycles or autonomous vehicles can be exploited, decreasing impact without loss in efficiency and effectiveness.

In the studied papers, however, no one consider adapting and improving something in all these three sections, but two at most, for example with trains moving goods into the city or next to it and EVs performing the remaining part not taking care of the unsaturation or else with EVs moving goods into some urban hubs and cargo-bicycles starting delivery tours from there.

What our thesis work aims to answer is if it is possible to set up a delivery network that consider green solutions from outside the cities to customers' homes in city centers and what would be the impact of it with respect to traditional deliveries. Given the analytical nature of the model we are planning to design, only Economical/Operational and Environmental impacts will be analyzed, leaving aside the social one.

Therefore, we can formulate the following research questions:

RQ1: Is it possible to design an integrated network of different green vehicles from out-of-cities to customers' homes?

RQ2: What is the Economic and Environmental savings that can be achieved in this way with respect to traditional networks?

The methodology employed to answer to these research questions are in detail described in the next Section.

3.2. Methodology

To answer our research questions a Simulation model has been developed from the point of view of an express courier that exploits the benefits of using railways, EVs, and Cargo-Bicycles in a new and green integrated network simulated in the city of Milan. Four different city characteristics influenced the choice Milan as set of the network:

- One of the biggest delivery volumes at city level in Italy.
- One of the most polluted cities in Italy.
- Location of our university.
- Carrying forward in the last years a significant process of increasing urban sustainability.

Like many papers in literature, we focused our case study on e-commerce deliveries, because of the huge and increasing relevance that this phenomenon has in urban logistics not only in terms of rapid growth of this market but also the relevance in terms of costs and environmental impact of the last-mile delivery compared with the entire logistic process. The other reason to consider e-commerce market is that most of the delivered parcels are limited in dimensions and therefore best suited for Cargo-Bicycles. The whole eCommerce over a certain area of the city of Milan has been considered, without any restrictions to a specific sector or industry like some studies do. Data were obtained through the Osservatorio eCommerce B2c (Politecnico di Milano) or websites of statistical analysis.

The performances of the designed network are then compared with the as-is situation in the measures of operational costs and emissions produced in a base case and in some different scenarios to perform sensitivity analysis on the effects of varying some of the inputs.

3.2.1. Modelling tool

The development and implementation of the model has been performed on ArcGIS, a geographical information system (GIS) that allows to perform geostatistical simulations. This choice allows us to have different benefits given by the nature of simulation models:

- Assess different scenarios given by inputs variability.
- Place customers into the real city map.
- Exploit the usage of population density data to distribute customers into the different areas.
- Consider real distances between stops.
- Include traffic data for time computations.

Given the inputs to the model, this will simulate the designed network and provide a solution in which all customers inserted as inputs are served optimizing the number of vehicles and total distances/time covered. The output considered will be for each type of vehicles the work performed in terms of total distance and time, and then through costs or emissions per unit of time or distance, total costs and emissions produced in a day of operations are computed. Then, the same is done for the traditional network considering only ICEVs and the economic and environmental performances of the two networks are compared.

3.2.2. Development phases

In this Section it is briefly presented the process that led towards the definition and design of the simulation model which constitute the core of the thesis work. Apart from being introduced here, the different steps will be exhaustively deepened and detailed in the next chapter.

Three main steps can be outlined in the model development process:

1. Definition of the network structure.
2. Identification of each activity needed during the whole process.
3. Development of the simulation model into ArcGIS.

First, we defined the structure of the network we wanted to analyze for the thesis work. This was done jointly with one of the most important players of the Italian delivery market that could share its knowledge and best practices to understand how the delivery network is structured in the as-is situation and to define a realist greener network that used innovative ways of delivering goods. It was decided to include into the scope of the model everything that happened from the moment in which the goods from the suburb are sent towards the city centers to the moment in which courier's vehicles are back at their initial location.

The first step of the identified network consists in moving goods from a hub outside the city to the nearest train station. Then, from there a freight train moves the low-weight goods from the outside of the city towards the city centers, where some EVs will collect them and move them to urban hubs from where Cargo-Bicycles will perform their delivery tour. The rest of the goods with higher weight will be directly delivered with other EVs as performed in many papers analyzed in our literature review. Lastly, to bring failed deliveries and reverse-flow parcels back to the initial hub, another EV at the end of the working day collects these parcels from the urban hubs where the bicycles operators leave them at the end of their tours.

Then, in the second phase we detailed all the activities that every operator and vehicles should perform into the network, dividing all activities in smaller groups that are iteratively repeated so to better schematize the process and define roles and responsibilities. Any group of activities was considered detailed once location and operators involved were defined for all activities. In this phase different resources were useful, first and foremost the outcomes of the meeting with the courier involved, but also some explorative or descriptive studies about network design, like Planning of Cargo-Bike Hubs (2019) from Otto-von-Guericke-Universität Magdeburg.

Lastly, it was the moment of developing the model capable of solving the delivery problem we wanted to analyze and give us the desired outputs. This was designed according to some assumptions regarding the choice of the vehicles, the role of different stakeholders in the network, some operational parameters, costs, and emissions considered. Some of these assumptions come from a summary of the literature or other contributions analyzed, others are instead based on the context of the model application. In this last case, when available data related to Italian context were considered, while if not first European data were searched or, as last resort, the most similar context possible.

As already said, the environment in which the model was developed is called ArcGis, a geoprocessing simulation tool used to solve routing problems given a group of customers as input and setting different vehicles and hubs to be used for the different movements. Specifically, in our case, we had to solve many VRP problems, one per each tour performed, considering:

- Micro-hub supply performed by EVs.
- Deliveries performed by EVs.
- Deliveries performed by Cargo-Bicycles.
- Return of reverse flow parcels performed by EVs.

To these 4 pieces of the flow, we also must add the first two, which are not serving customers but fixed points and therefore do no need a VRP problem, but only computation of distances travelled, and time needed based on positions and speed of the vehicles:

- Movement of goods from courier hub to train station performed by the truck.
- Movement of goods from peripheral train station to city center one, performed by train.

3.2.3. Model Application

The other macro-phase of the thesis work is the model application, consisting in everything that comes after the model definition, in which there is the formulation and analysis of all the results obtained. Details on the process and the results are presented in the next chapters.

Three main steps can be outlined:

1. Evaluation of different setting parameters.
2. Base case simulation and analysis.
3. Sensitivity analysis on input values.

Even if the model out of the Development phase was defined, there were still some parameters on which we were doubtful about the choice to take and wanted to understand if different choices would bring to significantly different values or else it was a not relevant decision. To get these answers we have run different times the model differentiating those characteristics and evaluating afterwards the gap that each choice, if significant, may have. After this first step, the final model used for the solution evaluation has been entirely set out and the real analysis was ready to be performed.

In the second step, therefore, we solved the base case considered and compared it to the as-is situation, i.e., the traditional way of delivering parcels to customers with ICEVs starting from the same hub from which the innovative green network starts. The differences were highlighted in both costs for the courier to perform the service and emissions generated during and for the service. Details about the costs and emissions considered are presented in the next Section.

Lastly, having the results for the base case, we decided to assess how varying some of the input to the model, the solution and its comparison with the traditional network would change. Therefore, more scenarios were defined and simulated, considering differences for example in delivery volume, starting point of the goods and share of adoption of cargo-bicycles. Also, an additional feature considered is the possibility of adding parcel lockers in the micro-hub locations, assigning a percentage of parcels to this kind of service instead of home-delivery, to consider the impact that this could have.

3.2.4. Performance assessment

The model is focused on the logistic activities related to courier delivery process and more precisely the last-mile delivery of eCommerce parcels. We also considered the handling activities related to the drivers of Cargo-Bikes, Vans and Truck to build a realistic simulation model with reality-consistent output considering time and distances covered from the moment in which the parcels are ready to leave the Courier Hub until the process is complete. The activities considered for the assessment are:

- Loading/unloading of parcels in the different infrastructures.
- Transportation of goods performed by vehicles.
- Delivery activity, considering parking and parcel delivery.

All the other precedent logistic activities like the sorting of the parcels and the preparation of the different delivery unit for each tour are not considered since they are not differential in the two different networks. Moreover, considering the economic and environmental impact generated by the network, the contribution that these costs and emissions linked to goods preparation activities may have compared to the ones considering are negligible.

To evaluate the economic impact of the innovative solution and compare it with the traditional network, we followed the approach coming from one of the papers analyzed into the literature review, specifically R. Mangiaracina et al. (2019), in which last-mile deliveries costs are computed. Looking at the paper, the main components of last-mile delivery cost are:

- Transportation mean cost, that depends on the distance travelled by each one and their cost per kilometer, which includes variable costs like feeding costs and allocation of fixed costs like maintenance and insurance.
- Driver cost, that is composed by the driver hourly fee and time needed by drivers to perform the delivery activities.

Starting from this cost structure, we also considered a renting cost of the vehicles used, computing an hourly renting cost distributing the yearly one over the working days and hours worked per day. The reason was to consider also the impact that vehicles prices have in comparing the two solutions, being the cost of electric vehicles quite higher than comparable diesel ones. Regarding the cost linked with the usage of the vehicles, it is only the feeding cost given that in our case the maintenance is already included in the renting cost. Feeding cost is computed considering the different mean of transports, each one with their own data on fuel or electricity consumption, and the distances travelled that come as output of the simulation model. Lastly, the drivers' costs derived from the time spent to on this network are calculated through the simulation model, just considering an hourly cost. In addition, for diesel vehicles driving inside Milan we considered a daily toll to be paid to enter the City Center.

The investment cost related to Micro-Hubs is not considered in this thesis work because, as usually happens in this innovative systems implementation, we assume that they are faced by the city municipality and not by the Courier, being this kind of project usually partially publicly financed.

The economic impact of the train, instead, is evaluated as a fare proposed by the railway operator to transport and handle the parcels from the station outside Milan until the one inside the city. Indeed, our point of view is the one of the courier, while both the train transportation of goods, the loading/unloading of the train and the store in the stations, are owned by the cargo train operator.

Regarding the environmental impact, different pollutants can be considered. One of the most used measures is the Greenhouse gas Emissions (GHG), that according to Kyoto Protocol includes different greenhouse gases like:

- Carbon dioxide (CO2), produced during energy production by fossil fuel, manufacturing, and transportation. It is the main component of GHG representing the 76% of the total greenhouse gas emissions (Intergovernmental Panel on Climate Change, 2014).
- Methane (CH4), produced by agricultural activities, waste management, energy use, and biomass burning.
- Nitrous oxide (NO2), also produced by agricultural activities and fossil fuel combustion.
- Hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulfur hexafluoride (SF6), produced by industrial processes, refrigeration, and the use of a variety of consumer products.

As a summary figure, Carbon dioxide equivalent (CO2e) is usually adopted, in which all the emissions coming from the different gases are expressed in reference to CO2 emissions. This is possible using the Global Warming Potential (GWP), that is the relative potency, molecule for molecule, of greenhouse gases, taking account of how long it remains active in the atmosphere. In our study, we used the CO2e to express the environmental impact of the solution given the importance of the measure and availability of conversion factors.

To evaluate the emissions generated from the logistics activities the two most used perspectives are:

- Life-Cycle Assessment (LCA), that analyses the comprehensive environmental impact of the product coming from the whole life cycle of the vehicle. It includes all the emissions linked to the extraction or generation and distribution of the primary source, fuel or electricity; and the ones related to the energy consumption during the usage of vehicle. In addition, as the name of the assessment suggests, it also considers the vehicle cycle, that means all the emissions coming from the procurement of raw materials, the production of the vehicle, its maintenance and its disposal or reuse/recycling.
- Well-To-Wheel analysis (WTW), in which emissions are computed considering the fuel production and the vehicle use. It is divided in two different steps that consider the two sources of environmental impact: Well-To-Tank and Tank-To-Wheel. The first phase takes into consideration the emissions required to produce and transport the energy to the distribution point, the other one evaluates the impact of vehicle during its driving cycle.

The approach used in our study was the Well-to-Wheel assessment, given that the LCA require too specific data on the product and consequently it gives a precise and really case specific result, that is not the aim of our thesis. Indeed, we prefer to study a more generic process producing an average estimation of the environmental impact.

The conversion factors coming from the WTW are then used in combination with vehicle data like fuel or electricity consumption and travel data expressed in kilometers driven by the different vehicles that comes from the simulation model or estimated in case of the rail transportation mode.

Also, when computing emissions generated into the infrastructures, both Courier Hub, Micro-Hubs and Stations are not taken into account being their impact negligible when compared to the emissions generated by the vehicles. While the Courier Hub and the Train Stations, the biggest facilities, would be active no matter the performing of the innovative network. The Micro-Hubs, instead, are supposed to be non-refrigerated Sea Containers and consequently they require very few electricity to work and produce almost no emissions.

4 Model Development

In this Chapter, the whole model definition and design are presented, starting from the traditional and to-be networks definition, and arriving at the model structure, data, and algorithm. In Section 4.1 the two processes are presented each with its own characteristics and activities detailed. Then, in Section 4.2, the simulation model developed for assessing the performances of both networks is deepened, specifying the algorithms and data utilized.

4.1. Definition of the process

With the aim of designing an innovative greener delivery network, the main knowledge base and brainstorming ideas come from a meeting had at the beginning of this thesis work development with an Italian courier with significant importance in the market. During the meeting, the experts first shared how their delivery network into the city of Milan works and then we jointly defined how a to-be network with usage of train, EVs, and Cargo-Bicycles could be practically implemented. During the whole work development, we analysed the problem from the point of view of the courier, evaluating the differences in environmental impact and operational cost can be achieved with the innovative network.

Once the bases of the delivery processes were defined, before developing the simulation model, it was useful to detail the different activities that need to be carried out so to have a guideline for the model design. This has been done grouping the different activities according to the stage of the process and defining for each the sub-activities in which it can be split if any, the activity type, the responsible of the activity and the operator that performs it.

For both the processes, traditional and greener, the focus is the last-mile activities starting from a courier hub, where all the e-commerce parcels that need to be delivered in Milan the next day are consolidated and sorted based on the delivery area.

4.1.1. Traditional process

The traditional network is defined as the network that in the as-is situation is used by a generic courier that delivers inside the city of Milan. The vehicles used, as are the ones usually used for deliveries, are assumed to be ICEVs (Internal Combustion Engines Vehicles) fuelled with diesel. Each van is fulfilled in a courier hub, performs its delivery tour and at the end of the day goes back to the hub to return the failed deliveries that need to be included in next day's deliveries and the collected parcels for return services.

Overall:

- Activities can take place in the Courier Hub or else in the city of Milan.
- There is only one responsible of activities: the Courier.
- Two types of operators intervene: Courier Hub Operator and ICEV Driver.

A representation of the path that each ICEV performs is displayed in Figure 7 while the activities identified are schematized in Table 3.

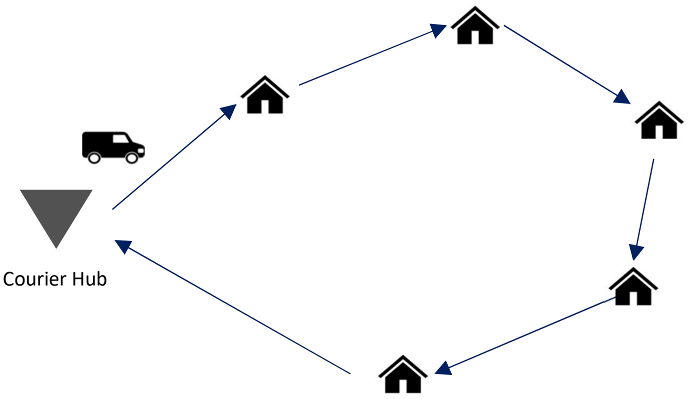


Figure 7 Traditional delivery network

#	Activity	Sub-activity	Activity Type	Location	Responsible	Operator
1. Preparation and loading of goods at Courier Hub						
1.1	Preparation of transportation units		Handling	Courier Hub	Courier	Courier Hub Operator
1.1.1		Load the parcels on the conveyor belt				
1.1.2		Automatic sorting per delivery tour				
1.1.3		Label transportation units				
1.2	Movement of the goods to onbound area		Handling	Courier Hub	Courier	Courier Hub Operator
1.3	Waybill emission		Order processing	Courier Hub	Courier	Courier Hub Operator
1.4	ICEV docking		Transportation	Courier Hub	Courier	ICEV Driver
1.4	Milan hub outbound (per each ICEV)		Handling	Courier Hub	Courier	ICEV Driver

1.4.1		Check and Register				
1.4.2		Loading of goods on the ICEVs				
2. Parcels deliveries and collection tour (per each ICEV)						
2.1	Parcel delivery (per each)		Last-mile delivery	Milan	Courier	ICEV driver
2.1.1		Driving				
2.1.2		Parking and walking				
2.1.3		Parcel handover				
2.2	Parcel pick-up (per each)		Last-mile delivery	Milan	Courier	ICEV driver
2.2.1		Driving				
2.2.2		Parking and walking				
2.2.3		Parcel collection				
3. Return to Courier Hub and handover of left parcels (per each ICEV)						
3.1	Return to hub		Transportation	Milan	Courier	ICEV driver
3.2	ICEV docking		Transportation	Courier Hub	Courier	ICEV driver
3.3	Courier Hub Inbound		Handling	Courier Hub	Courier	ICEV driver
3.3.1		Parcels unloading				
3.3.2		Empty bags unloading				

Table 3 List of activities traditional network

The starting point of the studied flow is a hub that the courier owns outside the city of Milan where the flows that need to be delivered over the considered area are preliminarily aggregated. The first activity of the network is to divide the parcels to be delivered in different bags according to the delivery tours and it is performed on an automated sorting machine, assumed to be present in the Hub, after which the bags are labelled. The goods are then moved towards the outbound area of the Hub and a Waybill is emitted to be handed to the ICEV Driver when they collect the goods. Indeed, after the ICEV docking, the last step at the Courier Hub in this part of the network is the loading of the goods over the ICEV, performed by the Driver itself, who moves the goods with a roll container and then load the bags on the van.

The second macro-phase of the delivery process, the main one, is the delivery tour itself, the section in which customers are served. There are two different kind of service that vans can perform for customers: parcel delivery or parcel pick-up, the first in case the customer order something and the second in case the customers want to return something. For each stop (delivery or pick-up) the driver must drive towards the point, park, and walk towards the customer location to finally handover or collect the parcel. In case of deliveries, which are the by far most of the stops, the delivery can be successful in case the customer is found and parcel delivered or failed in case the customer is not at home when delivering. When organizing the delivery tours, it is assumed that deliveries, either if they are successful or not, and pick-ups have no difference in fixed time for delivery spent by the courier.

Once the delivery tour is performed, each ICEVs must return to the Courier Hub and unload both the parcels to be processed into the hub, the failed deliveries and the returns, and the empty bags where the delivered parcels where located that will be re-used at the next tour preparation.

The main assumption, worth to remember, on which this process is based is that parcels are already consolidated at the hub from which all the ICEVs start their delivery tours. Moreover, while for deliveries it is considered the possibility of having failed deliveries, this is not done in case of reverse flow parcels, which are assumed to be always successful.

4.1.2. To-be process

The to-be network was developed with the aim of evaluating an innovative and greener way to deliver parcels in the city of Milan, more specifically e-commerce parcels. As already anticipated, this delivery process includes different types of vehicles and therefore also different stakeholders and more operator types than the traditional network. In particular, it exploits the usage of Truck, Train, EVs and Cargo-Bicycles to move and deliver goods from the Courier Hub outside the city to customers locations. However, not all customers are served in the same way, indeed, according to the weight of parcels ordered the delivery can be performed by:

- Cargo-Bicycles – weight lower than 2kg.
- EVs – weight higher than 2kg.

EVs also serve some customers with 0-2kg parcels if these are close to some customer they already must serve. Specifications on this are provided during the Model presentation.

As the customers, also the network can be split in two main flows. To these two flows an additional one is added, which is the one of EVs collecting failed deliveries and return parcels related to Cargo-Bicycles deliveries and bring them back to the Courier Hub.

All the flows and paths related to the To-be process are displayed in Figures 8, 9, 10. While the Truck and the Train are sufficient with just one vehicle per type to move all the goods, as regards the EVS and the Cargo-Bicycles, the number of vehicles shown in the representation is only indicative.

Cargo-Bicycles Deliveries

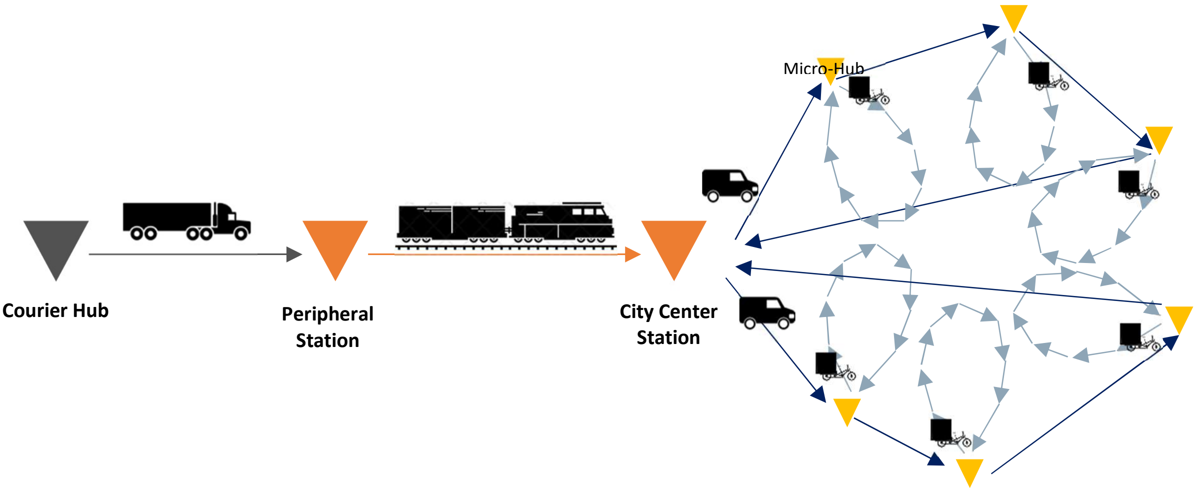


Figure 8 To-be delivery network, Cargo Bikes

EVs Deliveries

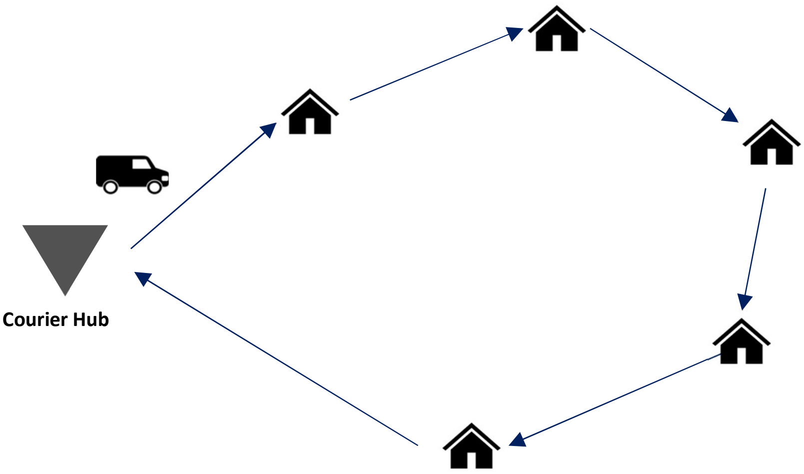


Figure 9 EVs Delivery network

Reverse Flow Management

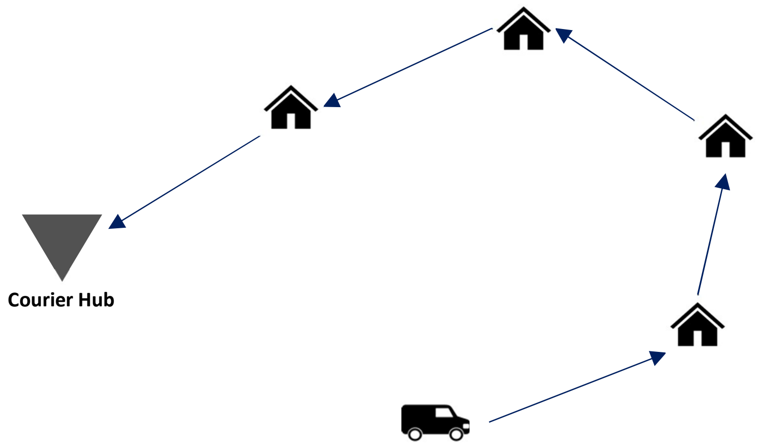


Figure 10 Reverse flow network

Before performing the deliveries according to the different networks, however, there is group of activities that takes place in the Courier Hub before the splitting of the flow, concerning the sorting of the already consolidate goods into transportation units assigned to specific vehicles. The activities are the same seen in the traditional network and represented below in Table 4.

#	Activity	Sub-activity	Activity Type	Location	Responsible	Operator
1. Part 1: Preparation of goods at Courier Hub						
1.1	Preparation of transportation units		Handling	Courier Hub	Courier	Courier Hub Operator
1.1.1		Load the parcels on the conveyor belt				
1.1.2		Automatic sorting per delivery tour				
1.1.3		Label transportation units				

1.2	Movement of the goods to outbound area		Handling	Courier Hub	Courier	Courier Hub Operator
1.3	Waybill emission		Order processing	Courier Hub	Courier	Courier Hub Operator

Table 4 List of activities at Courier Hub, to-be network

4.1.2.1. Cargo-Bicycles Deliveries

At the Courier Hub a truck is fulfilled with the goods to be delivered with Cargo-Bicycles and move towards the nearest train station.

Here the goods are handed over to a Railway logistics operator that is paid by the courier for moving parcels from there to a very central station inside the city center of Milan. This is possible thanks to the usage of a light railway infrastructure called “Passante Ferroviario” that goes through the Milan Metropolitan Area, a huge area around Milan city.

Once the goods arrive to the City Train Station, these are handed over from the Railway Operator to the Courier again, specifically the EV Drivers that will reach the Station from a parking located near it. The scope of these EVs is to bring the parcels to some hubs dislocated over the served Area.

The hubs where the EVs bring goods are called Micro-Hubs. These are some small urban hubs with the only aim of containing the goods that the Cargo-Bicycles should deliver and to work as base-station for the bicycles also for leaving there the failed deliveries’ and returned parcels. To design this kind of Hubs, we based mainly on real application cases of deliveries with urban hub-based cargo bikes and on a brochure specialized on this called “Planning of Cargo Bike Hubs” by Otto-von-Guericke-Universität Magdeburg (2020). Out of the studies performed and considering also the space scarcity and cost inside the central area of the city of Milan, the decision is to consider each Micro-Hub as a stationary container with the structure and dimension of a Sea Container, as done by many couriers using Cargo-Bicycles.

At the end of daily tour, each bicycle will go back to the Micro-Hub in which it is based, and will handover returned parcels and failed deliveries, so that an EV can collect them later.

Being the most complex and articulated part of the network, it includes all the vehicle types, locations, stakeholders, and operator types that play any role in the network:

- 4 Vehicle types: Truck, Train, EV, Cargo-Bicycle.
- 5 Locations: Courier Hub, Peripheral Station, City Center Station, Milan, Micro-Hubs.
- 2 Stakeholders: Courier, Railway Operator.
- 4 Operator types: Courier Hub Operator, Truck Driver, EV Driver, Cargo-Bicycle Driver, Train Operator.

The activities in which the process was broken-down are displayed in Table 5 and described below.

	Activity	Sub-activity	Activity Type	Location	Responsible	Operator
1. Part 2: Movement of goods to Peripheral Train Station						
1.4	Truck docking		Transportation	Courier Hub	Courier	Truck Driver
1.5	Courier Hub Outbound		Handling	Courier Hub	Courier	Truck Driver
1.5.1		Check and Register				
1.5.2		Loading of goods on the truck				

1.6	Driving		Transportation	Milan	Courier	Truck Driver
2. Movement of goods to City Center Train Station						
2.1	Truck docking		Transportation	Peripheral Station	Courier	Truck driver
2.2	Register drop-off		Order processing	Peripheral Station	Courier	Truck driver
2.3	Peripheral Station Inbound		Handling	Peripheral Station	Railway operator	Train Operator
2.3.1		Inspect freight				
2.3.2		Check and register freight				
2.3.3		Goods unloading				
2.4	Movements of transportation units to train loading area		Handling	Peripheral Station	Railway operator	Train Operator
2.5	Waybill emission		Order processing	Peripheral Station	Railway operator	Train Operator
2.6	Transportation units loading		Handling	Peripheral Station	Railway operator	Train Operator
2.7	Train movement towards City Center Station		Transportation	Milan	Railway operator	Train Operator
3. Handover to EV Drivers						
3.1	Train docking		Others	City Center Station	Railway operator	Train Operator
3.2	City Center Station Inbound		Handling	City Center Station	Railway operator	Train Operator

3.2.1		Check and Register				
3.2.2		Unload the goods				
3.2.3		Movements of the goods to storage area				
3.3	EV Driving to City Center station		Transportation	Milan	Courier	EV driver
3.4	EV Docking (per each EV)		Transportation	City Center Station	Courier	EV Driver
3.5	Delivery receipt emission		Order processing	City Center Station	Railway operator	Train Operator
3.6	Movement of goods to outbound area (per each EV)		Handling	City Center Station	Courier	EV Driver
3.7	Milan Station outbound (per each EV)		Handling	City Center Station	Courier	EV Driver
3.7.1		Check and Register				
3.7.2		Loading of the transportation units on the EV				
4. Fulfillment of Micro-Hubs (per each EV)						
4.1	Driving to Micro-Hub (per each Micro-Hub)		Transportation	Milan	Courier	EV Driver
4.2	EV Docking (per each Micro-Hub)		Transportation	Milan	Courier	EV Driver

4.3	Micro-Hub Inbound (per each Micro-Hub)		Handling	Micro-Hub	Courier	EV Driver
4.3.1		Unload the transportation units				
4.3.2		Check and Register				
4.3.3		Movements of the goods to storage area				
4.4	Return to starting point		Transportation	Milan	Courier	EV Driver
5. Parcels deliveries and collection tour (per each Cargo-Bike)						
5.1	Micro-Hub Outbound		Handling	Micro-Hub	Courier	Cargo-bike Driver
5.1.1		Check and Register				
5.1.2		Load of the goods on the Cargo-Bike				
5.2	Parcel delivery (per each)		Last-mile delivery	Milan	Courier	Cargo-bike Driver
5.2.1		Driving				
5.2.2		Parking				
5.2.3		Parcel handover				
5.3	Parcel pick-up (per each)		Last-mile delivery	Milan	Courier	Cargo-bike Driver
5.3.1		Driving				
5.3.2		Parking				

5.3.3		Parcel collection				
5.4	Driving back to Micro-Hub		Transportation	Milan	Courier	Cargo-Bike Driver
5.5	Storage of the returned and unsuccessful parcels		Handling	Micro-Hub	Courier	Cargo-bike Driver

Table 5 List of activities for Cargo-Bike last-mile delivery, to-be network

The starting point of this section of the flow in the designed network is the hub that the courier owns outside the city of Milan where the goods are already sorted and divided in different bags according to the delivery tours to be performed.

The first phase is related to the truck that arrives to the Courier Hub to load the goods and move them towards the Peripheral Station, from where the next transportation will be performed. At the Peripheral Station, after the truck docking, the goods are unloaded and handed over to a Railway Operator, performing a service to the courier. The train is therefore loaded by the Train Operator and the train movement starts, with direction City Center Station. After the train arrives to the central station, the goods are unloaded and moved to an area dedicated for temporary storage of the goods. In the meanwhile, the EV Drivers, starting from a parking located near the city center, reach the City Center Station, receive the goods from the Railway Operator and each one their own tour for supplying goods to Micro-Hubs. During the tour an EV can have multiple stops and for each must reach the Micro-Hub and unload the goods that must be delivered by Cargo-Bicycles assigned to it. At the end of the Micro-Hubs fulfilment tour, each EV is considered to go back at the initial departure points since it’s assumed to be assigned to other tasks not related to this network for the rest of the working day. It’s now the time of the Cargo-Bicycles tours, during which each Cargo-Bike Driver performs the deliveries and collection assigned. The first step is the loading of the goods to be delivered into the cargo box, then the deliveries and the collections are one by one performed, until all customers are served. At the end of the tour the rider drives back to the Micro-Hub, where the storage of returned parcels and failed deliveries takes place so that afterwards a van can collect them to bring them back to the original hub.

4.1.2.2. EVs Deliveries

Deliveries performed with EVs have no structural changes to the network with respect to the traditional one. The two main changes are:

- Vehicle used, that is now an EV instead of an ICEV.
- Goods delivered, since in the traditional network ICEVs deliver every kind of parcel while in our to-be network EVs are mainly focused on 2kg+ parcels.

Apart from these differences, the overall network is the same:

- Activities can take place in the Courier Hub or else in the city of Milan.
- There is only one responsible of activities: the Courier.
- Two types of operators intervene: Courier Hub Operator and EV Driver.

Activities' structure and details are displayed below in Table 6. Being these the same of the traditional network, no further explanations are needed. The only difference at activity level is on the operator that performs the delivery-related activities that instead of being an ICEV Driver is an EV Driver.

#	Activity	Sub-activity	Activity Type	Location	Responsible	Operator
1. Part 2: Goods loading on EV (per each EV)						
1.4	EV docking		Transportation	Courier Hub	Courier	EV Driver

1.5	Milan hub outbound		Handling	Courier Hub	Courier	EV Driver
1.5.1		Check and Register				
1.5.2		Loading of goods on the EV				
2. Parcels deliveries and collection tour (per each EV)						
2.1	Parcel delivery (per each)		Last-mile delivery	Milan	Courier	EV driver
2.1.1		Driving				
2.1.2		Parking and walking				
2.1.3		Parcel handover				
2.2	Parcel pick-up (per each)		Last-mile delivery	Milan	Courier	EV Driver
2.2.1		Driving				
2.2.2		Parking and walking				
2.2.3		Parcel collection				
3. Return to Courier Hub and handover of left parcels (per each EV)						
3.1	Return to Courier Hub		Transportation	Milan	Courier	EV driver
3.2	EV docking		Transportation	Courier Hub	Courier	EV driver
3.3	Courier Hub Inbound		Handling	Courier Hub	Courier	EV driver
3.3.1		Parcels unloading				
3.3.2		Empty bags unloading				

Table 6 List of activities EV delivery, to-be network

4.1.2.3. Reverse Flow Management

Both Cargo-Bicycles and EVs perform deliveries, out of the which a group is left as failed deliveries, and also parcels collection of customers that want to return a package or else to deliver something privately.

EVs that perform deliveries start from and go back to the Courier Hub, therefore these will just handover this group of parcels left in the trunk directly at the end of the working day at the Courier Hub. Cargo-Bicycles, instead, only operate inside the city center in the proximity area of the Micro-Hubs, and this create the need of another vehicles that brings failed deliveries and returned parcels related to customers served by the Bicycles.

What happens in the designed network is that Cargo-Bicycles at the end of their tours go back to the Micro-Hubs where they collected the parcels to deliver and leave there the parcels to be returned at the Courier Hub. Later, one or more EVs, performing other activities not related to this network during the rest of the day, perform a parcel collection tour among the different Micro-Hubs and return them to the Courier Hub. During these activities also the empty bags left by the Cargo-Bicycles are collected and returned to the Micro-Hub. The activities performed are detailed in Table 7.

#	Activity	Sub-activity	Activity Type	Location	Responsible	Operator
Reverse Flow Management						
1	Reverse parcels pick-up (per each Micro-Hub)			Milan	Courier	EV driver
1.1		Driving to nearest Micro-Hub				
1.2		Parking				

1.3		Check and Register				
1.4		Loading of goods on the EV				
2	Return to Courier Hub		Transportation	Milan	Courier	EV driver
3	EV docking		Transportation	Courier Hub	Courier	EV driver
4	Courier Hub Inbound		Handling	Courier Hub	Courier	EV driver
4.1		Parcels unloading				
4.2		Empty bags unloading				

Table 7 List of activities reverse flow, to-be network

Given that the EVs performing this kind of path is not dedicated to this network, they are assumed to start from a random point of city. From there, considering the set of Micro-Hubs to be visited for collecting reverse flow parcels, each EV goes to the nearest Micro-Hub and collects both the parcels and the empty bags to be returned at the Courier Hub. Once this is done for all Micro-Hubs to be visited, each EV goes back to the Courier Hub where the parcels and empty bags are unloaded and subsequently processed again.

4.2. Description of the model

In Section 4.1 both traditional and innovative networks are presented and described, as a consequence the first research question (RQ1) is partially answered. Indeed, we developed an innovative last mile delivery solution using three different modes of transportation in order to deliver e-commerce parcels from the courier hub outside the city to the customers’ locations in a less impactful way. This section defines in detail the structure of the model designed and assessed to answer to our second research question (RQ2), comparing costs and emissions produced by the designed solution with the as-is situation, understanding the benefit as well as the possible negative impacts of the innovative network.

4.2.1. General structure

The model was developed to evaluate the performances of a possible alternative last-mile delivery solution simulated in the city of Milan with the aim to exploit as much as possible the benefits of railways, EVs and Cargo-Bicycles. This solution must be then compared with the traditional delivery way, so to assess the differences in impact achievable with the designed network.

The first output comes out from the implementation of a simulation model using ArcGis, a geographical information system, that given some inputs produces the operating results of the process in term of distance travelled and total time required by the different means of transport. The results coming from the simulation model are then processed in order to compute the final costs and emissions of the network, through emissions factors and costs parameters. This is performed for both innovative and traditional networks and then the results of the two processes are compared. The unit of analysis considered for performing the final comparison is the parcel delivered in the process, distributing therefore the whole emissions and costs produced in the total amount of parcels delivered. In this way results are comparable also between networks that work with different value of total parcel volume. Considering the whole computational process, five different categories of data are involved:

- Input data, which are the ones inserted into the model and that can be eventually changed to evaluate different scenarios. These are related to market data, considering aggregated delivery volumes and parameters that allow us to derive the specific flows we are considering.

- Context data, which are based on the context of application of our study, information given by the courier or else data gathered in analysed studies and academic material. In this group we have therefore data related to application area, vehicles and activities.
- First Output data, which are the results of the simulation model in terms of distance travelled and total time required by the different means of transport.
- Consumption data, the data that starting from the model output allow to get the Final Output data. These are therefore all the costs and emissions factor needed to compute the total impacts starting from operational results.
- Final Output data, the last result of the model developed, consisting in the total operative costs faced and emission produced for delivering the parcels considered in the network.

The general computational framework is displayed in Figure 11 and the different components are detailed in the following Sections.

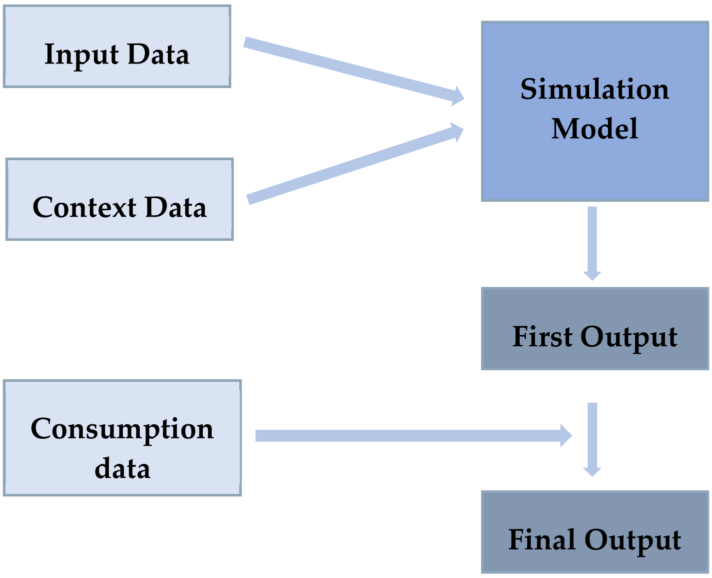


Figure 11 Model description

4.2.2. Input data

The Input data collect the variables that must be processed before running the simulation.

Our study focuses on e-commerce deliveries performed over a restricted central area of the City of Milan by one of the most relevant couriers in Italy and in the region analysed. Therefore, the starting point of our data collection was to understand the market size of e-commerce deliveries in the city of Milan. In this, the first data source is the "Osservatorio eCommerce B2C" of Politecnico of Milan, specifically a publication of October 2021 about values and trends related to B2C e-commerce in Italy for the same year. Having the value for Italy, then the value of deliveries in Milan is computed thanks to the opinion of industry experts that suggested a percentage of Italian flow that can be considered to compute the one belonging only to the city of Milan. Through an assumption of number of working days per year taken from R. Mangiaracina et al. (2020), the daily flow is then obtained. However, the figures computed are related to the whole flow and not a single courier, whose flow is instead estimated thanks to couriers' market shares values got from the "Osservatorio sulle Comunicazioni 2021" of AGCOM, a report developed by the Italian Authority for Communication Guarantees on market share of each service providers for the different communication services, including the data about courier market share in parcels deliveries. The value of daily deliveries that the courier performs in the city of Milan is at this point defined. The data just mentioned are displayed in Table 8.

Data	Value	Source
Number of e-commerce deliveries in Italy 2021	578,000,000	Osservatorio eCommerce B2c (2021)
% Italian flow in Milan	8%	Experts opinion

Number of e-commerce deliveries in Milan 2021	46,240,000	Computed
Yearly working days	260	R. Mangiaracina et al. (2020)
Daily e-commerce deliveries in Milan	177,846	Computed
Courier market share	18%	AGCOM (2021)
Daily e-commerce deliveries in Milan by courier	32,012	Computed

Table 8 Input Data

However, our network is not considering the whole City of Milan, but only a central part of it, specifically the area enclosed by the main Ring Road, therefore we need to distribute the flow delivered to each neighbourhood and then consider only some of them. To do this, we get the distribution of the population in the difference neighbourhoods from a report published by the Municipality of Milan and, considering a correspondence between the number of deliveries and the amount of resident population, we distribute the flow.

Data of %Population by neighbourhood used are displayed in Table 9.

Neighbourhood	%Resident population
Brera	1.32%
Buenos Aires –Venezia	4.47%
De Angeli – Monte Rosa	1.53%
Duomo	1.21%
Farini	0.27%
Ghisolfa	1.30%
Guastalla	1.10%
Isola	1.64%
Magenta – S. Vittore	1.28%

Pagano	1.28%
Garibaldi Repubblica	0.41%
Tortona	1.08%
Washington	1.95%
Ticinese	1.43%
Navigli	1.23%
Vigentina	0.98%
Portello	0.62%
Porta Romana	1.20%
Sarpi	2.23%
Centrale	1.37%
Tre Torri	0.16%
XXII Marzo	2.28%
TOT	**30.36%**

Table 9 Percentage of resident population per neighborhood

Lastly, to identify the part of the flow that is considered eligible for Cargo-Bikes, which is the flow of parcels with weight lower than 2kg, information about distribution of e-commerce parcels weight was gathered. Specifically, the source in this case is a global Survey published in April 2021 by E. Mazareanu about average weight of packaged delivered worldwide.

The data obtained in terms of percentage of Parcels per range of weight are displayed in Table 10, together with the derived values for the ranges of our interest.

Weight range	%Flow	Source
Less than 0.2 kg	17.9%	E. Mazareanu (2021)
0.2 kg to 0.5 kg	31.6%	E. Mazareanu (2021)

0.6 to 1 kg	24.2%	E. Mazareanu (2021)
1.1 kg to 2 kg	14.7%	E. Mazareanu (2021)
2.1 kg to 5 kg	7.4%	E. Mazareanu (2021)
More than 5 kg	4.2%	E. Mazareanu (2021)
Less than 2kg	88.4%	Computed
More than 2kg	11.6%	Computed

Table 10 Data on percentage of parcels per range of weight

The last input of the model is the number of Micro-Hubs that are used in the covered area as support infrastructures to Cargo-Bicycles deliveries. The highest is the number of hubs, the closest will be the bicycles to their customers and the most spread the starting points will be, therefore the best it can be for the network performances. However, each Micro-Hub requires the space to be obtained or rented and given the space scarcity and cost in Milan City Center, too many Micro-Hubs may cause bring to an unsuitable condition. Following the just mentioned reasoning, a number of Micro-Hubs equal to 6 was considered reasonable and was chosen.

4.2.3. Context data

In this Section, Context data are presented, which can be define as the data lay the foundation of the model developed, composed of data related to parcels and deliveries, vehicles and activities. In the following sections each group of them is presented.

4.2.3.1. Parcels and deliveries

Here we present the data used regarding parcels dimension, transportation units and equipment capacities, but also parameters related to deliveries operation.

As regards parcels, considering the weight distribution coming from the survey of E. Mazareanu (2021), we assumed a representative weight for each range as the average of the lower and upper limit and then computed the average weight for the three flows of our interest: 0-2kg, 2kg+ and "All". Also, an indicator of the average volume of a parcel is necessary to understand space occupancy of parcels and to get this a density of 166.67 kg/m^3 is assumed. Moreover, parcels are assumed to be grouped into different bags according to the delivery tours and, given the different characteristics of weight and volume among the ranges of delivered parcels and also of the different delivery processes, the bags are assumed to contain a different number of parcels in each.

Another component to look at is the equipment used to move the goods at the hubs, both Courier Hub and Micro-Hubs, and how many bags can fit in it, so to be able to know how many movements are needed to move a certain amount of goods. The assumption is that the goods are moved thanks to a Roll Container, whose values of maximum capacity have been gathered from the web: 400kg in weight and 1 m^3 in volume. Considering these capacities, it can be computed the number of bags that can fit on a roll container in the different cases analysed.

A summary of data related to parcels and equipment by type of flow are displayed in Table 11.

Weight range	%Flow	Average weight	Average volume	#Parcels/bag	#bags per roll container
Less than 0.2 kg	17.9%	0.1 kg	0.0005 m3	-	-
0.2 kg to 0.5 kg	31.6%	0.35 kg	0.0020 m3	-	-
0.6 to 1 kg	24.2%	0.8 kg	0.0047 m3	-	-
1.1 kg to 2 kg	14.7%	1.55 kg	0.0092 m3	-	-
2.1 kg to 5 kg	7.4%	3.55 kg	0.0212 m3	-	-

More than 5 kg	4.2%	9.75 kg	0.0584 m3	-	-
Less than 2kg	88.4%	0.623 kg	0.0037 m3	100	2
More than 2kg	11.6%	5.805 kg	0.0348 m3	10	2
All	100%	1.222 kg	0.0073 m3	10	14

Table 11 Data on parcels and equipment by type of flow

Deliveries, however, can be multi-parcel and not only single parcel, and in this perspective, we assumed an average value of 1.25 parcels per delivery performed to each customer, in line with different thesis studies observed.

The two last parameters included in this section are related to two different situations that can occur and that need to be considered. The first is the failed deliveries rate, which means what percentage of deliveries are unattended by the customers and therefore need to be brought back to the Courier Hub and delivered again the next day. The second one instead is a percentage of customers stops that instead of being deliveries are parcels pick-up, basically for returns that need to be performed. Both values were obtained during the meeting with the courier we performed at the beginning of the thesis work and are specifically 5% for failed deliveries and 3% for the reverse flow to be considered.

4.2.3.2. Vehicles

The main aspect characterizing the network designed in this study is the variety of vehicles used, each one used for what the most suitable for. Indeed, each vehicle has different peculiar characteristics that make it well-suited for the phase of the delivery it is performing. Specifically, the differences presented in this section are related to dimensions, speed, capacity and consumption, while data about emissions and costs related to each vehicle are presented in Section 4.2.4.

The first vehicle in the network is a 18t truck that moves all the parcels that need to be delivered by the cargo-bikes from the Courier Hub to the Peripheral Station. In this case, we took the capacity data provided by an Italian Transportation Service company on their website. Regarding the truck consumption data, it comes from DEFRA 2021, that is an annual report done by UK government on greenhouse gas conversion factors, in which the average consumption per ton-kilometer of a truck is computed taking into account the statistics of 2020 for Great Britain proposed by the Department of Transports. The consumption data coming from DEFRA considered how much a truck is loaded in weight, more precisely if it is full or half loaded. Consequently, starting from DEFRA data, we computed the consumption of the truck in term of liters per ton-kilometers using an interpolation that considered the weight loading factor of the truck for each case analysed.

The second vehicle is the train, a freight electric train but with very peculiar characteristics, given the very specific path and that it needs to move among the railways inside the city of the "Passante Ferroviario" which are not suitable for typical freight trains dimensions. Therefore, different assumptions were needed, and these were based on the trains that actually perform the public transportation service on the same railways, supposing to have a freight train of similar dimension. We assume to have a train composed by a locomotive and 2 flat wagons, in each of which 3 TEUs (Twenty-foot Equivalent Units, ISO) can fit, for a total of 6 TEUs. The train energy consumption in term of KWh per ton-kilometer was taken from Railway Handbook of 2017, that is a report written by the International Energy Agency (IEA) and the International Union of Railways (UIC) with the objective to provide insights on worldwide rail sector energy and CO2 emissions performance. In particular, the European railway specific energy consumption for freight trains of 2015 was considered in our model as train energy consumption.

There are then the EVs, used for both deliveries to a part of the customers departing from the Courier Hub and for fulfilling Micro-Hubs. The capacity and consumption data about EVs were obtained directly from the producer considering one of the most popular ICEVs in Italy used by delivery companies which is the Fiat Ducato. Same logic for the EVs, used in the greener system, for which it was considered the corresponding electric version, the Fiat e-Ducato.

Last vehicle are the Cargo-Bicycles, whose capacity data just like for the EVs and ICEVs were taken directly from the producer, and specifically from a company called Yokler and precisely the model Yokler XL, which perfectly suited our study case. Instead, regarding the energy consumption data, the value was taken from Martin Koning et al. (2015), in which an estimation on the consumption of a Cargo-Bikes was computed examining eleven different Cargo-Bike's companies and comparing the findings.

In Table 12 is presented a comparing among the different vehicles' characteristics.

	Train	**Truck**	**EV**	**ICEV**	**Cargo-Bicycle**
Capacity (kg)	129,600	10,000	1,160	1,600	240
Capacity (m3)	198.6	45	10	10	1.4
Consumption (l/km)	-	* Computed for each case	-	0.06175	-
Consumption (KWh/km)	0.04861115*	-	0.217	-	0.0089

Table 12 Vehicles' characteristics, * KWh/t*km

As regards vehicles speed, for the EVs, ICEV and truck, there was no need of investigating them since creating the related object into the simulation software, the different speed characteristics are already considered, and this applied to vans and truck. When it comes to the bicycles instead, a limit had to be defined and the limit of 25 km/h valid in Italy and coming from the Regulation (EU) No 168/2013 of the European Parliament, was considered to set a maximum speed of the object "Cargo-Bicycle" into ArcGis. For the train instead, neither the speed nor the time involved in the train activity had any influence in our model results, therefore the data was not collected.

Lastly, in case of EVs and Cargo-Bicycles, being these vehicles electric, also the ranges in km that the two vehicles are capable of covering with a charge were considered. These are 60 km for the cargo-bicycles, that performs an average of 10 km per day in our network, and 235 km for the EVs, which performs around 10 km or 50 km according to the task they do, if fulfilling Micro-Hubs or serving customers. Therefore, no ranges issues are present in our case, and this aspect is therefore not considered in the model.

4.2.3.3. Activities

A fundamental part of the context data, essential for the model to be set up, are related to the time needed for the different activities performed by operators of the network, apart from the driving which instead is based only on the road network that the ArcGis is built on.

The different activities considered relevant, and therefore included in the numerical analysis are listed in Table 13, together with the times assumed, the types of operators that performs it and the locations in which they take place.

Activity	Time	Operator types	Location
Docking at hubs (fixed)	3 min	EV Drivers, Cargo-Bicycle Drivers, ICEV Drivers	Courier Hub, Micro-Hubs
Docking and goods collection of EVs at City Center Station (fixed)	15 min	EV Drivers	City Center Station

Truck docking and goods loading (fixed)	45 min	Truck Driver	Courier Hub
Truck docking and goods unloading (fixed)	45 min	Truck Driver	Peripheral Station
Loading of a bag on Roll Container (per bag)	30 sec	EV Drivers, Cargo-Bicycle Drivers, ICEV Drivers	All Hubs and Stations
Unloading of a bag from Roll Container (per bag)	30 sec	EV Drivers, Cargo-Bicycle Drivers, ICEV Drivers	All Hubs and Stations
Roll container movement (per single movement)	3 min	EV Drivers, Cargo-Bicycle Drivers, ICEV Drivers	All Hubs
Loading of a parcel from the vehicle on Roll Container (per parcel)	5 sec	EV Drivers, Cargo-Bicycle Drivers, ICEV Drivers	All Hubs
Unloading of a parcel from the Roll Container (per parcel)	5 sec	EV Drivers, Cargo-Bicycle Drivers, ICEV Drivers	All Hubs
Loading of a parcel on Cargo-Bicycles (per parcel)	10 sec	Cargo-Bicycle Driver	Micro-Hubs
Parcel delivery/pick-up regular	5 min	EV Drivers, Cargo-Bicycle Drivers, ICEV Drivers	Customers' locations
Parcel delivery/pick-up close customers	4 min	EV Drivers, Cargo-Bicycle Drivers, ICEV Drivers	Customers' locations

Table 13 Time of activities

Docking activities are considered whenever a vehicle arrives to an infrastructure to include the time spent in parking, going out of the vehicle and enter the Hub, and this is considered in the green solution for EVs and at the Courier Hub and EVs and Cargo-Bicycles at Micro-Hubs, while in the traditional one for at Courier Hub. At the City Center Station for EVs docking it is not considered because it is instead used a different higher value that also considers the handover that takes place between the railway operator and the courier after the train movement. For the Truck, docking is not considered neither at the Courier Hub nor at the Peripheral Station, because in these cases a fixed time for the whole truck loading or unloading process, since it is assumed that also other operators in the same infrastructures will help. For the EVs and the Cargo-Bicycles instead, the loading and loading of goods is considered performed only by the Drivers and depend on the amount of goods moved. As already mentioned in Section 4.2.3.1, the movements of the parcels are performed with them grouped in bags, which are then moved, when considering ICEVs, EVs and Cargo-Bicycles, on a Roll Container from the Hub to the vehicles and vice versa, and for this it is defined a unit time of loading and unloading of a bag on and from the Roll Container and also the time needed on average for the actual movement. Different is the case of failed deliveries and returned parcels unloaded by the vehicles at the end of their tours at the Micro-Hubs or the Courier Hub according to the type of vehicle, in which parcels are directly loaded on the roll container without the usage of bags, and in this case a time per parcel of loading and unloading was included. Moreover, while for EVs and ICEVs it is enough to unload the bag from the Roll Container to have it on the vehicle, in the case of Cargo-Bicycle, and additional step is required, which is the loading of the parcels into trunk, therefore a loading time per parcel is considered

Lastly, there are the delivery/pick-up times, which do not depend on the vehicle that performs the service but are differentiated according to the fact that customers have others close to them or not. Indeed, if customers are close each other, they will be served by the same vehicle and can be served during the same stop, decreasing the total time needed for the multiple deliveries with respect to the one needed in more stops. Therefore, a lower fixed time for delivery was considered for customers that have another customer in the 20 meters close to them.

4.2.4. Consumption data

Data related to the impact studied of each vehicle, so in terms of costs and emissions, presented in this section, are those figures that, starting from the simulation output in terms of km and time related to each vehicle, allow us to compute total costs and emissions of the network, to then compute the cost and emissions per parcel.

4.2.4.1. Costs data

A significant difference among the cost logic of the different vehicles is only present in the case of the train movement, a service performed by a third company and not by the courier and therefore paid as such, according to the weight of the goods moved and the km performed.

The train fare comes from the Association of American Railroads, considering the average freight revenue per ton-mile of 2019, considering as weight the whole weight of train. Then, this price was converted from \$/(t • mile) into €/(t • km) using the average exchange rate between dollar and euro of 2019 and the conversion factor from mile to km. In addition, another conversion factor was used to adapt the value to European freight train market, in which significantly smaller trains are used and for much lower distances. This conversion factor was computed as a ratio between the unitary revenues of USA and EU studied during our Academic path. Table 14 summarizes the data related to the computation of train revenue:

Train revenue USA ($/t*mile)	Exchange rate $/€ 2019	Conversion factor mile to km	Conversion factor USA to EU	Train revenue UE (€/t*km)
0.0442	0.8931	1.60934	2.375	0.058255665

Table 14 Computation Train Revenue

As regards the operations directly performed by the courier instead, the cost is made of different components:

- Driver: the main cost in the network, assumed to be equal no matter the vehicle that is driven by the operator.
- Feeding: cost of fuel or electricity, according to the vehicle.

- Vehicle cost: cost related to vehicle ownerships, already including maintenance costs.
- Road toll: special tolls that are applied in the city of Milan to traditional combustion vehicles that wants to enter the city center.

As operating costs, there would have been also Insurance and Ownership cost that, however, have a meaningless effect on the daily operations and even less on the cost/parcel, therefore are negligible and not included in the analysis.

The costs mentioned in the bullet points above are displayed in Table 15 for Trucks, EVs, ICEVs and Cargo-Bicycles.

Weight range	Truck	EV	ICEV	Cargo-Bicycle
Driver (€/h)	25	25	25	25
Feeding (€/l or €/kWh)	1.653	0.188	1.653	0.188
Vehicle cost (€/h)	8.654	4.118	1.783	1.319
Road toll (€/h)	-	-	3	-

Table 15 Vehicles' cost parameters

The sources of the different data are described in the following paragraph.

While the Driver cost was assumed, the feeding costs come from Global Petrol Price, a website tracking retail prices of any kind of fuel globally.

Vehicle costs are obtained through vehicle renting companies, specifically for EVs, ICEVs and Cargo-Bicycles. For EVs and ICEVs both data were obtained with consistency to the type and dimension of vehicles used in the studied network, while for Cargo-Bicycles only a monthly fee for a Cargo-Bicycle with lower capacity and power than the one used were found. Therefore, the monthly rent of the model was then adapted to our case multiplied by the ratio between the different vehicle’ purchasing value related to the different Cargo-bicycles. Lastly, the value of Road Toll applied to the ICEVs inside the city of Milan is taken from R. Mangiaracina et al. (2020), in which a comparison of last mile deliveries with ICEVs or EVs in the city of Milan is presented. For Cargo-Bicycles instead, the values are obtained from J. Freselle et al. (2021), in which performances of a mixed fleet of vehicles are studied, included EVs and Cargo-Bicycles. However, the values consider in this last paper for EVs were higher than the ones taken from R. Mangiaracina et al. (2020), and therefore the obtained Cargo-Bicycles data were reduced according to the same "conversion" ratio from one paper to the other. Lastly, for the truck the source used was a study performed by the Albo Nazionale Autotrasportatori (2006), an Italian national institution of the minister of infrastructures and sustainable mobilities.

4.2.4.2. Emissions data

The environmental impact of the two processes is evaluated taking into consideration emissions conversion factors in term of Carbon dioxide equivalent (CO2e) per km. For Train and Truck, the conversion factor is instead the Carbon dioxide equivalent (CO2e) per ton-km being weight moved relevant for the emissions generated by these two means of transport and being possible to use it given the constant load on these vehicles.

The approach used to compute the emissions generated by the different means of transport was the Well-To-Wheel approach, which, as reported in Chapter 3, is divided in two phases.

The first is the Well-To-Tank, in which the emissions produced by the extraction or generation and distribution of the primary source of the vehicle's engine, fuel or electricity, are analysed.

For diesel vehicles, which means Truck and ICEVs, the conversion factor is obtained considering the emissions produced by the extraction and distribution of fuel and the consumption of the vehicles as follows:

$$CF_{WTT} = WTT_d * FC$$

Where:

- CF_{WTT}: Conversion factor for diesel vehicles for Well-To-Tank phase.
- WTT_d: gCO2 generated for extraction and distribution of a liter of diesel (gCO2/l).
- FC: Fuel Consumption of the vehicle, l/km in ICEV and l/(t*km) multiplied by the weight moved in case of truck.

For electric vehicles, which means EVs, Cargo-Bicycles and Train, the conversion factors consist instead in the emissions generated for the production and the distribution of the electricity consumed, computed as follow:

$$CF_{WTT} = WTT_e * FC$$

Where:

- CF_{WTT}: Conversion factor for electric vehicles for Well-To-Tank phase
- WTT_e: gCO2 generated for production and distribution of a KWh of energy (gCO2/KWh).
- FC: Fuel Consumption of the vehicle, KWh/km for EVs and Cargo-Bicycles and l/(t*km) multiplied by the weight moved belonging to the courier under consideration in case of train as written in Section 4.2.4.1.

The second phase is the Tank-To-Wheel, which consists in considering the emissions generated during the usage of the vehicles, so it includes only the Carbon dioxide Equivalent (CO2e) generated by diesel vehicles.

Finally, the conversion factors coming from these two steps are summed up to compute the overall emission factor which will be gCO2e/km in case of variable load vehicles and gCO2e/t*km in case of constant load ones.

The data and results just mentioned with the relative values are shown in Table 16. As regards Energy Production emissions, values were taken from INSPRA (2021), representing the estimation of Gross Electricity Production, while for Fuel Production emissions the values are taken from JEC Well-To-Tank (2020), a report written by JEC consortium in which greenhouse gas (GHG) emissions were computed observing a wide range of powertrains and fuels options, within the European context. The value reported in Table 16 is the estimation of WTT diesel emissions as of 2020. The Energy or Fuel Production as gCO2e per km was then obtained through the product of Energy or Fuel Production emissions and energy consumption of the specific vehicle under analysis.

	Well-To-Tank			**Tank-To-Wheel**	
Vehicle	**Energy Production (gCO2e/KWh)**	**Fuel production (gCO2e/l)**	**Energy/Fuel Production (gCO2e/Km)**	**Energy Consumption (gCO2e/km)**	**gCO2e/km**
Truck	-	683.12	52.891*	195.65*	248.54*
Train	263.40	-	12.80*	-	12.80*
EV	263.40	-	57,16	-	57.16
ICEV	-	683.12	42.18	265.29	307.47
Cargo Bikes	263.40	-	2.34	-	2.34

Table 16 Vehicles' Well-To-Wheel conversion factor data, * gCO2e/t*km

Finally, the Energy Consumption data comes from DEFRA (2021), in which the emissions per kilometer released by diesel vehicles, truck and ICEV, are computed looking at statistics of 2020 for Great Britain proposed by the Department of

Transports. In case of truck, as done for consumption data, it is considered how much a truck is loaded, more precisely the loading factor. Starting from DEFRA data, we computed the Tank-To-Wheel emissions of the truck, in term of gCO2e per ton-kilometers, using an interpolation that considered the actual loading factor of the truck for the case.

In the last column of the Table 16 is displayed the emission conversion factor used to compute the environmental impact of each mean of transport in our solution, given by the sum of the conversion factors coming from Well-To-Tank and Tank-To-Wheel phases.

4.2.5. Output data

The output data shows the performances of both processes, the one considering Train, Electric vans, and Cargo bicycles, and the traditional one with only diesel vans. Firstly, from the model developed in ArcGis operational data related to the studied networks are obtained and following costs and emissions generated in each are computed, both as total values and per parcel delivered.

4.2.5.1. First Output data

The results of the simulation model are grouped by object of the network, and therefore for each mean of transportation and each type of task performed, which means: EVs Deliveries, EVs Micro-Hubs, EVs Return, Cargo-Bicycles, ICEVs. Starting from the characteristics of each route included in the solution obtained, for each group of vehicles and task type the following information are exported and aggregated:

- Numbers of vehicles.
- Numbers of points served.
  - Customers (EVs Deliveries, Cargo-Bicycles, ICEVs).

    - Micro-Hubs (EVs Micro-Hubs, EVs Return).
- Distance travelled.
- Time spent in serving the points.
    - Deliveries/pick-up at customers locations (EVs Deliveries, Cargo-Bicycles, ICEVs).
    - Fulfilling Micro-Hubs (EVs Micro-Hubs).
    - Collecting parcels from Micro-Hubs (EVs Return).
- Time spent in handling goods.
- Time spent in driving.

Additionally, ArcGis is used for measuring the distance travelled by the train and computing the distance covered and time spent by the truck for moving the parcels from the Courier Hub to the Peripheral Station.

4.2.5.2. Final Output data

The outputs of the model are then processed combining each result to the appropriate consumption, which means emissions factors and cost parameters, to produce the main results:

- Carbon footprint generated in a typical delivery day of each network ($kgCO_{2e}$/day).
- Cost associated to a typical delivery day of each network (€ /day).
- Carbon footprint per parcel delivered ($kgCO_{2e}$/parcel).
- Cost associated to a parcel delivered (€/parcel).

Regarding the greener process, the two mentioned results are specified per each type of vehicle used to show the impact of each of them in the aggregated result.

4.2.6. Model phases and steps

The simulation model has been created using ArcGis, a geographical information system (GIS) that allows to perform geostatistical simulations, that has been used to compute the routes of the different means of transportation. Different characteristics of the model and features considered make the model highly realistic, for example the consideration of the different distribution of customers among the city area and the capability of the software to consider different traffic condition during the different time of the simulation. Also, as regards the time considered, apart from the fixed time for delivery, all loading and unloading activities of parcels and bags performed at the different Hubs and Stations have been included, and the same for time spent in docking. As already mentioned in Section 4.2.3.3, to be as real as possible, fixed time for delivery to customers was differentiated according to the presence or not of close customers near it, assuming in case this is true a lower fixed time for delivery. To do this, when inserting the fixed times for delivery into ArcGis, a function called "Near" was used, which identified all points that had others closer than a certain threshold, that was set at 20 meters.

If we look at the overall model of the analysis performed in this thesis, this is not only limited to the simulation model part, but includes also some preceding and following data processing, which was performed on Microsoft Excel.
Figure 12 illustrates the process flow starting with data processed on Excel, then put as input of the simulation model, which produces as output operational outcomes that are again elaborated in Excel and combined with consumption data to produce the Final Output Data.

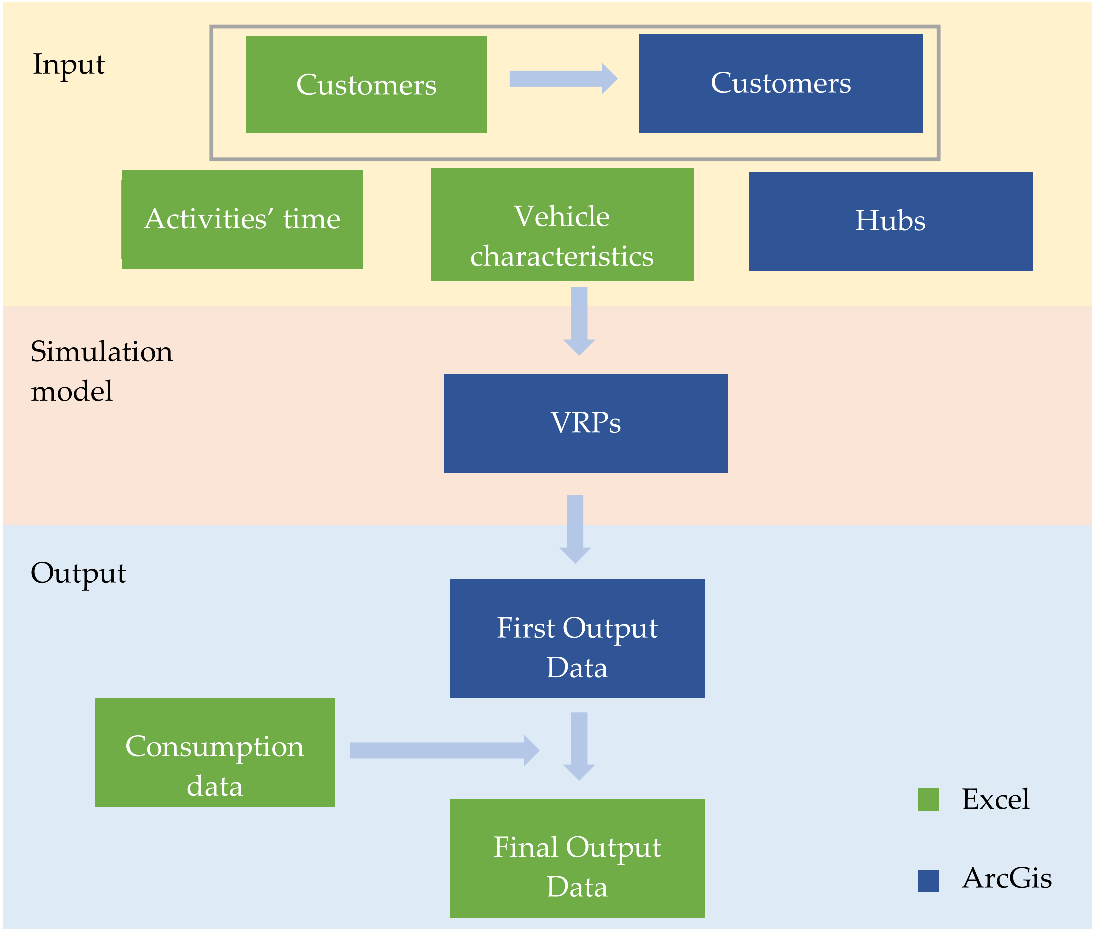


Figure 12 Process flow of the model

4.2.6.1. Input of the simulation model

The input of the simulation model mainly coming from Excel, in which they are elaborated, only the Courier Hub and the Stations are directly created in ArcGis choosing the position where to located them.

The generation of the demand and therefore customers served in the simulation model lays its foundations on the daily deliveries in Milan computed by a courier, increased by 3% to also consider pick-ups and not only deliveries. Then, through to the percentages of population in the different neighbourhoods into the Milan Ring Road (Section 4.2.2), the customers served in each neighbourhood are obtained.

When it comes to the innovative solution, this data is also split in the two categories of customers under analysis looking at the according to the parcels per range of weight (E. Mazareanu, 2021): the customers that could be served by the cargo bike, that are the ones with parcels weight from 0 to 2Kg, and the ones that order parcels heavier than 2Kg that are served by the electric vans.

Before computing the customers per neighbourhood, however, some of the population percentages are adjusted given that the areas of some neighbourhoods extend beyond the ring road while our analysis do not. The final values of customers to be served in each neighbourhood are displayed in Table 17.

Neighbourhood	Tot Customers	Customers 0-2 Kg	Customers 2+Kg
Brera	423	374	49
Buenos Aires –Venezia	932	824	108
De Angeli – Monte Rosa	508	449	59
Duomo	395	349	46
Farini	41	36	5
Ghisolfa	429	379	50
Guastalla	334	295	39
Isola	544	481	63
Magenta – S. Vittore	392	346	46
Pagano	365	322	43
Garibaldi Repubblica	126	111	15
Tortona	334	295	39
Washington	623	550	73
Ticinese	391	345	46
Navigli	361	319	42
Vigentina	275	243	32

Portello	206	182	24
Porta Romana	397	351	46
Sarpi	620	548	72
Centrale	269	237	32
Tre Torri	55	48	7
XXII Marzo	522	461	61
TOT	8542	7545	997

Table 17 Customers to be served per neighbourhood

These numbers are imported in ArcGis, in which the function Create Random Points generates in each neighbourhood the customers to be served in the related number. In the traditional network the customers, being all served by the same vehicles, are generated in a unique layer, which is a set of points that is then used as customer base for the VRP, while for the to-be network two different layers of customers are present, corresponding to the split represented in Table 17 and to different VRPs.

Other fundamental inputs for the correct execution of the model and solution of the problem analysed are then inserted. Per each customer, a parcel volume and weight are assigned according to the group of customers they belong to and also a fixed time for delivery value according that they "regular" or "close" as explained in Section 4.2.3.3. Into each VRP problem are instead inputted the related activities times and vehicles characteristics coming from context data. Lastly, while the Courier Hub and the Stations have been inserted into the map of ArcGIS according to the real locations of the interviewed courier's hub and the chosen stations of Segrate and Garibaldi, the micro-hubs, have been placed using a Location-Allocation Problem that is successive explained in Section 4.2.6.4.1.

4.2.6.2. Simulation model

The simulation model uses the vehicle routing problem (VRP) to create the routes through which each vehicle performs their tasks, serving customers, fulfilling Micro-Hubs or collecting parcels, according to the case. For each route then distances and times are obtained as presented in Section 4.2.6.3. The VRP is an optimization and integer programming problem aiming to service a number of customers with a fleet of vehicles.

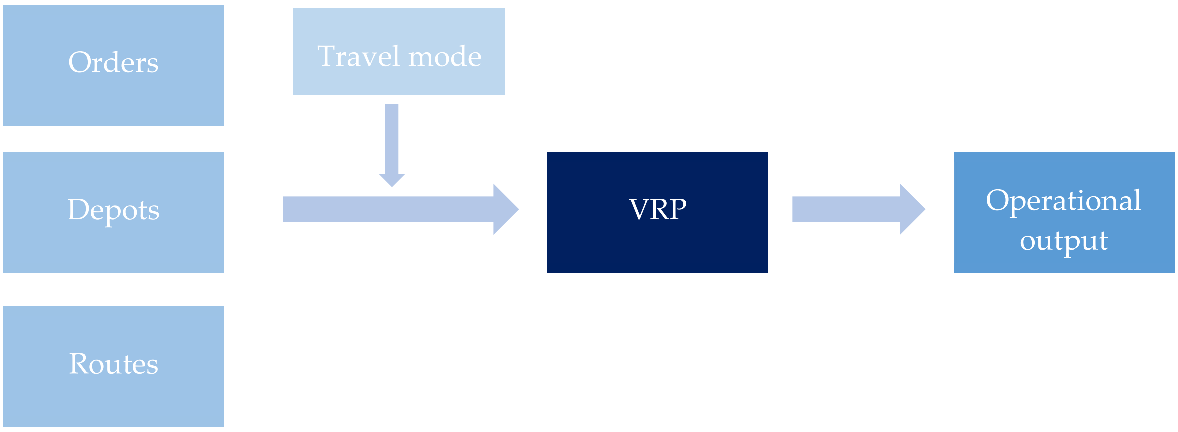


Figure 13 Input and output of VRP

The different VRPs, one for each type of vehicle used in the network, as schematized in Figure 13, in order to run need to be inputted the following objects:

- The points to be served, with relative information on fixed time for delivery and delivery quantity in term of volume and weight.
- The infrastructures, hubs or stations, from where the vehicles start and end their routes.

Moreover, two different types of travel mode are used, given that the VRPs are built for Cargo-Bicycles and vans, no matter if EVs or ICEVs, that moves differently through the network. In particular, the difference among the two is that in case of Cargo-Bicycles it is set a maximum speed of 25 km/h being this the limit imposed by Europe and valid also in Italy.

Lastly, the routes must be set, defining for each of them the starting and ending points, fixed time spent in both, capacity of vehicle in terms of volume and weight, departure time, and maximum hours available.

Once all is set up, the VRP can be run, and produce the results in term of operational output as explained in the next Section.

Regarding the truck and train routes in the to-be network, instead, they are fixed and computed by ArcGis in two different ways. For the truck, a simple route linking the courier hub with the train station in the periphery of Milan is computed with the aim of minimizing the time spent to perform it. On the other hand, for the train, the path of the "Passante Ferroviario", a regional train that crosses the city center of Milan, is considered and the distance covered measured with a tool integrated in ArcGis.

4.2.6.3. Output

Once the simulation is over, the results obtained, for each of the vehicles that play a role are:

- Number of points served.
- Travel time.
- Total fixed time for delivery.
- Total handling time.
- Distance travelled.

These results are then transferred to Excel in which they are processed to obtain grouped data for each specific vehicle and performed activity.

From the operational results, combining them with emissions conversion factors and cost parameters, the final output in term of environmental impact and cost of the solution are obtained.

Finally, to obtain unitary values of emissions generated and cost associated to a single parcel delivery, the computed daily values are divided by the total number of parcels delivered in the day.

In the following sections the two different networks are presented including description of each step performed in the simulation model and of each VRP generated and solved.

4.2.6.4. To-be network

In this Section it is presented how the problems related to the different vehicles are composed and solved, with all the computational steps, both in ArcGis and outside it in Excel.

Specifically, the different vehicles are Cargo-Bicycles and EVs, the latter of which may perform three different type of tasks and therefore three different VRPs are built. The first are the ones that perform the delivery of parcels with weight higher than 2 kg plus the ones originally belonging to group of the Cargo-Bicycles ones and that were migrated to the EVs ones because of the proximity to the already served ones with more than 2kg. The reason behind this choice is to create a simulation model as much as possible close to the reality, indeed if a delivery is very close to another, they will both be performed in the same tour. The second EV type is the one that fulfilled the Micro-Hubs with the parcels to be delivered, starting from a parking point near the city center and collecting the parcels at Garibaldi Station before moving towards the Micro-Hubs. Lastly, there are the EVs that collect the failed deliveries and returns left by the Cargo-Bicycles drivers in the Micro-Hubs at the end of their tours and bring them back to the Courier Hub.

As mentioned, four different VRP have been developed:

- VRP Cargo Bikes.

- VRP EVs Deliveries.
- VRP EVs Fulfilling.
- VRP EVs Returns.

The location of the different infrastructures inside the Map of Milan City Center can be observed in Figure 14, in which the black triangle is the Courier Hub, the red ones are the Micro-Hubs and the points with a train logo are the train stations, the Peripheral one next to the Courier Hub and the City Center one inside Milan ring-road.

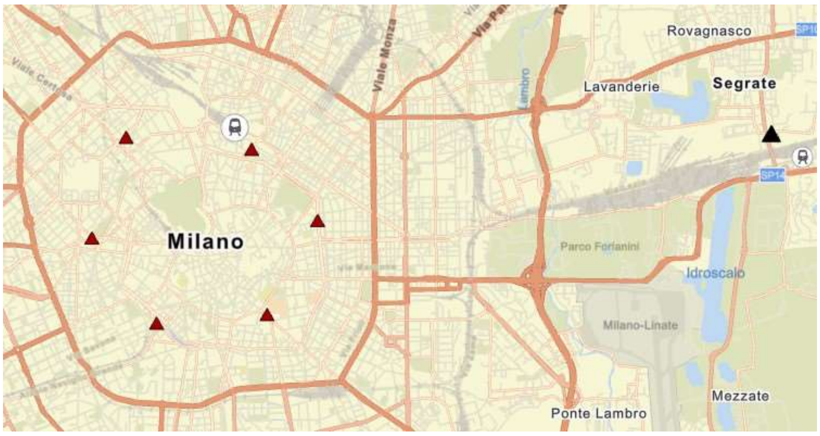


Figure 14 Location of infrastructures inside the Map of Milan City Center

In the next Sections each VRP developed is detailly described, with peculiarities and outputs produced to generate the final solution.

4.2.6.4.1. VRP Cargo Bike

The base of each VRP are the points to be served, therefore in this case the customers that require deliveries or pick-ups. These are the orders eligible for cargo bikes deliveries, which means the ones with parcels lower than 2kg in weight minus the group migrated to the EVs Deliveries because of the proximity.

The starting point for all the Cargo-Bicycles are the Micro-Hubs, the only depots used in this specific VRP. To arrange these hubs, a Location-Allocation (LA) analysis was performed which, given a set of candidate points and the number of facilities to be chosen and the customers to be served, locates the facilities such that the transportation cost from facilities to customers is minimized.

To create the layer of candidate points, we considered two different circumferences with center in the center of the Area considered and radius respectively ½ and 2/3 of the radius of the circumference that surrounds the area, which is Milan ring-road, distributing uniformly 19 points in the two circumferences, having a total number of 38 possible candidate locations to put the Micro-Hubs (Figure 15).

Considering only the Cargo-Bicycle customers as customers to be served also for the LA analysis, the chosen locations out of the 38 possible for Micro-Hubs are shown in Figure 15.

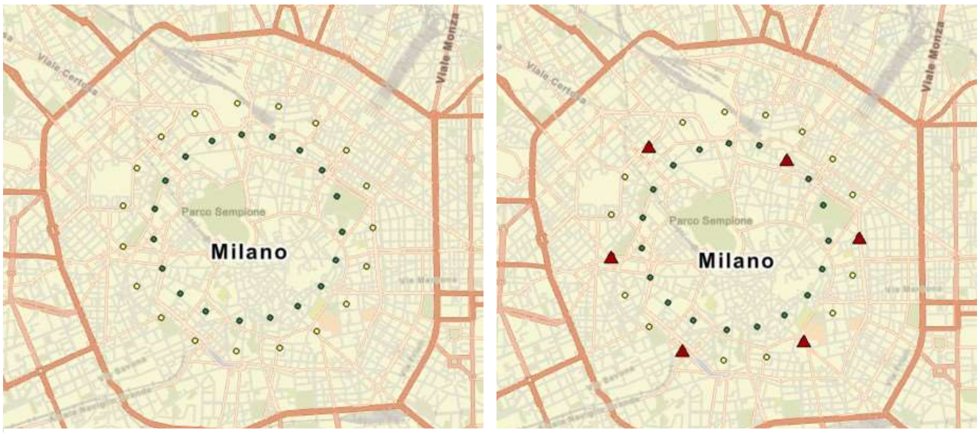


Figure 15 Insertion of Micro-hubs

Once the Micro-Hubs are located, it is possible to create the routes, which are created in a high enough number to be always higher than the tours, since each tour need one route. When setting the routes, the following information are needed:

- Starting point → Micro-Hub.
- Ending point → Micro-Hub.
- Time spent by the Cargo-Bicycles Drivers at the Micro-Hubs before the tour to start get ready and load the parcels.

- Time spent by the Cargo-Bicycles Drivers at the Micro-Hubs after the tour to unload the parcels of returns and failed deliveries from the Cargo Bikes.
- Weight capacity of the Cargo-Bicycle.
- Volume capacity of the Cargo-Bicycle.
- Time available of the Cargo-Bicycle driver.
- Speed limit.

Given the three macro-inputs just described, the VRP is ready to be solved, with the optimization objective of minimizing the time spent for performing all deliveries, while also minimizing the number of vehicles. All the operational outputs illustrated in Section 4.2.6.3 are moved then to Microsoft Excel to be elaborated to obtain the number of bikes delivering from each Micro-Hub and, considering all of them are computed the following values:

- Number of customers served.
- Number of parcels delivered, with total weight and volume.
- Total number of parcels delivered from there and the corresponding volume and weight.
- Total time spent by Cargo-Bicycle Drivers split into Fixed Time for delivery, Travel Time and Handling time.
- Total distance travelled by the bikes of that micro-hubs.

Based on these some figures needed as input to the VRPs of two of the EVs types.

Given the parcels that each EV Fulfilling has to move from the City Center Station to the Micro-Hubs, and therefore given the amount of parcels to be delivered from the served Micro-Hubs, EVs Drivers will need to spend different time at both the Station and the Micro-Hubs to load, move and unload the parcels. This is considered as Fixed Time for delivery of the Micro-Hub from the EV Driver and computed as follow:

$$TmH = NB * (TLB + TUB) + \left(\frac{NB}{NBRC}\right) * TRC + TD$$

Where:

- TmH: Fixed time to deliver the parcels for each Micro-Hub.
- NB: number of bikes of a Micro-Hub, equal to the number of bags to be transported.
- TLB: Time to Load a Bag on a roll container (Table 13).
- TUB: Time to Unload a Bag from a roll container (Table 13).
- NBRC: Number of Bags per Roll Container (Table 11).
- TRC: Time to perform a movement with the Roll Container (Table 13).
- TD: Time for Docking the EV in the Micro-Hub (Table 13).

The second input to be compute relates to the VRP of the EV returns, which will spend different time at each Micro-Hub visited to collect the parcels according to the number of parcels picked-up and not successfully delivered by the Cargo-Bicycles working from that Micro-Hub. This is computed as follows:

$$NRP = TNP * \%RF + NPD * FDR$$

Where:

- NRP: Number of return and failed deliveries parcels.
- TNP: Total Number of Parcels belonging to the network.
- %RF: %Reverse Flow.
- NPD: Number of Parcel Delivered from the Micro-Hub.
- FDR: Failed Deliveries rate.

This is then used to both know the total weight and the volume of parcels collected by the EV and the time spent by the vans to perform this task at each Micro-Hub, considered also in this case as the Fixed Time for delivery of the VRP.

$$TRmH = TRC + (TLP + TUP) * NRP + TD$$

Where:

- TRmH: Fixed time for delivery of each Micro-Hub for returns.
- TRC: Time of a Roll Container movement (Table 13).
- TLP: Time Loading Parcel on Roll Container (Table 13).
- TUP: Time unload Parcel from Roll Container (Table 13).
- NRP: Number of Returned Parcels.
- TD: Time for Docking the EV in the Micro-Hub (Table 13).

The network related to Cargo-Bicycles deliveries on ArcGis is shown in Figure 16, in which each green point is a customer, and an example of a single Bicycle route is displayed in light blue.

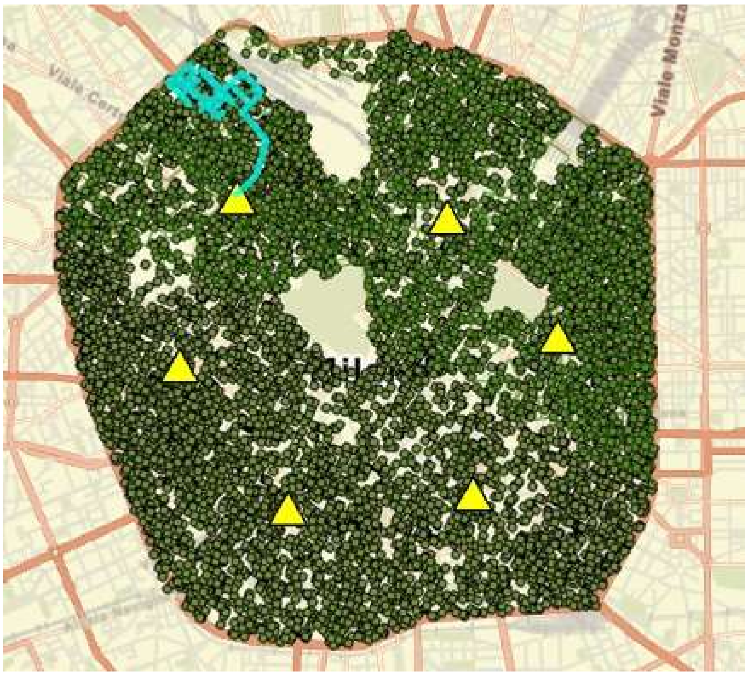


Figure 16 Example of Cargo-Bicycles network with tours

4.2.6.4.2. VRP EVs Fulfilling

The first step is also in this case to define the points to be served, which are in this case the Micro-Hubs that need to be fulfilled with the parcels to be served by Cargo-Bicycles. Therefore, some fictional customers are created on top of them, with fixed time for delivery computed as the TmH in Section 4.2.6.4.1. To these points, moreover, is assigned a Time-Window that ends at 9 am, considering that the Cargo-Bicycles at that point in time should start their tours and therefore the parcels should be already at the Micro-Hubs.

Before serving the Micro-Hubs, each EV, starting from a Parking Location inserted into the map near Milan Ring-Road, must go to the City Center Station to collect the parcels. This step is preliminary to the actual VRP, and a fixed time is considered to collect those parcels.

In order to create the routes, always enough in number, the following information are inserted:

- Starting point → Parking Point.
- Ending point → Parking Point.
- Weight capacity of the EV.
- Volume capacity of the EV.
- Time available of the EV driver.

The VRP is then solved, with the optimization objective of minimizing the time spent for performing all fulfilling activities, while also minimizing the number of vehicles. All the operational outputs illustrated in Section 4.2.6.3 are moved then to Microsoft Excel to be elaborated to obtain the number of EVs used to perform this task and having for each of them the following outputs:

  - Number of Micro-Hubs served.

- Number of parcels transported with their relative volume and weight.
- Total time spent by EV Drivers split into Fixed Time for delivery, Travel Time and Handling time.
- Total distance travelled by the EVs Fulfilling.

In Figure 17 is shown an example of a path covered by one of the EVs Fulfilling, starting from the parking place, collecting the goods at the City Center Station and then serving some of the Micro-Hubs before going back to the same parking spot.

Figure 17 Example of EVs Fulfilling network with tours

It needs to be highlighted that the just presented VRP is solved with a limit in optimality, given by the fact that, when possible, a Micro-Hub is preferably served by as less vehicles as possible, even if splitting more Micro-Hubs to more EVs may be more convenient. However, this is also reasonable in operational terms, since it's smoother to split the demand of a Micro-Hubs in the least EVs possible.

4.2.6.4.3. VRP EVs Returns

All the return and failed deliveries parcels accumulated in the Micro-Hubs from the various tours of Cargo Bikes are transported with one or more electric vans until the Courier Hub, in which they are sorted for the next day, in case of failed deliveries, or they keep their path in case of returns.

In this second EVs-related VRP the points to be served, are still the Micro-Hubs as in the case of the EV Fulfilling, so the same fictional customer logic is adopted, but with different fixed time for delivery which is instead as the TRmH in Section 4.2.6.4.1. Also in this case, a Time-Window is assigned, which is after 6pm, considering that the parcels should be already returned at the Micro-Hubs and therefore Cargo-Bicycles must have closed their tours.

Given that these EVs are needed only during late hours of the day and so are assumed to be dedicated to different tasks before performing this service, they are not assumed to start from any depot but from a point of the map. The only depot is so the Courier Hub where to return the collected parcels.

In order to create the routes, always enough in number, the following information are inserted:

- Starting point → Random point in Milan.
- Ending point → Courier Hub.
- Time spent by the EV driver at the Courier Hub to unload the parcels.
- Weight capacity of the EV.
- Volume capacity of the EV.

The VRP is then solved, with the optimization objective of minimizing the time spent for performing the collection, while also minimizing the number of vehicles, that however is in any cases only one. All the operational outputs illustrated in Section 4.2.6.3 are moved then to Microsoft Excel to be elaborated to obtain for the EV used to perform this task the following outputs:

- Number of Micro-Hubs served.

- Number of parcels transported with their relative volume and weight.
- Total time spent by EV Driver split into Fixed Time for delivery, Travel Time and Handling time.
- Total distance travelled by the EV Returns.

The typical path performed by the EVs Return is shown in Figure 18 in which the blue points inside and outside the City Center are respectively the random starting point and the Courier Hub, while the yellow ones are the Micro-Hubs.

Figure 18 Example of EV Return route

4.2.6.4.4. VRP EVs Deliveries

The starting point are also in this case the points to be served, therefore in this case the customers requiring parcels heavier than 2 kg and customers belonging to the other group but that are directly served by EVs because of the proximity to the higher size deliveries.

As regards the depots included in this VRP, only the Courier Hub is present, which, is directly inputted into ArcGis. Then, it is needed to create the routes, which, again, are created in a high enough number. When setting the routes, the following information are needed:

- Starting point → Courier Hub.
- Ending point → Courier Hub.

- Time spent by the EV driver at the Courier Hub to get ready and load the parcels.
- Time spent by the EV driver at the Courier Hub after the tour to unload the parcels of returns and failed deliveries.
- Weight capacity of the EV.
- Volume capacity of the EV.
- Time available of the EV driver.

Given the three macro-inputs just described, the VRP is ready to be solved, with the optimization objective of minimizing the time spent for performing all deliveries, while also minimizing the number of vehicles. All the operational outputs illustrated in Section 4.2.6.3 are moved then to Microsoft Excel to be elaborated to obtain the number of EVs used to perform this task and, considering all of them are computed the following values:

- Number of customers served.
- Number of parcels delivered, with total weight and volume.
- Total time spent by EV Drivers in Fixed Time for delivery and in Travel Time.
- Total distance travelled by the EVs Deliveries.

In Figure 19 is displayed the network related to EVs Deliveries, with the customers served by them in green and in light blue an example of path performed by one of the EVs is highlighted.

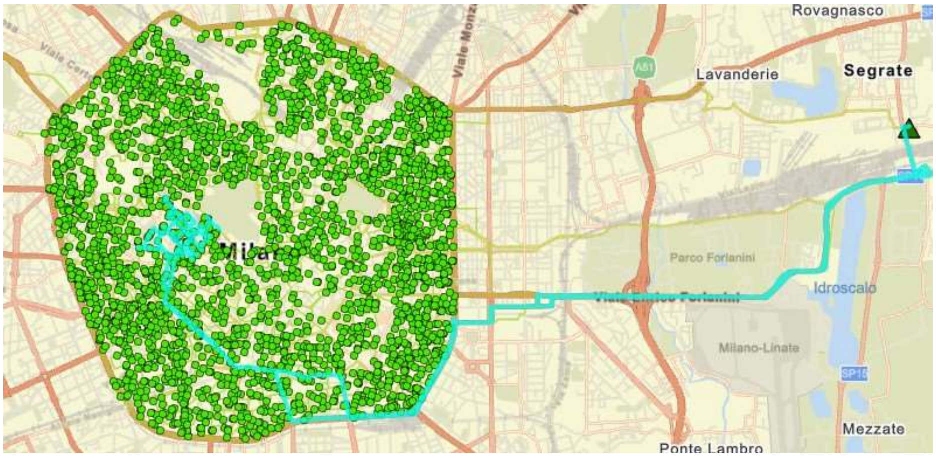


Figure 19 Example of EVs Deliveries network with tours

4.2.6.4.5. Truck

The distance travelled and time spent by the truck driver for the movement of the parcels delivered by the Cargo-Bicycles from Courier Hub to Periphery Station, were computed on ArcGis, with a single Route between the two points, setting as travel mode the specific one of trucks.

To compute the total time spent, it was added to the travel time also the time spent by the driver and by train operator to handle the parcels moved, and therefore to load and unload them respectively at the Courier Hub and at the Peripheral Station.

4.2.6.4.6. Train

For what concerns the train, the only data needed is the distance travelled from the Periphery Station until the Station in the city center, since the Railway Operator performing the transportation service applies that only depends on the weight of the goods moved and distance covered. To extrapolate the distance covered by the train, we took into consideration the line on which the train is imagined going through, with is called "Passante Ferroviario", that is the route used by regional passenger trains crossing Milan city center. The distance covered by the train was computed in ArcGis thanks to a measurement tool directly applied on the map looking at the real path of the railways linking the two Stations as shown in Figure 14.

4.2.6.5. Traditional Network: VRP ICEVs

In the traditional network the vehicles used are only the ICEVs, which perform the last-mile delivery into the Milan Ring-Road starting from the Courier Hub outside the city. One VRP is enough to solve the whole traditional network, almost identical to the one of the EVs Deliveries, with two main operational differences:

- Customers are in this case all customers, with no distinction of weight ranges.
- ICEVs have higher weight capacity, because of a lower weight of the empty vehicle.

The only depot is therefore the Courier Hub and, as for all the already presented VRPs, it is needed before solving to create and set up the routes, which is done with the following considered information:

- Starting point → Courier Hub.
- Ending point → Courier Hub.
- Time spent by the ICEV driver at the Courier Hub to get ready and load the parcels.
- Time spent by the ICEV driver at the Courier Hub after the tour to unload the parcels of returns and failed deliveries.
- Weight capacity of the ICEV.
- Volume capacity of the ICEV.
- Time available of the ICEV driver.

The VRP is then solved with the optimization objective of minimizing the time spent for performing all deliveries, while minimizing also the number of vehicles. Moving the outputs to Microsoft Excel, these are elaborated to obtain the number of ICEVs used for the deliveries and, grouping by all ICEVs, the following values are computed:

- Number of customers served.
- Number of parcels delivered, with total weight and volume.
- Total time spent by ICEVs Drivers in Fixed Time for delivery and in Travel Time.
- Total distance travelled by the ICEVs Deliveries.

In Figure 20 is shown the traditional network on ArcGis, with all customers served as purple points an example of path performed by one of the ICEVs highlighted in light blue.

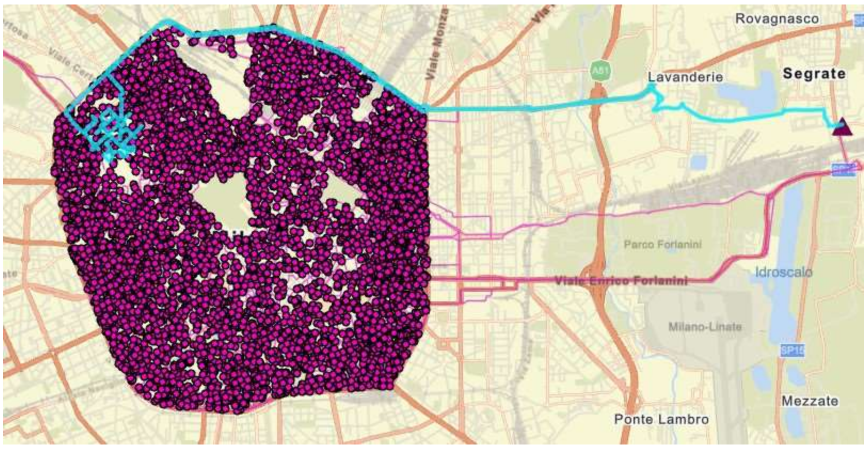


Figure 20 Example of traditional network with tours

4.2.6.6. Emissions and Costs formulas

As described, after the Vehicle Routing Problems of the different groups of vehicles, as well as after the computations related to the train and truck, the following outputs are used to compute the costs and emissions generated:

- Distance travelled by each vehicle.
- Total time spent by each Courier operator of the network for travelling, serving customers and handling parcels.

- Weight of parcels moved by the truck/train.

These three are combined with consumption data relative of each type of vehicle to obtain the environmental impacts and operating costs of both traditional and greener solution.

4.2.6.6.1. Emissions formulas

The calculation of the emissions generated by the different mean of transports can be divided in two groups considering the two different ways in which they are calculated.

The first is related to the truck and the train emissions that are calculated considering not only the distance travelled by these two types of vehicles but also the weight transported during the movements. Indeed, they transport the same weight for the whole path and therefore more accuracy can be achieved considering the data per kg, given that the weight transported has a great impact in the emissions produced.

As regards the truck, the carbon footprint was computed using the following formula:

$$TVF = DTT * TWP * TCF$$

Where:

- TVF: Truck Vehicle Footprint.
- DTT: Distance Travelled by the Truck.
- TWT: Total Weight of the parcels moved on the Truck.
- TCF: Truck Emissions Conversion Factor (Section 4.2.4.2).

Then, the carbon footprint accountable for a parcel delivery relative to the truck movement is derived as follows:

$$TPF = TVF/TNP$$

Where:

- TPF: Truck Parcel Footprint.
- TVF: Truck Vehicle Footprint.
- TNP: Total Number of Parcels belonging to the network.

To estimate the carbon footprint of the train, the following formula was adopted:

$$TnVF = DTTn * TWTn * \%courier * TnCF$$

Where:

- TnVF: Train Vehicle Footprint.
- DTTn: Distance Travelled by the Train.
- TWTn: Total Weight of the train considering the structure of the train as well as the average load of each TEU that composed the train.
- %courier: Allocation Factor based on the train load occupied by the parcels of our network.
- TnCF: Train Emissions Conversion Factor (Section 4.2.4.2).

Also in this case, the carbon footprint related to the train associated to a single parcel is computed as follows:

$$TnPF = TnVF/TNP$$

Where:

- TnPF: Train Parcel Footprint.
- TnVF: Train Vehicle Footprint.
- TNP: Total Number of Parcels belonging to the network.

The other group of vehicles is instead composed by the vehicles for the which a VRP is run, which are also the ones that serve different points and therefore during their path move different weight. For these, which means Cargo-Bicycles, EVs and ICEVs, only the distance travelled is used to compute the environmental impact, given the variable load. In general, to compute the carbon footprint generated by each of the three vehicles the following formula was adopted:

$$VF = DT * VCF$$

Where:

- VF: Vehicle Footprint.
- DT: Distance travelled.
- VCF: Vehicle emission conversion factor (Section 4.2.4.2).

This was applied to each of the vehicles of the group, and therefore Cargo-Bicycles, EVs Deliveries, EVs Fulfilling, EVs Returns and ICEVs. For each the total distance travelled obtained from the simulation models was multiplied by the vehicle-specific conversion factor (Section 4.2.4.2) to obtain the vehicle footprint.

As done for trucks and train, from the carbon footprint of each vehicle, the parcel carbon footprint by parcel and vehicle can be derived as follows:

$$PF = VF/TNP$$

Where:

- PF: Last-mile vehicle Parcel Footprint.
- VF: Last-Mile Vehicle Footprint.
- TNP: Total Number of Parcels belonging to the network.

Finally, summing up the emissions of all vehicles belonging to the studied network, we get the total emissions, which can be obtained for the overall network or by parcel.

4.2.6.6.2. Costs formulas

For each mean of transport, excluding the Train, which is presented at the end of the Section, the daily cost is calculated as follows:

$$TMC = DC + VC$$

Where:

- TMC: Transportation Mean Cost.
- DC: Driver Cost.
- VC: Vehicle Cost.

Then, the cost associable to each parcel delivered it is computed as follows:

$$PC = TMC/TNP$$

Where:

- PC: Cost per Parcel.
- TMC: Transportation Mean Cost.
- TNP: Total Number of Parcels belonging to the network.

The first component of the Operating Cost is the Driver cost, which was computed for each vehicle as follows:

$$DC = DHC * TT$$

Where:

- DC: Driver Cost.
- DHC: Driver Hourly Cost.
- TT: Total time.

This was applied to each of the vehicles, and therefore Cargo-Bicycles, EVs Deliveries, EVs Fulfilling, EVs Returns, ICEVs and Truck. To compute the Total Time, all the operators and specifically Drivers were considered, obtaining their aggregated time to then multiply it by the Driver Hourly Cost.

The second cost typology is instead the Vehicle Cost, related to the usage of the vehicle in terms of distance covered, which is computed for each vehicle as follows:

$$VC = FC * DT \ + VR * \mathrm{TT}$$

Where:

- VC: Vehicle Cost.
- FC: Fuel cost per km.
- DT: Distance Travelled.
- VR: Vehicle Rent.
- TT: Total Time.

With fuel consumption and distance travelled the cost related to Feeding is computed, and to this the daily cost related to the Vehicle Rent is added to get the full Vehicle Cost.

As regards the fuel cost computation, in case of the Truck, we also considered the weight of the goods moved, since this influences the overall fuel consumption. The Truck Vehicle Cost was therefore computed with the following specific formula:

$$VC_{Truck} = TFC * FC * TLF \ + \ TVR$$

Where:

- TFC: Truck Fuel Consumption.
- FC: Fuel Cost.
- TLF: Truck Loading Factor, specific of each case analysed.
- TVR: Truck Vehicle Rent.

In case of vehicles with variable weight moved, which means EVs, Cargo Bicycles and ICEVs, instead, an average fuel consumption in l/km was used.

In addition to the just presented costs, when evaluating ICEVs costs, it is taken into account also a daily toll cost that the courier must pay for each diesel van that enters the City of Milan as described in Section 4.2.4.1.

$$TDC_{ICEV} = OC_{ICEV} + TF$$

Where:

- TDC_{ICEV}: Total Daily Cost ICEV
- OC_{ICEV}: Operating Cost ICEV.
- TF: Toll Fee.

Finally, the cost related to train transportation from the Peripheral Station to the City Center Station is computed in a different way respect to the other described in this Section. Indeed, the transportation by train is performed by a third company and not by the courier and therefore paid through a fare applied, considering the weight of goods moved and km performed. The cost of the train is therefore computed as follows:

$$TnC = DTTn * TnLF * TnF$$

Where:

- TnC: Train Cost.
- DTTn: Distance Travelled by the Train.
- TnLF: Train Loading factor, that is the weight of the parcels of the courier analysed loaded in the train in the different cases.
- TnF: Train Fare

5 Results

In the previous Chapter the Model Development was presented, with detailed overview of the network and the methodology of the analysis. First, the two different processes were presented, traditional and innovative, specifying all the vehicles, infrastructures and activities considered. Data used for the model and the computations were divided into input, context and consumption and presented, and the same for the output data, divided into the ones coming out from the model and the final ones which the first processed with the consumption data. Consequently, the simulation development was step by step described, including some data processing phases performed between different simulation ones. Finally, the computations of final costs and emissions for each vehicle and network were detailed.

In this Chapter, the results obtained are presented and analyzed, and therefore the performances of the designed network evaluated. Indeed, main goal of our study is to evaluate costs and emissions generated in the to-be network and to compare them with the ones generated in the traditional one. Consequently, in this Chapter we answer to the second research question, that means if the designed innovative network can generate savings in term of emissions and costs with respect to the traditional network.

The first analysis is done taking into consideration a Base Case, which is the case described during the previous chapter when talking about the network.

After the Base Case comparison, the impact, on costs and emissions generated, of variability in some of the inputs is evaluated in the Input Sensitivity Analysis presented in Section 5.2. Details on the different Inputs for which different values or decisions were evaluated are presented in Section 5.1.1.

5.1. Base Case results

The Base Case takes into consideration the parcels related to e-commerce deliveries performed by a courier in the area inside Milan Ring Road during a working day. A consolidation in a specific infrastructure outside the city called Courier Hub is assumed to be priorly performed and from there the parcels start their paths. In the traditional process these are directly delivered by ICEVs while in the innovative one the deliveries are split between Cargo-Bicycles and EVs, assuming a threshold of 2kg for the weight of parcels deliverable with the first ones. Some Cargo-Bicycle customers were then migrated to the EVs ones because of a proximity rule. At the end other EVs collect the returned parcels left at Micro-Hubs by the Cargo-Bicycles and bring them back to the Courier Hub.

In the first of the following Sections an analysis on fixed time for delivery and proximity value is developed to understand the goodness of two parameters fixed in the base case scenario. Then, the results related to base case in the to-be and the traditional network are presented, firstly in terms of model outputs, which means operational figures, and then in terms of costs and emissions generated. Then, the results of the two networks are compared, evaluating benefits or trade-offs of the solution proposed.

5.1.1. Analysis on fixed time for delivery and proximity value

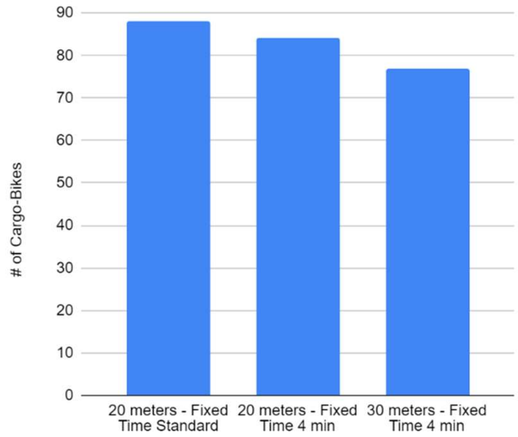
As written in Chapter 4, once the customers eligible for Cargo-Bicycles deliveries, which means the ones with parcel weight lower than 2kg, are inserted into the simulation model, some of them are moved to the group of customers served by EVs according to a proximity parameter. Then, the same proximity measure is used for both groups of customers to aggregate the customers near each other in the same delivery given that, if customers are that close, the Drivers will park only once and perform more deliveries for just one stop and as a consequence they will spend less time to do it. The parameters chosen for the Base Case are 20 meters as proximity factor and 4 minutes as fixed time of delivery for customers served in same stop. These are analyzed in this Section comparing the base case with two alternative scenarios, one in which no fixed time for delivery reduction for close customers is considered, and the other one in which the proximity factor is 30 meters instead of 20.

To perform this sensitivity analysis, the Operational Results coming from the simulation model as well as the emissions and costs considered are the ones last-mile delivery vehicles only, which means Cargo-Bikes and EVs, given that for Truck and Train the results wouldn’t change.

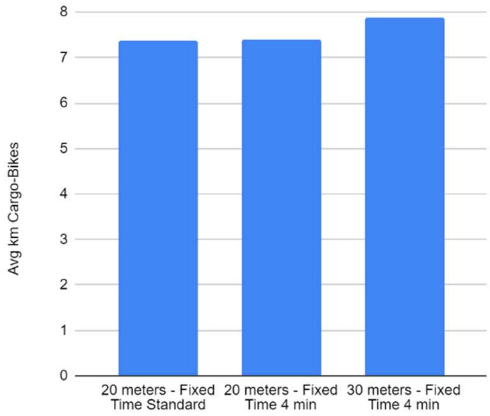
Regarding the Operational Results on Cargo-Bikes, Graphs 15, 16 and 17 show the difference between base case, with 20 meters and delivery time of 4 minutes for close customers, and the other two above-mentioned cases.

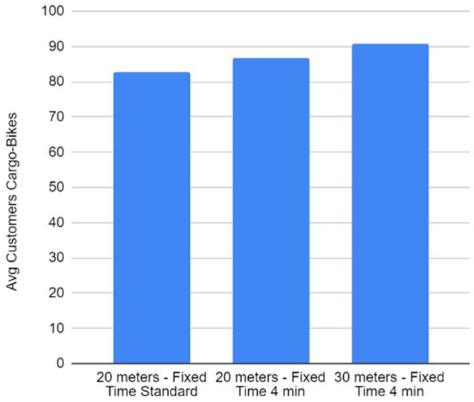
In case of no fixed time differentiation, the number of Cargo-Bikes increases a bit, from 84 to 88, while it decreases more significantly in case of 30 meters of proximity factor with respect to the Base Case from 84 to 77.

The customers served by each Cargo-Bicycles slightly decreases in case with no fixed time differentiation from almost 87 to 83, while it increases from 87 to 91 in case with 30 meters of proximity factor. Finally, the average kilometers driven by each Cargo-Bike are almost the same in case of standard fixed time, but they increase of 5% in case of 30 meters proximity factor, because of the higher number of customers served by each Cargo-Bicycles.



Graph 15 Number of Cargo-Bikes

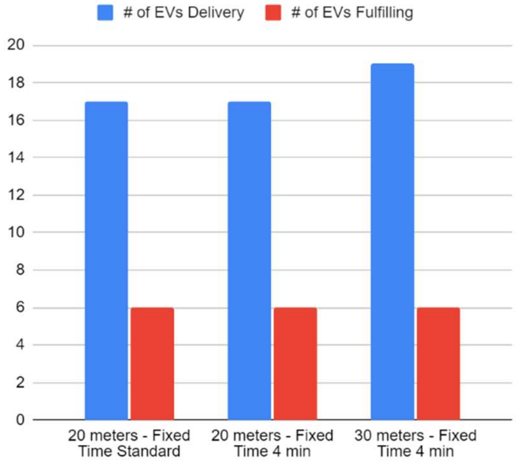




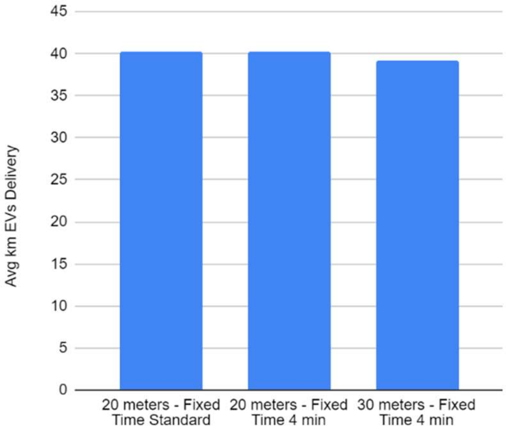
Graph 16 Average Km Cargo-Bikes

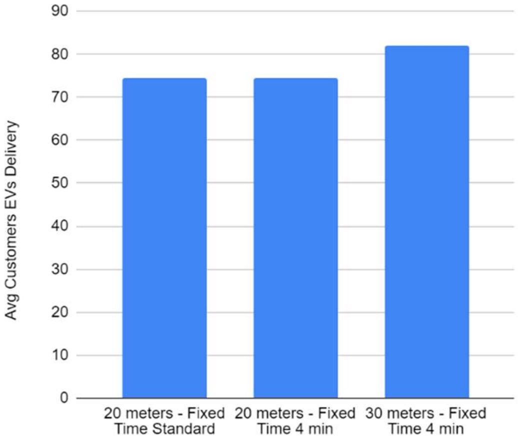
Graph 17 Average Customers Cargo-Bikes

Operational Results on EVs are instead displayed in Graphs 18,19 and 20, showing how the number of EVs Deliveries and EVs Fulfilling changes in the different cases, but also the number of average customers served by EVs Deliveries, and the average number of kilometers covered by these.



Graph 20 Number of EVs



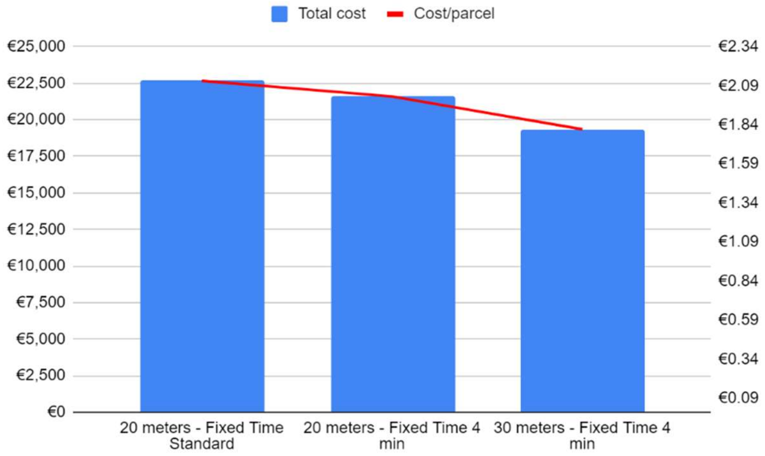


Graph 19 Average Km EVs Delivery

Graph 18 Average Customers EVs Delivery

What is clear is that there are no differences between Base Case and the Case with no fixed time differentiation, while there are differences between Base Case and scenario with 30 meters as proximity factor. Indeed, two more EVs for Deliveries are used and also the customers served by each EV is a little bit higher and average km driven by each of them is a little bit lower. While the increase in customers served is given by the benefits in delivery times, because more customers will have lower fixed time, the reason of the higher number of EVs is that more customers from the group served by Cargo-Bicycles will migrate to the group of the EVs because of the higher proximity factor. This however also increases the proximity of customers served by EVs and therefore the kilometers travelled by each decrease of around 2.5% even if the average number customers served increase of almost 10%. The number of EVs used for fulfilling, instead, remains the same.

In Graph 21, impact on costs is analyzed, presenting both total cost and cost per parcel in the three scenarios.

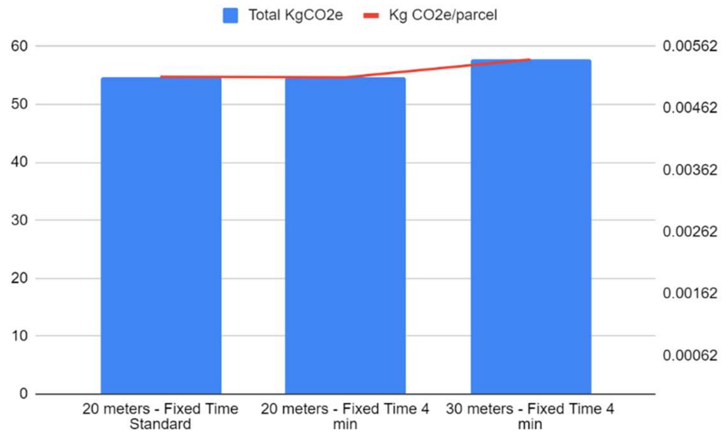


Graph 21 Total cost and cost per parcel

In the solution with the equal fixed time for all customers, the cost is higher respect to the Base Case given that there is not any exploitation of grouped deliveries to customers close each other, which brings to higher total times. Instead, changing the factor of proximity from 20 meters to 30 meters, the cost per parcel 2.02 € per parcel to 1.81€. This is because of the higher benefits of a lower fixed time of delivery more than in base case given that more customers are considered near each other.

The results on emissions generated are instead presented in Graph 22.

It is clear how there are almost no differences between Base Case and the scenario with no differences in fixed time of deliveries between customers, instead the emissions generated by case with 30 meters of proximity factor are higher of almost 6%. The reason is that, even though the number delivery vehicles used overall is lower, there are two more EVs, which have an emission conversion factor that is far higher than the one of Cargo-Bicycles.



Graph 22 Total KgCO2e and KgCO2e per parcel

To sum-up, some difference between the scenarios analyzed with different choices on proximity factor and fixed delivery time to assign to close customers were identified. However, these are not hugely influencing the results and also the Base case proved to be a balanced case, in which considering 4 minutes of fixed time for close customers is something that makes sense, but at the same time considering 20 meters and not 30 meters allows to avoid giving a too much optimistic evaluation.

5.1.2. To-be process

As already described, the first output obtained are the results of the simulation model, which can be defined as Operational Results. Indeed, the results obtained and presented in this Section are related to the number of vehicles by each transportation mean type and task, time spent by operators, distances covered, and deliveries performed.

In the To-be process, there are different vehicles, each with some peculiar characteristics, specifically:

- Truck
- Train
- EVs Deliveries

- EVs Micro-Hubs
- Cargo-Bicycles
- EVs Return

Results related to each transportation mean, are presented below, at both aggregate and average level when applicable.

Regarding the Truck and Train tasks, the results coming from the model are presented in Table 18, specifically showing Total kilometers driven by each vehicle and the Total Time spent by Truck Driver to complete its tasks, which means transporting the parcels from the Courier Hub to the Peripheral Station, including also the time needed to load and unload the goods on the vehicle.

	Total Time	Total km
Truck	1.53	1.28
Train	-	13

Table 18 Operational results Truck and Train

Even though the Truck drives only 1.28 km to transport the parcels delivered by Cargo Bikes, the time spent to perform this activity is high in comparison. This is because most of the time is needed to handle the high volume of parcels in the Courier Hub and Peripheral Station much more than driving. Regarding the Train, only the kilometers travelled to transport the parcels from Peripheral Station to Garibaldi are considered, being this activity managed by a Railway operator and therefore not relevant in terms of costs and emissions for the Courier side.

Looking at the vehicles moving within the City Center to deliver the parcels to customers as well as to move or collect parcels to and from the Micro-Hubs, interesting consideration can be deducted. The following Tables (19, 20 and 21) sum up the most useful operational outputs of the different vehicles.

In Table 19 are presented the results of EVs deliveries to customers that ordered heavier parcels and the ones in proximity of them with lighter ones.

EVs Delivery					
# of vehicles	**Total time**	**Total km**	**Avg Customers**	**Avg Time**	**Avg Km**
17	129.79	684.20	74.47	7.63	40.25

Table 19 Operational results EVs Delivery

Specifically, 17 Electric Vans are needed to perform this activity, each of them serves on average 75 customers exploiting the entire daily time capacity limited to the 8h, instead of the vehicle capacity, which is saturated only at the 37.7 %. The time spent by the EVs to deliver the parcels is composed mainly from the Fixed Time for delivery needed to perform the delivery at customers' locations, indeed it represents the 74.5% of the Total Time. The average route distance for each EV is 40.25 kilometers, which means half of the kilometers that were usually considered in the papers we analyzed, and in particular in R. Mangiaracina et al. (2020). The reason of this is based on the delivery density due to which customers stops are very close each other and therefore each van can serve a quite high number of customers with a quite low number of kilometers travelled. It is also worth to say that, out of the Avg km travelled by one of these EVs, slightly less than half of them regard the distance covered to reach the served area from the Courier Hub and to go back to it after serving all the assigned customers.

The other type of activity performed by EVs is the fulfilling of Micro-Hubs, whose operational results are shown in Table 20.

EVs Fulfilling					
# of vehicles	**Total time**	**Total km**	**Avg Micro-Hubs**	**Avg Time**	**Avg Km**
6	10.58	84.74	1.17	1.76	14.12

Table 20 Operational results EVs Fulfilling

A total of 6 EVs Fulfilling are used even though each of them spent less than 2 hours to perform this activity, so they spent more or less only 22% of their available time to transport the parcels from Garibaldi Station to Micro-Hubs. Differently from the EVs Deliveries, then, in this case what is saturated is the vehicle capacity and not the time capacity of the driver. Indeed, each Micro-Hub requires a high number of parcels, given the number of customers served by all Cargo Bicycles delivering from each. On average, each EV doesn’t serve only one Micro-Hub and the reason is that there is Micro-Hub for which the parcels to be moved there exceed the capacity of the EV, and therefore it needs to be served by two EVs instead of only one.

In Table 21 are instead presented the main operating outputs on Cargo Bicycles coming from the simulation model. A significant number of Cargo-Bicycles, specifically 84, are used in the solution which was quite expected given the high number of customers served by this type of vehicle, that is 7276.

Cargo-Bicycles					
# of vehicles	**Total time**	**Total km**	**Avg Customers**	**Avg Time**	**Avg Km**
84	655.45	621.70	86.62	7.80	7.40

Table 21 Operational results Cargo-Bicycles

These are distributed over an area of less than 26 square km, which brings to a huge customer density. This is consequence of both the population density and the relevant ecommerce adoption in the city of Milan and specifically inside the Ring-Road. Customers are then very close each other, and the number of them that a Cargo-Bicycle serves on average is quite high, 86.62, higher than the number of customers served considered for last-mile deliveries tours in in literature, such as 80 in R. Mangiaracina et al. (2020). The huge customer density has a double effect in this, because both customers are close, so distances are low, but also since distances are low Cargo-Bicycles disadvantage of the lower speed is less effective. The other avoided issue is the lower weight capacity of Cargo-Bicycles compared to vans, because the number of parcels related to a tour does not saturate none of the vehicles in weight capacity, but in time available of the shift.

As regards the kilometers covered, on average a Cargo-Bicycle drives only for 7.40 kilometers per day, which is around the half of an EV Deliveries. The reasons of this are the time spent in serving customers (91% of total time) and the higher proximity of points served by Cargo-Bicycles respect to the EVs ones, being the flow assigned to the two transportation means not comparable. Also in this case, given the nature of last-mile deliveries tours in such a dense network, the low distance travelled reduces the effects of the lower speed. Also, the Micro-Hubs are already located inside the delivery area, while the EVs departure from outside, even if close by.

Table 22 displays the outputs of the last vehicle, the EV Returns, which collects the parcels left at the Micro-Hubs at the end of the tour by the Cargo-Bicycle drivers and brings them back to the Courier Hub. The high amount of time needed to perform this kind of activity is due to the time spent to collect the parcels in each Micro-Hub as well as the time spent to unload the parcels in the Courier Hub, respectively they are the 46.7% and 38.5% of total time.

EV Return	
Total time	**Total km**
5.55	24.45

Table 22 Operational results EV Return

Once obtained all the operational results we then computed the performances on the impacts under analysis, which means cost faced and emissions generated.

As regards the costs, as explained in Chapter 3 and 4 for all vehicles apart the train, the costs are computed as sum of the Driver Cost, based on total working time related to vehicles and hourly costs, and Vehicle Cost, composed of fuel cost, a cost per km times distance travelled, and the cost of vehicle rental. For the train instead, it was considered a cost derived from a fare that the railway operator providing the external service would apply based on distance travelled and weight moved.

Results related to costs attributable to each transportation mean, are presented below in Table 23, showing both the inputs of the computations, which means total distance, time and weight moved, and the outputs, as total cost, and as cost per parcel in the network.

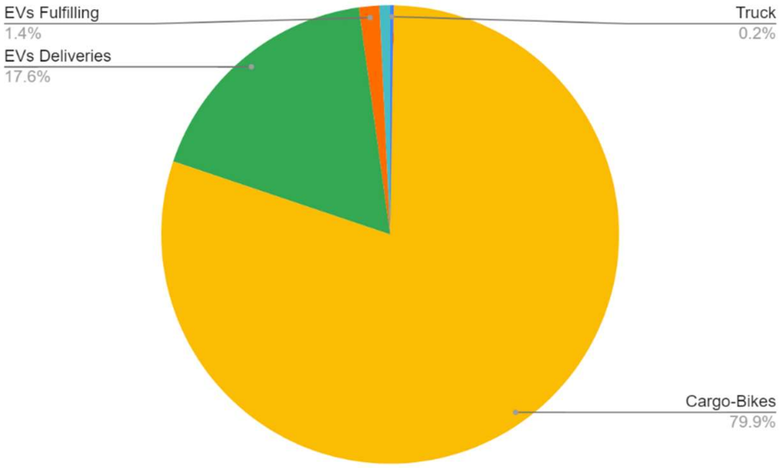
	Tot time	Tot km	Tot weight	Tot cost	Cost/parcel
Truck	1.53	1.28	5494	€ 52,33	€ 0.0049
Train	-	13.00	5494	€ 4.16	€ 0.0004
EVs Deliveries	129.79	684.20	7443	€ 3,807.14	€ 0.3566
EVs Micro-Hubs	10.58	84.74	5494	€ 311.56	€ 0.0292
Cargo-Bicycles	655.45	621.70	5494	€ 17,251.70	€ 1.6157
EV Returns	5.55	24.45	446	€ 162.72	€ 0.0152

Table 23 Total cost and cost per parcel Base Case

In order to compare the different vehicles, it's interesting to compute and analyze also how much of the cost is composed by Vehicle Cost, composed of fuel/electricity and rental, different among the vehicles, considering that the rest is Driver Cost, in which the hourly factor is undifferentiated for all vehicles. Specifically, the Vehicle Cost weight increases as the dimension of the Vehicles increase, as expected because of increasing rental cost and consumption, and it's only 5% for Cargo-Bicycles, 15% for all EVs, Deliveries, Micro-Hubs and Returns, and 27% for the Truck.

Considering that in case of walkers delivering it would be 0%, the 5% of the Cargo-Bicycles, one third of the EVs values, is a very good result.

The weight of each transportation mean in the overall cost of the network, and per parcel, is displayed in Graph 23.



Graph 23 Weight of each transportation mean in the overall cost of solution

As said, Cargo-Bicycles are the main vehicle that affects the overall cost, generating the 79.9% of it. The EVs used for deliveries are the second in total cost, with 17.6% of costs originated by it. Looking at the remaining vehicles, the only one category that has an incidence on costs higher than 1% is the one regarding the EVs Fulfilling with 1.4%, while all the others are minimal: the EV Returns accounts for the 0.75% of the total cost while the Truck and the Train respectively for the 0.24% and 0.02%.

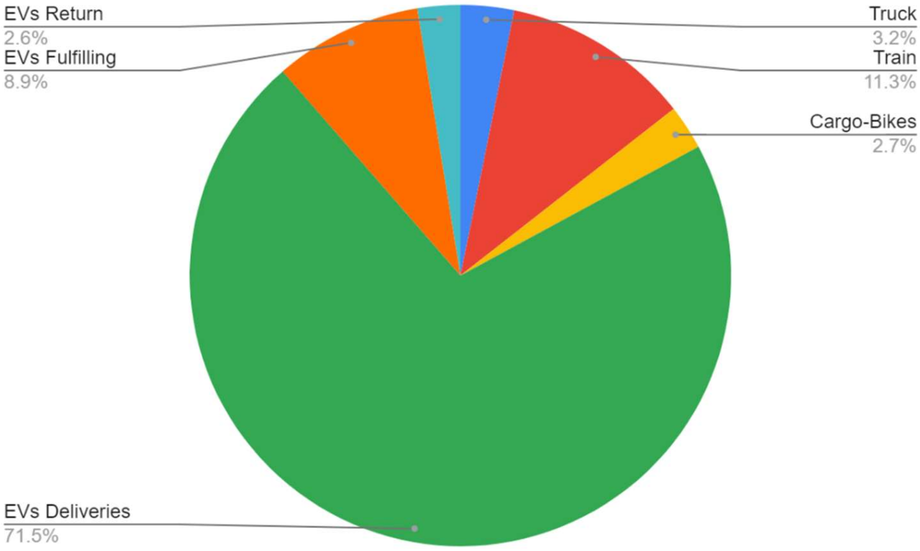
Moving to emissions, the total distance covered by each vehicle, with the only addition of the weight moved for the truck and train, was sufficient to compute the footprint of each vehicle and the network. The emission factor is indeed reduced to gCO2e/km for EVs, Cargo-Bicycles and ICEVs, and gCO2/(ton*km) for Truck and Train. Computations related to the conversion factors have been presented in Section 4.2.4.2.

Results related to each transportation mean, are presented below in Table 24, showing for each the inputs of the computation, the total distance and the weight moved, and the outputs, as both total emissions and emissions per parcel in the network.

The contribution of each transportation mean to the total emissions generated in the network, and per parcel, is instead displayed in Graph 24.

	Tot km	Tot weight	Tot KgCO2e	KgCO2e/parcel
Truck	1.28	5493.99	1.74	0.00016
Train	13.00	5493.99	6.16	0.00058
EVs Delivery	684.20	7443.27	39.11	0.00366
EVs Micro-Hubs	84.74	5493.99	4.84	0.00045
Cargo-Bikes	621.70	5493.99	1.46	0.00014
EV return	24.45	446.42	1.40	0.00013

Table 24 Total emissions and emissions per parcel Base Case



Graph 24 Weight of each transportation mean in the overall emissions of solution

It is evident that the most impacting vehicles are the EVs performing the deliveries, cause of the 71.5% of the emissions generated by the solution studied. Among the EVs, these are the most polluting ones because of two reasons: the higher number of vehicles for this task and the higher distance travelled by each. The second and the third means of transport in term of incidence in the generation of emissions by the innovative solution are the Train and the EVs Fulfilling. The Train has a significant role in emissions generated (11.3%), even though it travels for few kilometers, however, the overall emissions are still very low, we are indeed comparing it with EVs and Cargo-Bicycles. The EVs Fulfilling instead represents the 8.9% while all the other vehicle types account for around the 3% each. Cargo-Bicycles role needs to be highlighted, because even if they are second highest number in term of total kilometers driven, only generate the 3% of the emissions.

5.1.3. Traditional process

As regards the traditional process, the results are much simpler to present, given the presence of one transportation mean only, the ICEVs, which performs all the deliveries and pick-ups, starting from the Courier Hub and going back there at the end of their tour.

The operational outputs from the simulation model are displayed in Table 25.

The total number of ICEVs needed to perform the last-mile delivery is 106, serving an average of 80.6 customers each, in conformity with the 80 observed in R. Mangiaracina et al. (2020). However, differently from this paper, the average number of kilometers travelled by the ICEV is only 30.7 km instead of 80 km, which is given by the high density of points to serve.

ICEV					
# of ICEVs	**Tot Time**	**Tot Km**	**Avg #Customers**	**Avg time**	**Avg km**
106	834	3248.87	80.6	7.92	30.65

Table 25 Operational results ICEV

As in case of EVs for deliveries in the greener solution, the ICEVs are saturated in term of time, with the time spent to physically served the customers that represents the 82.4% of the total time, only the 6.2% of the weight capacity is occupied by the parcels.

Using costs parameters and emissions factors presented in Section 4.2.4.2 the costs and emissions were then computed.

Focusing on costs, also in this case the cost is composed by the Driver Cost and the Vehicle Cost, split into cost of fuel and cost for rental, and adding at the end a fixed road toll. The same similarity with the To-be process is present in the computation of the emissions generated. which are based only on the distance covered and a conversion factor in gCO2e/km.

In Table 26 all the outputs regarding the traditional network in terms of costs produced, daily and per parcel, and emissions generated, daily and per parcel. In next section, the results coming from the two processes are compared to understand the possible savings of the greener solution compared to the traditional one.

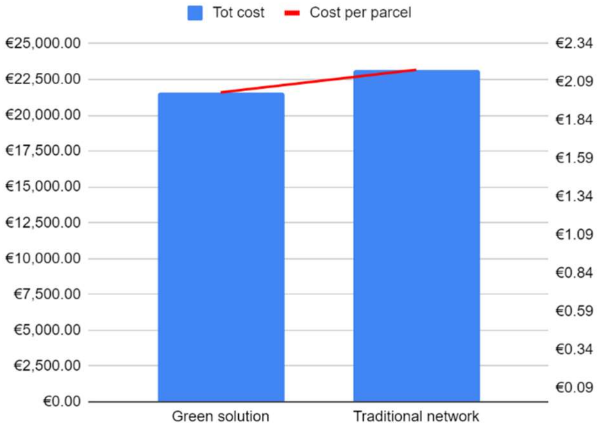
ICEV			
Tot cost	**Cost/parcel**	**Tot KgCO2e**	**KgCO2e/parcel**
23,145.93	2.17	998.94	0.09356

Table 26 Final results ICEV

5.1.4. Comparison

In the two Sections above, the innovative and the traditional processes were both presented in terms of operational output and impact performances. The aim of this Section is to compare the results of both, specifically considering the emissions generated and the costs faced by the company for performing the service during one working day, which is the timeframe considered in the simulation model. These figures, both costs and emissions, are considered at aggregate level. which means the whole network, and at parcel level, which allows to compare also among scenarios with different demand. Results on costs generated are presented in Graph 25, both at aggregate and parcel level.

The cost of the to-be process is lower compared to the cost of the traditional one, more precisely the saving obtained with it is 6.7%. This result comes from the exploitation of Cargo-Bikes in the greener solution, because of their lower costs compared to other mean of transports. Indeed, most customers are served by Cargo-Bikes while only few by EVs, that instead have the highest renting cost, usually not offset by reduction in consumption. Cargo-Bicycles instead are the cheaper vehicle to rent and the least consuming, and therefore the higher cost of EVs is offset at aggregate level and also savings are obtained.



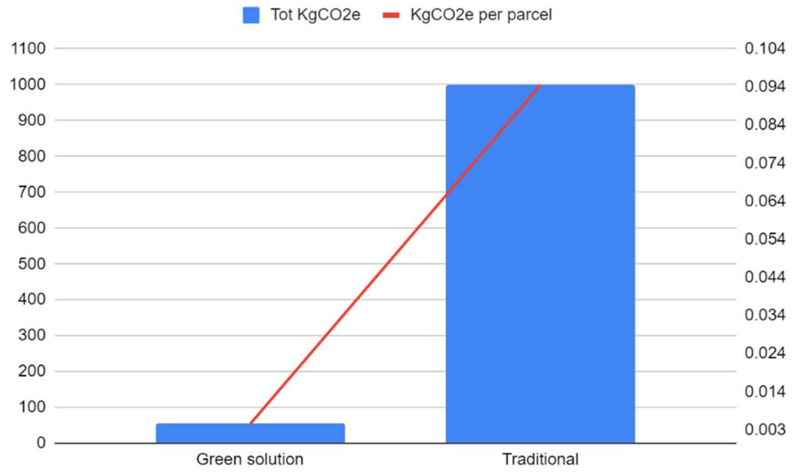
Graph 25 Comparison of costs, To-be vs traditional process

As already said in Chapter 3, costs related to infrastructures were not taken into account, neither investment nor maintenance in any of the hubs. While the maintenance is negligible, the investment one is not differential for the Courier Hub and is assumed to be faced by Municipality of Milan for the Micro-Hubs. in charge to provide these hubs to the courier as also usually done in similar cases with Cargo-Bicycles deliveries.

The main savings were instead expected on the environmental impact of the two solutions, since the usage of electric vehicles out of which many are Cargo-Bicycles instead of ICEVs is disruptive in terms of emissions generated.

Results related to emissions generated for serving customers in the two networks are represented in Graph 26, total values and per parcel.

The savings obtained in terms of emissions generated are huge and precisely correspond to the 94.5% of the gCO2e generated for performing the exact same service with traditionally fueled vans only.



Graph 26 Comparison of emissions, To-be vs traditional process

5.2. Input sensitivity analysis

In this Section are presented the results of the Sensitivity Analysis performed on some of the inputs to the model, in order to evaluate how differently the network would perform and how the comparison with the traditional network changes. Specifically, the sensitivity analyses performed are related to:

- Adoption rate of the innovative network.
- Cargo-Bicycle weight range.
- Number of Micro-Hubs.
- e-Commerce Volumes.

For each analysis performed, all the differences with the Base Case will be presented, at operational level first and then the monetary and environmental impacts. Beside comparing each result to the base case, it is object of the results presentation to show also how differently each scenario of the sensitivity analyses diverges from the traditional network, in terms of % of deviation on costs faced and emissions generated, divided by the parcels of each network so to get a comparable measure for all cases.

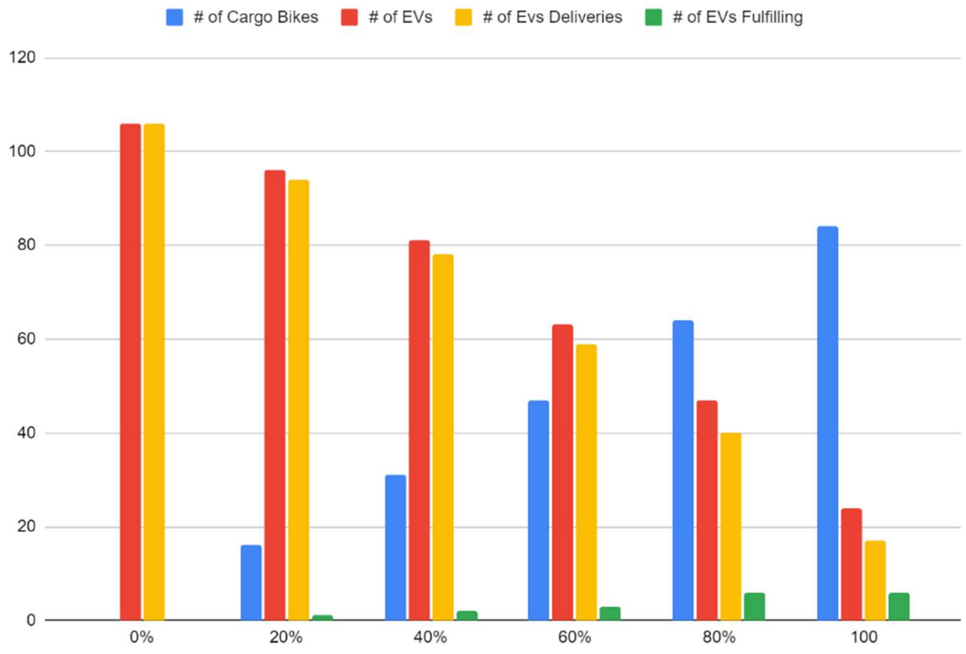
It needs to be pointed out that in some cases, due to the changes performed to the scenario, some of the Context Data presented in Section 4.2.3 are adapted in different scenarios than the Base Case, specifically data related to Parcels and Equipment presented in Section 4.2.3.1. Modifying the assignment of customers to Cargo-Bicycles and to EVs Deliveries, which happens in the Sensitivity Analyses about the Adoption rate and the Cargo-Bicycle weight range, the average weight and volume of the parcels in bags, both Cargo-Bicycles bags and EVs Deliveries ones, change. With a different dimension of the parcels, and therefore of the bags, also the number of these transportable in a single movement of Roll Container is adapted, considering the capacity values of this last one presented in Section 4.2.3.1. These changes, considered for consistency of the model, don't bring anyway any significant change in the performances obtained.

5.2.1. Adoption (0-100%) with 100% = base case

The first Sensitivity analysis concerns different adoption rates that may be used in the first stages of the implementation of the network. Considering the significant volume managed by the Courier each day inside the city center of Milan, we decided to analyze what would be the benefits obtained with a partial adoption of the Cargo-Bicycles for last-mile deliveries. This is considered applying a percentage factor called adoption rate to the total amount of good eligible for Bicycles deliveries, which means the parcels within the range 0-2kg. The different partial adoption rates considered are: 20%, 40%, 60%, 80%. To these are added to the comparison two additional cases, the 100%, which is the Base Case and a 0% which is Deliveries with Vans only. All scenarios were then considered with both EVs or ICEVs as vans for Deliveries, Fulfilling the Micro-Hubs, and collect the Returns, given EVs may be or not already in use by the company.

While the number of vehicles and operational results vary as the adoption rates changes, for the Vans for Returns the only different results is the time spent by the operator since the number of parcels handled, and therefore the time needed to do it, changes while the distance travelled are the same. For the Truck and the Train, instead what changes is the volume moved, and therefore the emissions generated for both and the cost also for the train, but not the distance travelled. Following, the operating results coming out from the simulation model are presented considering the solution with EVs as vans at first, and presenting the differences obtained with ICEVs afterwards.

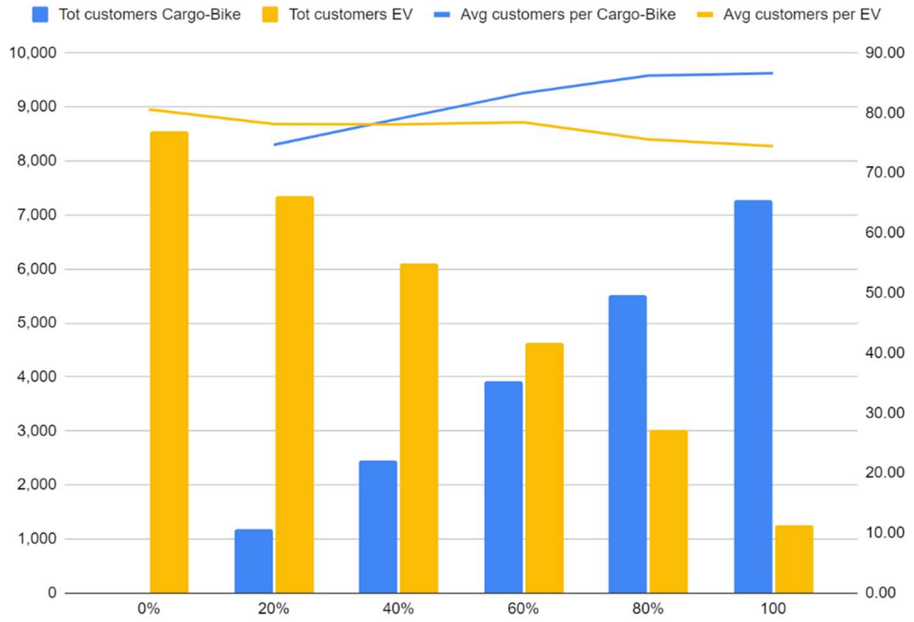
First of all, in Graph 27 are shown the differences in number of vehicles, considering Cargo-Bikes, and for EVs both the total the split in EVs Deliveries and EVs Fulfilling.



Graph 27 Adoption sensitivity - Number of vehicles per type

As the percentage of adoption of the proposed solution increases, the number of bikes exploited in the greener network increases in a linear way, from 0 bikes used in the solution whit only EVs to 84 in 100% adoption case, while the total number of EVs used in the solution decreases, from 106 EVs in case of EVs Deliveries only, to 24 in case all 0-2Kg parcels can be transported with Cargo Bikes. Looking at the breakdown of total number of EVs, the ones performing the deliveries decreases linearly following the curve of total number of EVs, while the one charged of transporting the parcels to Micro-Hubs increases from 0 if Cargo-Bikes are not used to 6 in 100% adoption case. More precisely, the number of EVs needed to fulfill the Micro-Hubs grows by one unit from 20% to 40% of adoption of Cargo-Bikes and the same happens with the transition from 40% to 60%, while in case of 80% and 100% of adoption the number of EVs needed for this task is stable at 6. This happens because one Micro-Hub is served by only one EV if it is possible, that means if the quantity of goods to be moved to that Micro-Hub is fits the EV capacity.

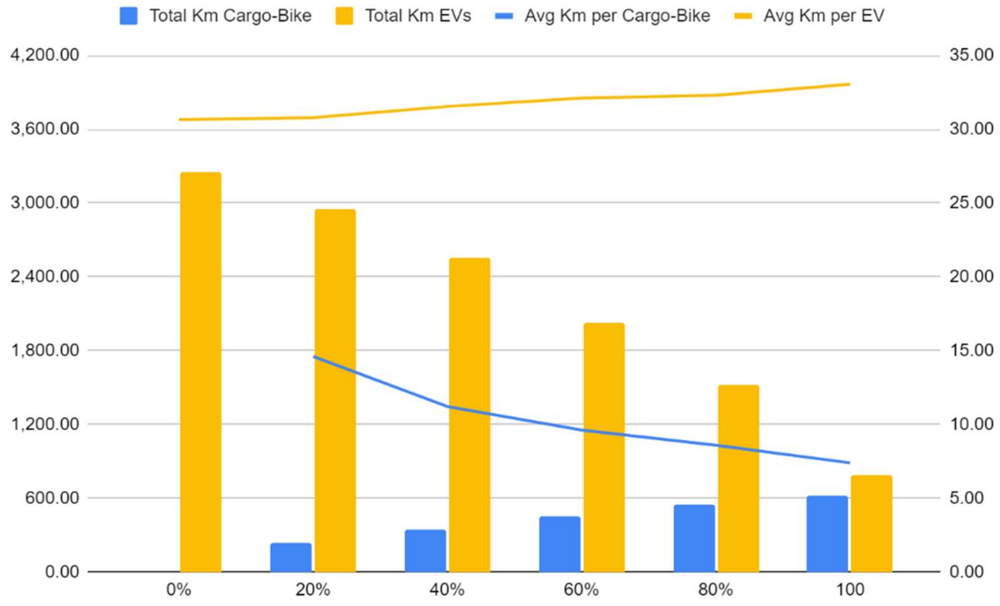
Going on, Graph 28 how the number of customers, both total and per vehicle, served by respectively Cargo-Bicycles and EVs changes according to the adoption rate.



Graph 28 Adoption sensitivity - Cargo-Bicycles and EVs, total and average customers

The total number of customers served by Cargo-Bikes as percentages of Adoption increases from 1195 customers in case of 20% of adoption to 7276 in case of 100% of Adoption. The growth of the total number of customers decreases while the percentage of adoption increases, from a growth of 105% in number of customers served by Cargo-Bikes going from 20% to 40% of adoption, to 32% going from 80% to 100%. The same thing happens to the total number of customers served by EVs but in opposite way, going from 8542 customers served in case with no usage of Cargo-Bikes to 1266 customers with 100% of Cargo-Bikes adoption, decreasing by 575%. Looking at the number of customers served by each Cargo-Bike in the different cases, it grows following a logarithmic trend, while in case of number of customers served by each EV, it's decreasing with a variable slope as the adoption of bikes increases.

Graph 29 shows the effect of Cargo-Bike adoption on the kilometers travelled by Cargo-Bikes and EVs looking at both total value and average per vehicle.

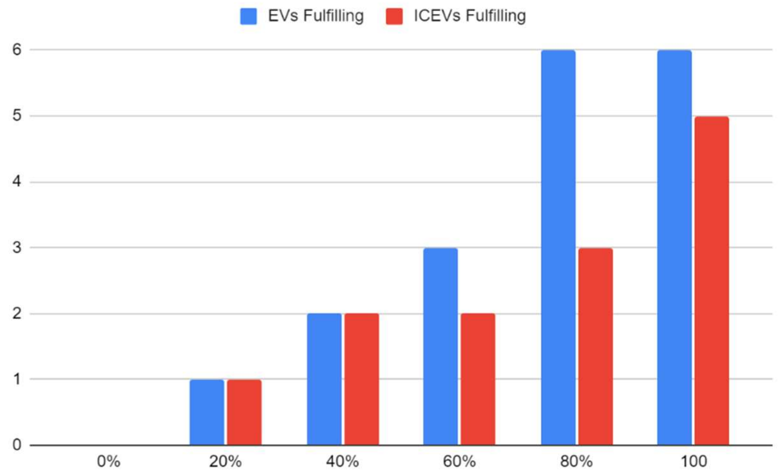


Graph 29 Adoption sensitivity - Cargo-Bicycles and EVs, total and average km

The total number of kilometers driven by Cargo Bikes increases from 20% to 100% of adoption going from 233.78 Km to 621.70 Km, for the EVs, looking at aggregate value of all types of them, the number of kilometers it decreases much faster than how Cargo-Bicycles total km increases, goes from 3248.87 with EVs only Km to 793.38 Km with 100% of adoption. The difference in the slopes of the curves comes from the number of kilometers travelled by each Cargo-Bike that is very low compared to the ones driven by each EV for the already described reasons. Looking at the kilometers covered by each vehicle, for both EVs and Cargo-Bikes the trends are inverted with respect to the curves of total kilometers, while the adoption increase the total km of bikes increases and the average decreases, while for EVs the total decreases and the average increases. The number of kilometers travelled by each van increases marginally from 0% to 100% of adoption, while in case of Cargo-Bikes the number of kilometers driven by each vehicle is halved thanks to the number and proximity of the customers served as the adoption increases.

In this sensitivity analysis it's supposed having lower percentages of adoption before having the complete innovative solution with all the parcels 0-2Kg that can be potentially delivered by Cargo-Bikes. In this context, it is realistic to imagine that there can be the possibility to not have the availability of a fleet of EVs to perform all different activities that the greener network required. In the next Graphs, the difference on the operative results by the usage of ICEVs instead of EVs to perform the fulfilling of Micro-Hubs are analyzed, because the ICEV has a capacity in weight higher than EV so it can transport a higher number of parcels in order to fulfill the Micro-Hubs. For the other two activities performed by vans, that means the delivery to customers as well as the collection of the returns and failed deliveries from Micro-Hubs, the operative outputs are the same given that the vans are not saturated in capacity.

The difference in number of vans used to perform the fulfilling of Micro-Hubs looking at the different percentages of adoption of Cargo-Bikes is presented in Graph 30.

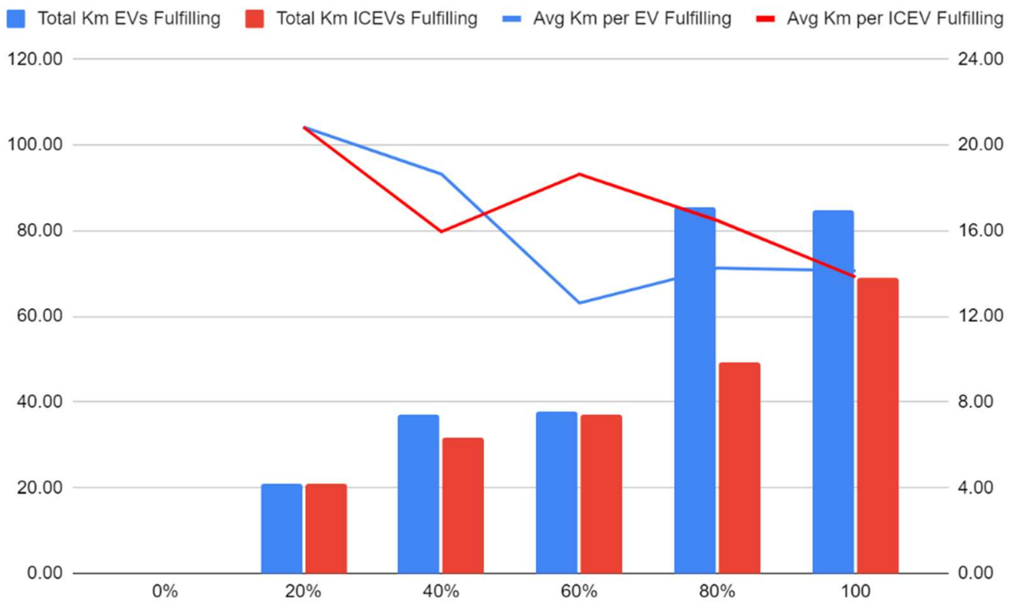


Graph 30 Adoption sensitivity - EVs vs ICEVs Fulfilling for number of vehicles

In case of 20% and 40% of adoption the number of EVs and ICEVs used is the same, while for the other cases with ICEVs less vehicles are used, specifically 2 vs 3 for 60%, 3 vs 6 for 80% and 5 vs 6 for 100%.

The kilometers travelled by Vans Fulfilling in the different cases, using ICEVs or EVs, are shown in Graph 31.

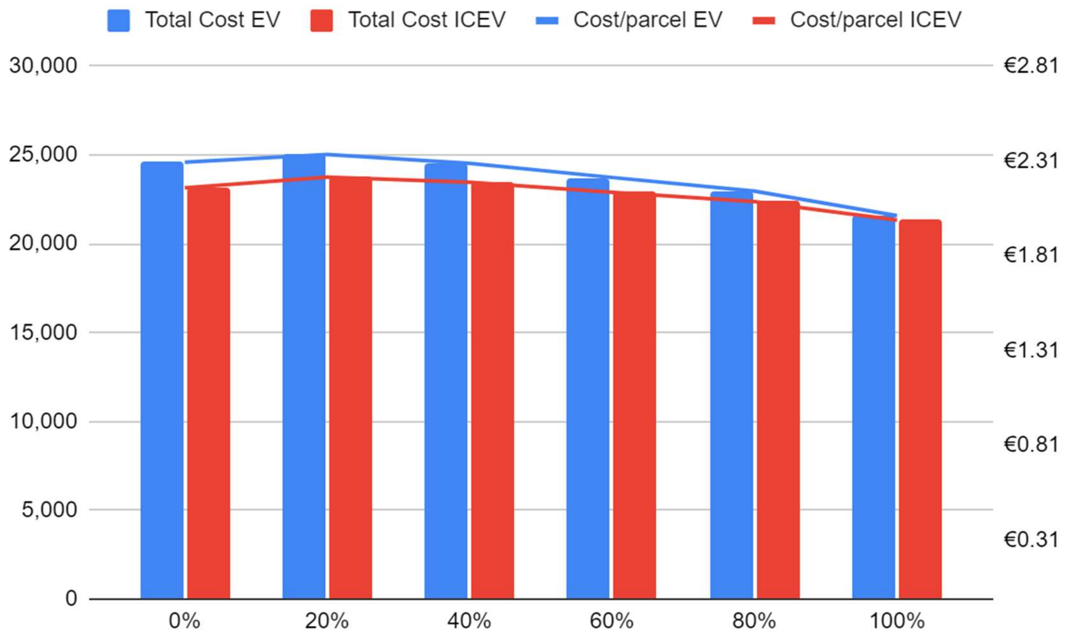
In case of 20% of adoption, the two solutions have the same results, indeed only one ICEV or EV is used, and the same path performed. In case of 40% of adoption, even though the number of vans is the same in the two cases, 2 for both, the kilometers travelled are less in case of ICEVs because the split is done differently according to the weight to move to each Micro-Hub. In case of 60% of adoption, the number of ICEVs are less than EVs, however, kilometers travelled are almost the same. As regards the average number of kilometers driven by each ICEV or EV for Fulfilling the Micro-Hubs, these overall decreases as the adoption increases but it doesn't happen for each step of adoption increase and it doesn't happen proportionally.



Graph 31 Adoption sensitivity - EVs vs ICEVs Fulfilling for distance travelled

The performances in terms of impact generated, costs and environmental emission, in the different scenarios are presented below, comparing the different adoption rates but also the usage of ICEVs and EVs as second vehicle, and how each scenario differently performs compared to the traditional network.

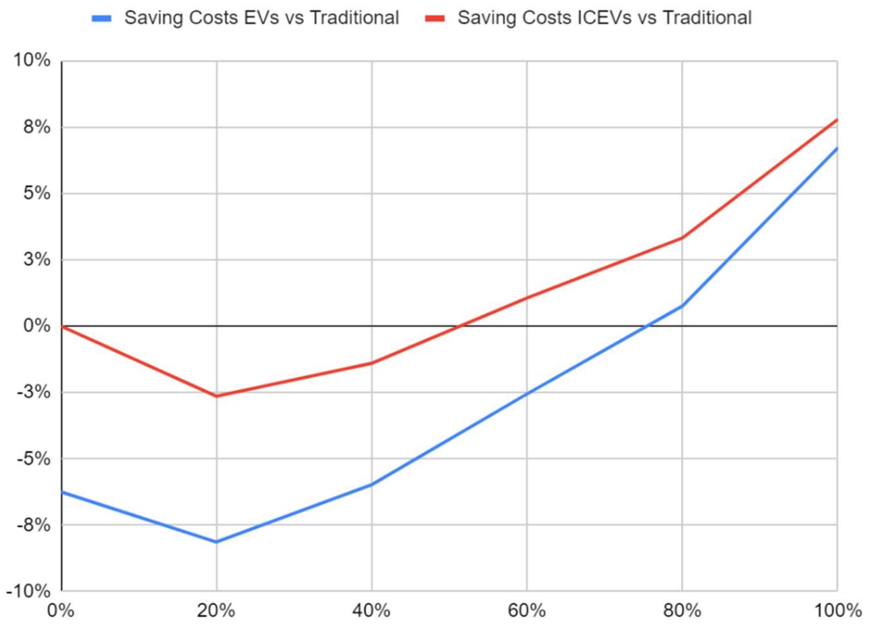
When it comes to compute the cost, for the Truck no changes are present since the time spent for loading and unloading the parcel at the different infrastructures is consider fixed for it. For the train, being the fare applied by the railway operator in €/(t*km), changing the amount of goods delivered by bikes, and therefore moved by the train, changes the total cost accordingly. Costs related to EVs, ICEVs and Cargo-Bicycles are computed as done in the Base Case and are due to the operational results presented. Total costs and costs per parcel faced in each scenario both with EVs and with ICEVs are displayed in Graphs 32.



Graph 32 Adoption sensitivity - EVs vs ICEVs, total cost and cost per parcel

The two curves, one for the case in which EVs are used to perform the deliveries, fulfillment of Micro-hubs and collecting returns, and the other one in which ICEVs are used instead of EVs to perform these activities, follow the same path along the different percentages of adoption. Since the Cargo Bikes are adopted, that means from 20% to 100% of adoption cases, in both solutions, the one with EVs and the other one with ICEVs, the cost decreases with the higher adoption of Cargo Bikes marginally in the different steps between 20% and 100%, from 2.34 € per parcel to 2.02 € per parcel in case with EVs and from 2.22 € per parcel to 2.00 € per parcel in case with ICEVs. As shown in the Graph 32, the solution using ICEVs is always cheaper compared to the one using EVs, this is because of the higher cost of renting the EVs instead of renting ICEVs. The difference in costs of the two solutions is lower and lower going from 20% to 100% of adoption, given that the weight of vans is lower given that the Cargo-Bikes are more used. On the other side, the 0% adoption case is in both EVs and ICEVs cases cheaper than the 20% and 40% cases, which means that in terms of cost it is not convenient to adopt the solution with less than 60%, given all of our inputs.

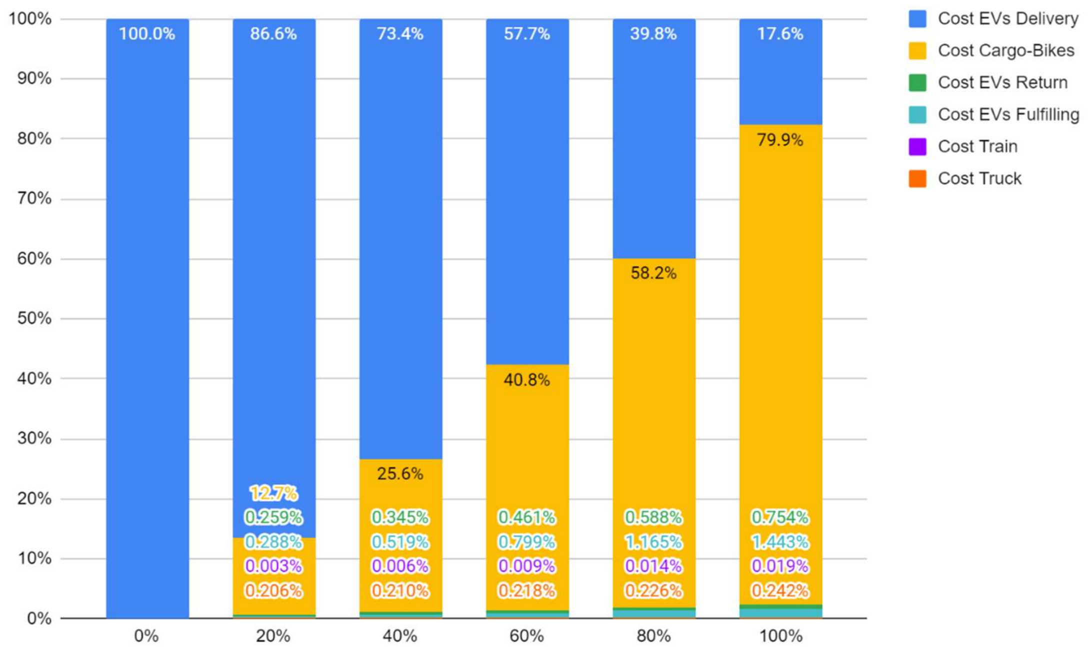
Similar conclusion can be obtained looking at the cost savings that the different adoption cases have, with both EVs and ICEVs, compared to the traditional network. Figures on cost savings are displayed in Graph 33.



Graph 33 Adoption sensitivity - EVs vs ICEVs, cost savings

For low percentages of adoption, the network is not convenient from an economical point of view, and according to the usage of EVs or ICEVs for the three activities performed by the vans, different percentages of adoption need to be reached for the solution to become convenient. Specifically, around the 50% is needed if using ICEVs, while using EVs almost the 80% is needed.

In Graph 34 are shown the contributions of the different vehicles to the cost generated in each adoption scenario.



Graph 34 Adoption sensitivity - Percentage of costs attributed to each vehicle type, EVs cases

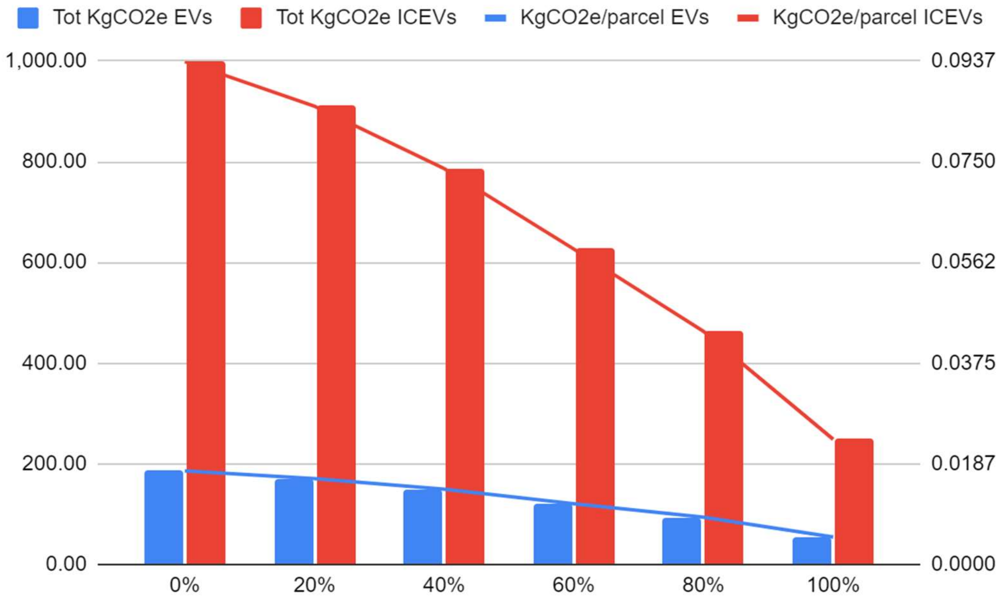
The main contributions in each scenario adoption come from the two vehicles used for the deliveries, that means Cargo-Bikes and EVs serving customers, indeed they presents in the different cases more vehicles, and therefore also of operators paid. As the percentage of adoption rises, the contribution in costs of Cargo-bikes rises as well, going from 12.7% with 20% of adoption to 79.9% with 100% of adoption. Consequently, the cost contribution of EVs using for deliveries has an opposite trend, indeed it decreases going from 86.6% in case of 20% of adoption to 17.6% in case of 100% of adoption. While the EVs Fulfilling in case of 80% and 100% of adoption overcome the 1% of costs generated, the other vehicle types never do, even if increasing the adoption of the green solution, the weight of this vehicle increases as well, both because costs related to those vehicles increase and because total cost decrease, increasing therefore weight.

If instead ICEVs are used, results obtained are displayed in Graph 35, which are not very differential from the EVs case.

Graph 35 Adoption sensitivity - Percentage of costs attributed to each vehicle type, ICEVs cases

Given that the unitary cost related to an ICEV is less compared to the one related to an EV, the cost percentages of ICEVs are all little bit lower than the ones before presented for EVs, and the ones of the other vehicles higher.

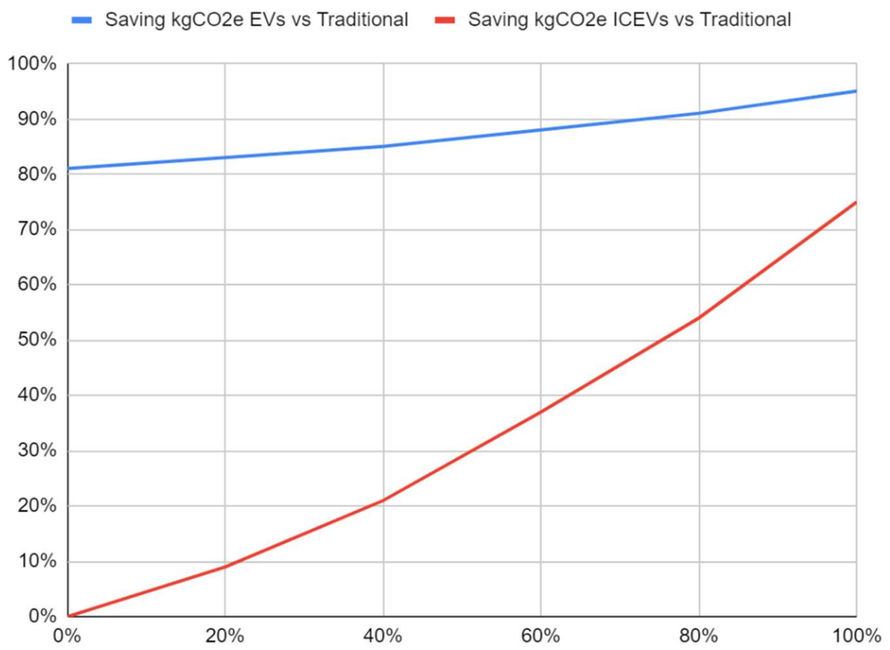
Going to the emission side, as already said, for the Truck and the Train the distances covered don't change if changing the % of adoption because the path performed is still the same, but the emission generated by both do change because of the different weight moved. As regards the other vehicles, emissions are obtained with the formulas presented in Section 4.2.6.6.1 and are based on the simulation results. Total emissions and emissions per parcel generated in each scenario both with EVs and with ICEVs are displayed in Graphs 36.



Graph 36 Adoption sensitivity - EVs vs ICEVs, total KgCO2e and KgCO2e per parcel

As for the total cost and cost per parcel also total emissions and emissions per parcel with EVs and with ICEVs the curves are both decreasing as the adoption increases. Obviously, the emissions generated in the solution using ICEVs are higher compared to the solution using EVs in all the different percentage of adoption scenarios. Going deeper, the effect on the increasing usage of Cargo-Bikes in case of ICEVs is stronger than in case for EVs, both in absolute and relative value. Indeed, the saving in term of kgCO2e going from 0% of adoption to 100% of adoption in the EVs case the emissions are reduced by around 130 kgCO2e, which corresponds to the 70.5%, and 750 kgCO2e in case of ICEVs, which corresponds to the 75%.

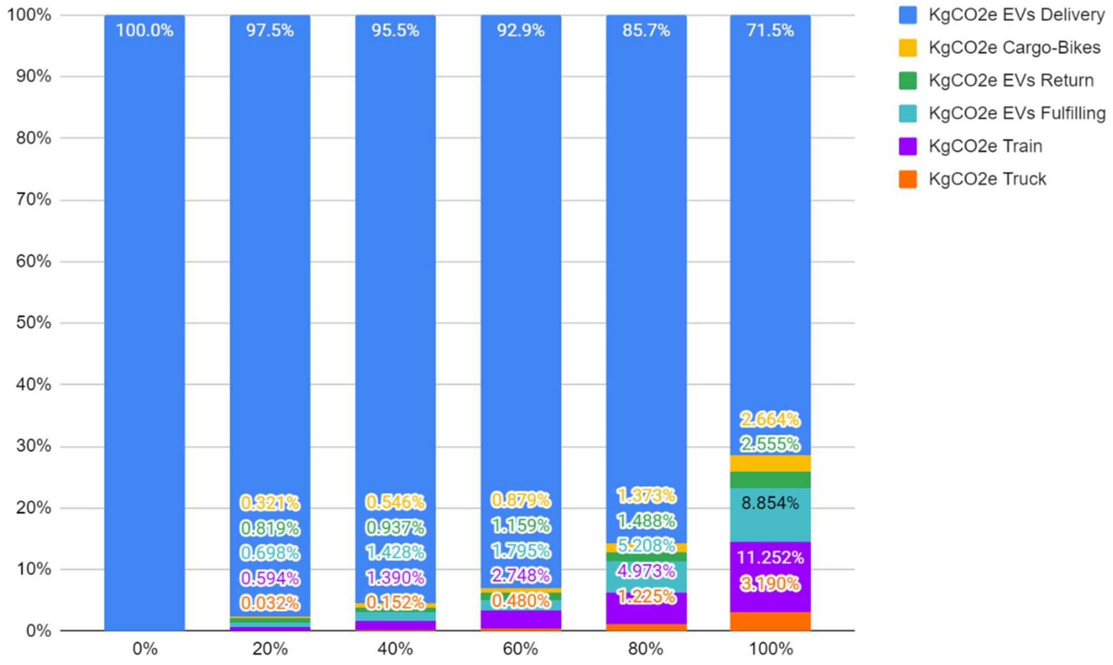
Similar conclusions can be obtained looking at the emission savings that the different adoption cases have, with both EVs and ICEVs, compared to the traditional network. Figures on emissions savings are displayed in Graph 37.



Graph 37 Adoption sensitivity - EVs vs ICEVs, emissions savings

As shown in the Graph, the savings coming from the network exploiting EVs are always higher than the ones coming from the solution with ICEVs for each percentage of adoption scenarios, even though increasing the percentage of adoption, the difference in savings between the two cases is lowered. However, the case with 0% adoption and EVs already has more than 80% of emission savings compared to the traditional network, which is higher than the savings obtained with 100% of adoption and using ICEVs. The main outcome here is that using EVs or the Cargo-Bicycles proposed systems can both help in achieving around 80% of emission saving, while using them combined, then, almost 95% of savings can be reached.

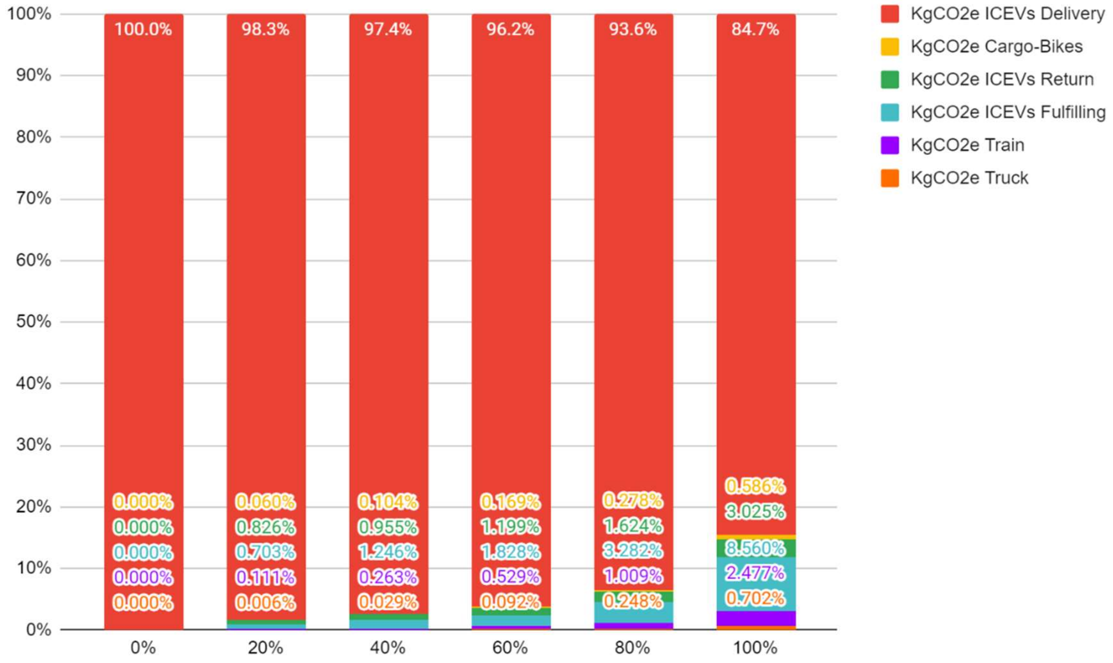
As done for the costs, the contribution to emissions produced of each different mean of transport used in the different adoption scenarios are presented in Graph 38.



Graph 38 Adoption sensitivity - Percentage of emissions produced by each vehicle type, EVs cases

The main emissions contribution comes from EVs used for the deliveries in all the different percentage of adoption scenarios. While from 0% to 60% Cargo-Bikes adoption, the EVs used for the deliveries are also by far more than other types of vehicles, in the other two scenarios, even though the number of Cargo-Bikes used for the solution overcome the number of EVs for the deliveries, the emissions contribution of EVs is still hugely higher because of the higher environmental impact per km and the more kilometers driven. Indeed, also in case of high percentages of adoption of the solution with Cargo-Bikes, the emissions contribution of Cargo-only 1.373% for 80% of adoption and 2.664% for 100% of adoption. Looking at the other types of vehicles, the contribution in emissions rises with the increasing of Cargo-Bikes solution adoption, in particular Train and EVs used to fulfill the Micro-Hubs have a quite high growth, with the emissions contributions of them increase respectively from 0.594% to 11.252% and from 0.698% to 8.854% going from 20% of adoption to 100% of adoption.

In Graph 39, instead, emissions contributions of the different vehicles when using ICEVs as cans are displayed.



Graph 39 Adoption sensitivity - Percentage of emissions produced by each vehicle type, ICEVs cases

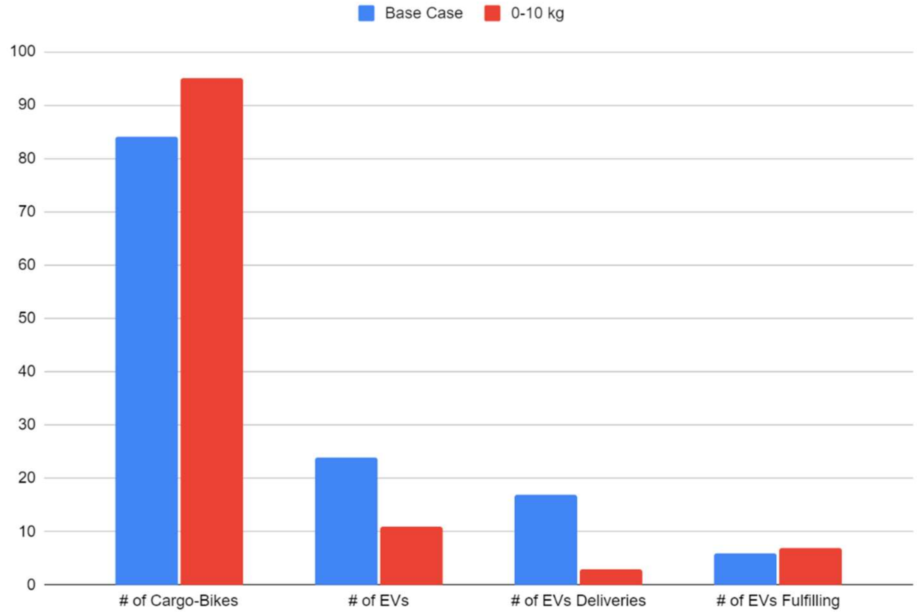
Given the higher environmental impact generate by ICEVs in comparison to EVs, the difference in the weight of each vehicle here is that the contribution of Cargo-Bikes, Truck and Train, which also weighted for more than 10% in case of 100% adoption with EVs, in this case falls.

5.2.2. Cargo-Bicycle weight range

The second analysis performed considers instead the possibility to define a different threshold for the assignment of the customers to Cargo-Bicycles or EVs, moving it from 2kg to 10kg, to understand if inefficiencies are created or else a higher use of Bicycles creates benefits.

The differences of the model with respect to the Base Case are the same generated in the first sensitivity analysis presented, being performed a change in the number of parcels delivered in the innovative way. Truck and Train changes are related to the weight moved while for EVs and Cargo-Bicycles the whole results are different and presented below.

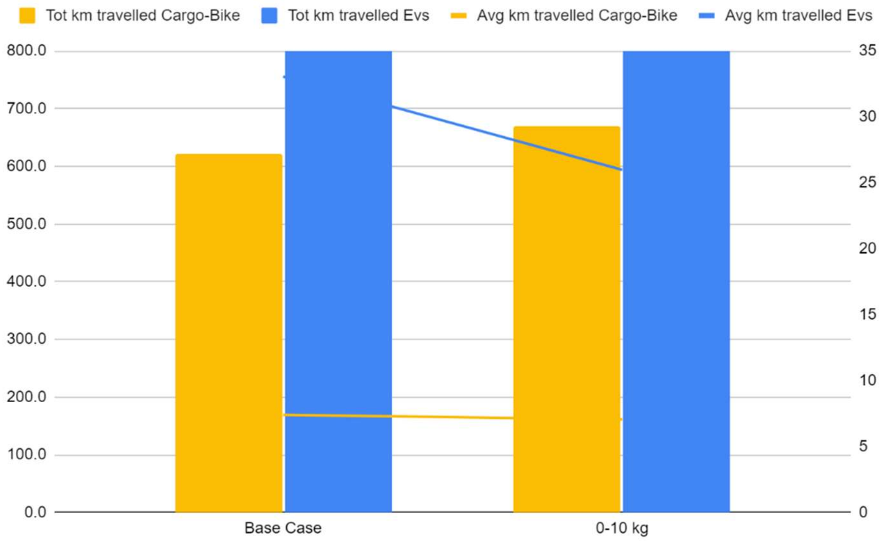
Graph 40 illustrates the differences in number of vehicles used, Cargo-Bikes and EVs, in the two cases: the base case in which the customers served by Cargo-Bikes are the ones ordered parcels lighter than 2 Kg and the solution in which the group of customers served by Cargo-Bike is larger, delivering all the parcels until 10 Kg.



Graph 40 Cargo-Bicycles weight range - Number of vehicles per type

The number of Cargo-Bikes increases by 11 from 84 in the base case to 95 in the 0-10kg case, the number of EVs, instead, decreases from 24 to 11, so by 13 vehicles. This means that overall, the network has both lower number of total vehicles and a greener mix, given by higher presence of Cargo-Bicycles. In particular, the number of EVs performing the deliveries going from 17 to only 3 while the number of EVs used to fulfill the Micro-Hubs increases of 1 unit (from 6 to 7) given the higher number and increased size of parcels to be delivered by Cargo-Bicycles and therefore to Micro-Hubs. The EV Return is in both cases only one.

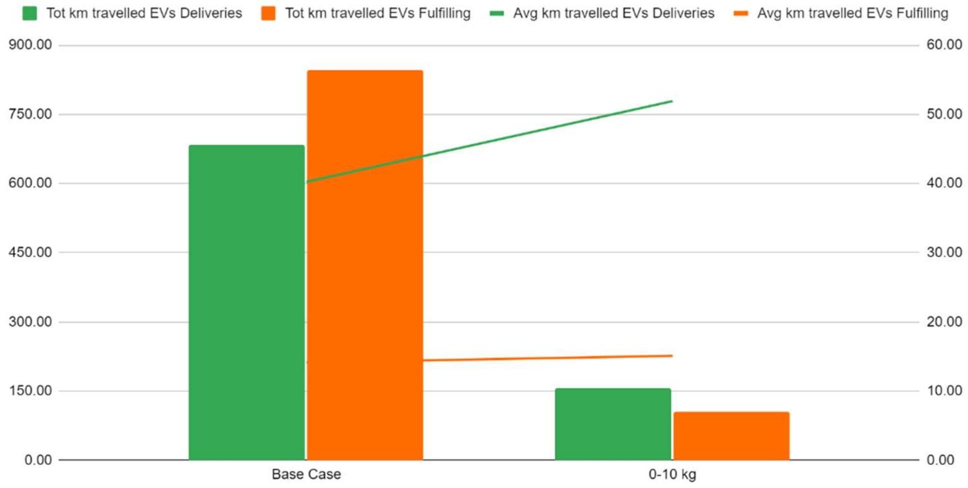
Following, Graph 41 displays the total kilometers travelled by the two means of transport as well as the average number of kilometers driven by each of them.



Graph 41 Cargo-Bicycles weight range - Cargo Bicycles and EVs, total and average number of kilometers

The total kilometers travelled by Cargo-Bikes increase of around 8%, while the number of kilometers driven by EVs decreases of more than 60%. Looking at the average values per vehicle both Cargo-Bicycles and EVs drive less kms per day, that's because of higher proximity of customers for Cargo-Bicycles and because in EVs in this case the weight on the total of the EVs Fulfilling, which covers shorter distance than the EVs Deliveries.

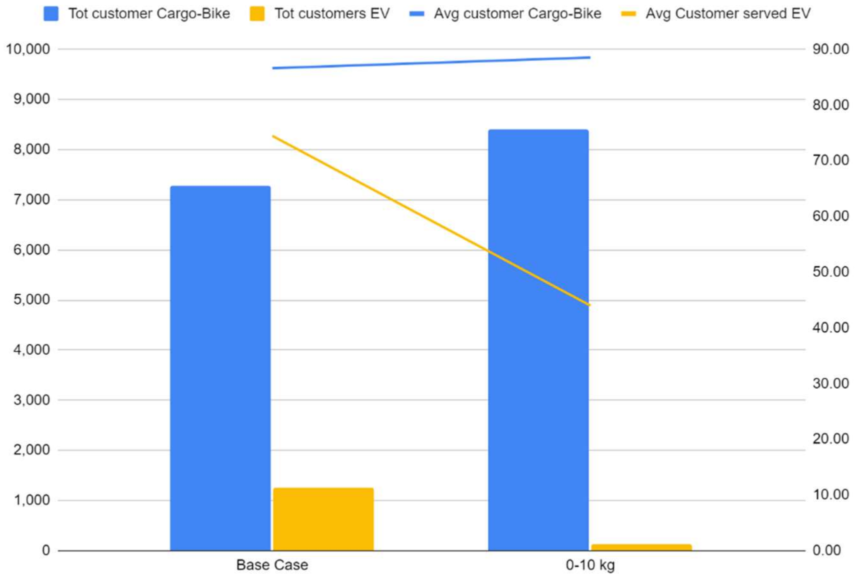
In Graph 42 indeed is shown how the average km travelled of EVs Deliveries increases in the 0-10kg case, given the less customers served by EVs and therefore the highest dispersion of them, while the EVs Fulfilling slightly increase because of the additional vehicle and different split of Micro-Hubs.



Graph 42 Cargo-Bicycles weight range - EVs Deliveries and EVs Fulfilling, total and average number of kilometers

Results regarding the number of customers served by the two types of vehicles, Cargo-Bikes and EVs, are shown in Graph 43.

In case all parcels in the range 0-10 Kg can be delivered by Cargo-Bikes the total customers served by these of course increases while the one of customers served by EVs decreases significantly in relative terms, specifically from 1266 customers served in the base case to only 132 customers in case with 0-10 kg. As regards the average number of customers served the one related to EVs goes down as wells, from serves 74.47 to only 44 customers, because they much more dispersed and travel time starts to assume an important weight in the total time spent by each vehicle to perform the delivery tour. The average number of customers served by the Cargo-Bicycles, instead, given the higher number and therefore proximity of customers served by them, increases by 2 customers.



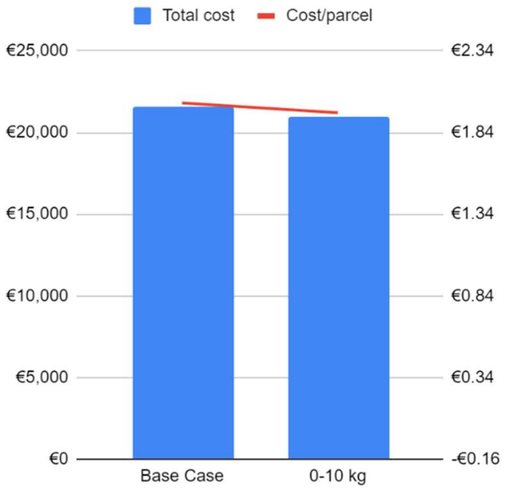
Graph 43 Cargo-Bicycles weight range - Cargo Bicycles and EVs, total and average number of customers

Once the operational results are obtained, performances in terms of impact generated, costs and environmental emission, can be computed and compared to the Base Case ones, considering also how differently the two cases perform in comparison to the traditional network. Computing costs, also in this case no changes are present for the Truck, while the train the costs of the services changes according to the goods moved. For the other vehicles costs are computed based on the operational results presented above. Total costs and costs per parcel of both the Base Case and the 0-10kg Case are presented in Graph 44.

Costs, both total and per parcel of course, decrease by 3% in the network considering all parcels 0-10 Kg deliverable with Cargo-Bicycles. The main reasons of the positive impact on costs of using Cargo-Bikes are two:

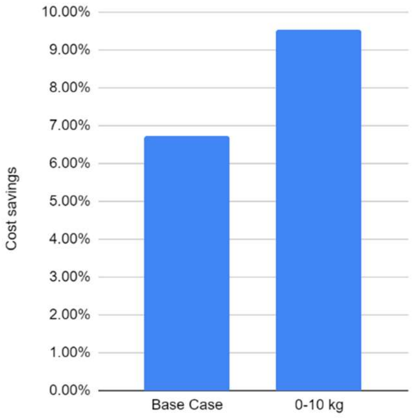
- The costs associated to Cargo-Bikes, lower compared to the ones of EVs. Renting of Cargo-Bikes is four time lower than the one of EVs and moreover the electricity consumption and therefore cost is lower.

- The decrease of the total number of vehicles that are present in the network. Decreasing number of vehicles brings a lot of savings to the company since less operators need to be paid, and driver's cost is a significant part of the total cost.



Graph 44 Cargo-Bicycles weight range - Total cost and cost per parcel

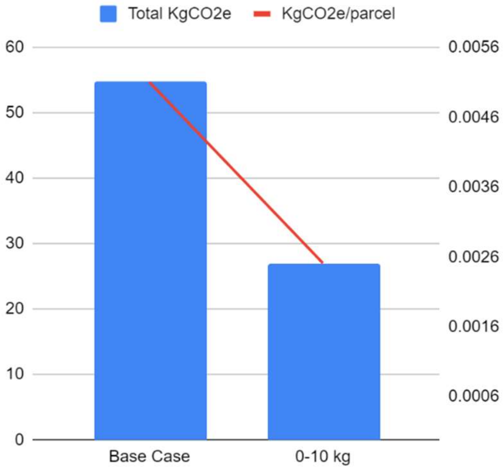
In Graph 45 are displayed savings coming from the two solutions with respect to the traditional network in terms of cost.



Graph 45 Cargo-Bicycles weight range - Cost savings

Given that traditional network compared with these two solutions is the same and the cost generated by the 0-10kg case was lower than in the Base Case, savings produced by this new solution are higher compared to the ones generated by base case, 9.52% vs 6.72%.

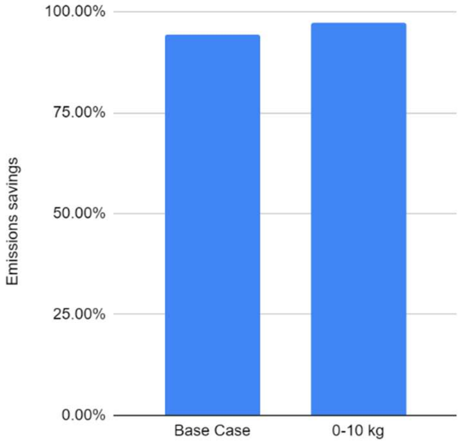
Going to the emissions, distances covered by Truck and Train don't change but the emissions generated do, because of the different weight moved. For the vehicles whose paths are obtained through the simulation model, emissions are computed as presented in Section 4.2.6.6.1. Total emissions and emissions per parcel generated in the two cases are displayed in Graph 46.



Graph 46 Cargo-Bicycles weight range - Total emissions and emissions per parcel

The total emissions as well as the emissions per parcel generated by the greener network exploiting Cargo-Bikes to deliver the parcels 0-10Kg are half respect to the ones produced in Base Case, precisely 27.02 vs 57.74 kgCO2e/parcel generated. This is caused by the higher utilization of Cargo-Bikes that have a minimal environmental impact compared to EVs, so the reduction in number of EVs is determinant for the fall of emissions. Even though the train transports more parcels, the incidence of this in the emissions generated by this mean of doesn't change much.

In Graph 47 are displayed the differences in percentage of emissions saved by using the greener solution, with both configurations, with respect to traditional network.



Graph 47 Cargo-Bicycles weight range - Emissions savings

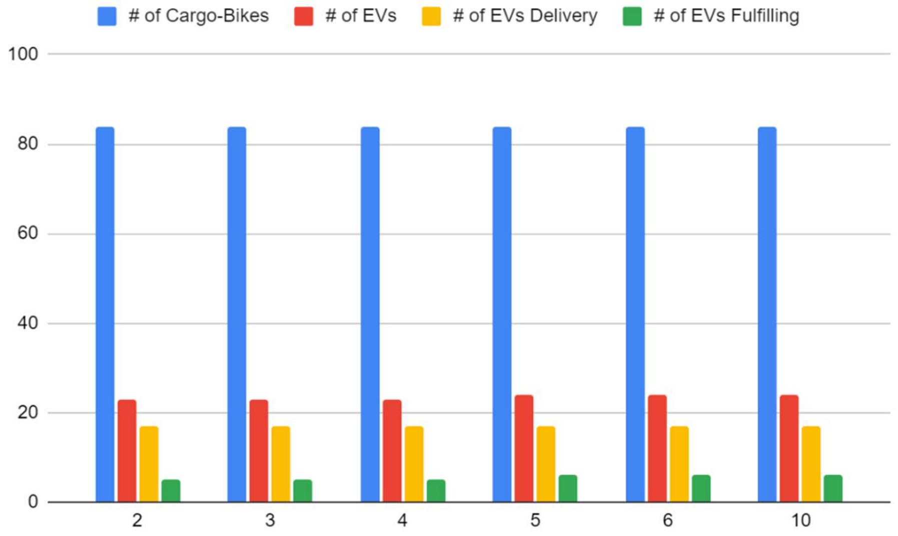
Of course, being the 0-10 kg case parcels is more environmentally friendly than the base case, the emissions savings of this scenario with traditional network are higher than Base Case savings. More precisely, the savings increase by almost 3%, from 94.5% to 97.3%, which however is due to a halving of the total emissions.

5.2.3. Micro-Hubs

Even if our analysis does not consider the cost related to the infrastructures, and therefore also to the investment in Micro-Hubs and their maintenance, it's reasonable to think that public property in the very center of Milan is quite expensive to obtain and complex to manage. Therefore, it's worth to evaluate the differences, and specifically the worsening of performances that should come with a lower number of Micro-Hubs, obtaining on the other hand other benefits linked to what was above mentioned. With less Micro-Hubs, each of them will be starting point of more bikes and will cover a larger area of customers, which means that it's higher probable that Cargo-Bicycles will need to perform a longer path, increasing the network overall impact.

Following, are explained the operational differences considering number of Micro-Hubs going from 2 to 6, which was our initial assumption, but also 10 Micro-Hubs to understand what happens if the number increases. In all cases, operational output regarding the EVs Deliveries do not change since these are not influenced by the number of Micro-Hubs, so they are not displayed. The differences will be given by difference related to Cargo-Bicycles, EVs Fulfilling and EV Return.

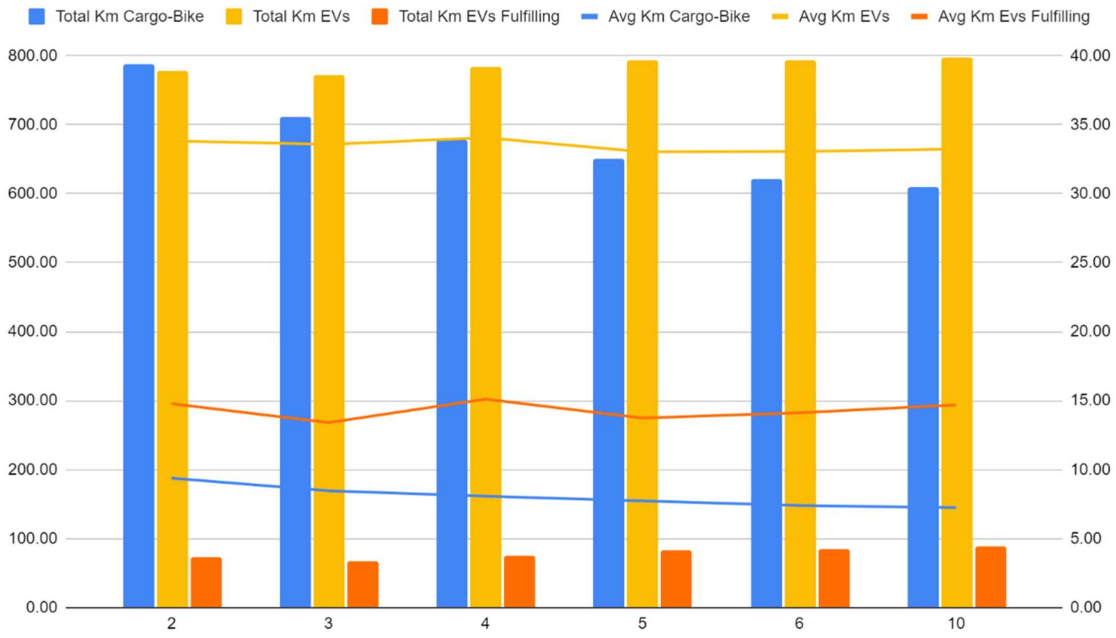
Graph 48 shows the number of Cargo-Bikes and EVs used in the six different scenarios.



Graph 48 Micro-Hubs sensitivity - number of vehicles per type

The number of Cargo-Bikes doesn’t change in any of the case, because even with less Micro-Hubs, the customers to serve are so dense that delivery tours with no additional inefficiencies can be made. For EVs, instead, it’s the same with 2, 3 or 4 Micro-Hubs, while the number increase by one in case of 5, 6 and 10 Micro-Hubs, going from 23 to 24. The reason of this slightly growth is given by the EVs used to fulfill the Micro-Hubs that going from 5 to 6 EVs, given the already mentioned constraint of the model that if the Micro-Hubs can be serve by 1 EV only, that’s preferred and therefore the number of EVs increases as the number of Micro-Hubs increases. However, this is reasonable and for costs and emission what is considered is time and distance, therefore no deviations are present.

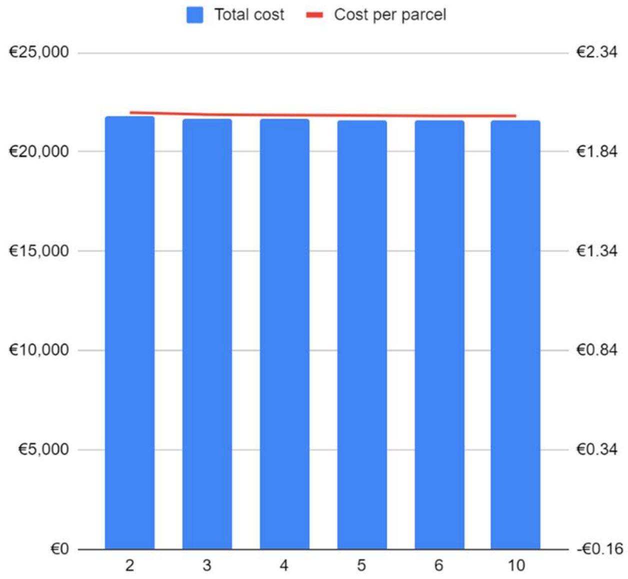
In Graph 49, instead, are presented the total and average kilometers driven by each mean of transport in the several scenarios with different number of Micro-Hubs.



Graph 49 Micro-Hubs sensitivity – Cargo Bicycles and EVs, total and average number of kilometers

In case of 2 Micro-Hubs the total number of kilometers travelled by Cargo-Bikes is equal to the ones driven by EVs, then increasing the number of Micro-Hubs, the total number of kilometers travelled by Cargo-Bikes decreases. This is because the number of kilometers travelled by each of them declines given that they can serve the same number of customers doing tours nearer the Micro-Hub, being these more dispersed. Specifically, the number of kilometers travelled by Cargo-Bikes is 9.39 Km in the case with 2 Micro-Hubs going down to 7.4 Km in the Base Case with 6 Micro-Hubs and 7.2 Km in the case with 10 Micro-Hubs. Regarding instead the EVs, the total kilometers by all of them tends to rise going from 2 to 10 Micro-Hubs. Looking at the average kilometers driven by EVs, instead, they decrease going from 2 to 10 Micro-Hubs, but the curve has a strange shape because of the increase in number of EVs fulfilling and therefore their weight in the total EVs category.

On the bases of the just described Operational results related to the scenarios with a different number of Micro-Hubs respect to the base case, the Costs and the Emissions in each of them was computed and the results are presented below. In Graph 50 are displayed the results related to the cost of the networks with the different Micro-Hubs setting.

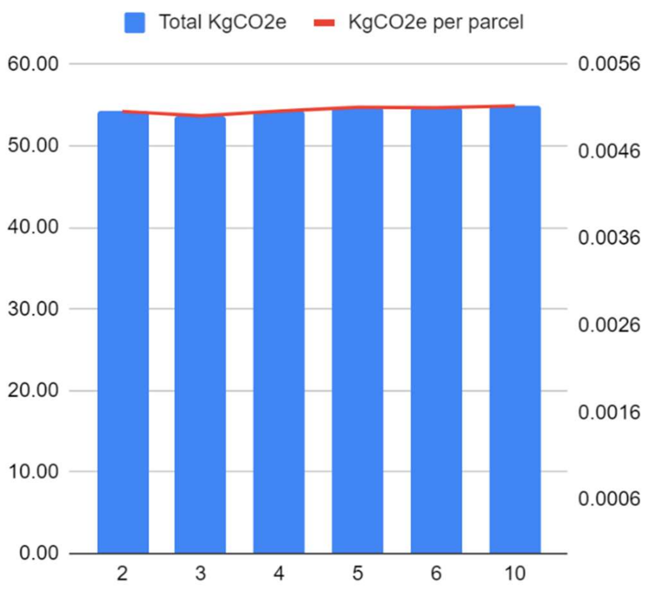


Graph 50 Micro-Hubs sensitivity – Total cost and cost per parcel

The cost of the greener solution, in term of total cost and cost per parcel, decreases going from 2 to 6 Micro-Hubs used, due to the less kilometers travelled and less time spent for deliveries by Cargo-Bikes. However, this difference is minimal (1%), indeed, the cost per parcel resulting from using 2 Micro-Hubs is 2.04€ while in case with 6 Micro-Hubs is 2.02€. The comparison between the base case and the scenario with a higher number of Micro-Hubs shows a slightly increasing on total cost as well as cost per parcel going from 6 to 10 Micro-Hubs. This result is given by the higher cost related to EVs performing the fulfill of Micro-Hubs and the ones that collect all the return and failed deliveries parcels from Micro-Hubs at the end of the day, indeed this higher difference is not fully compensated by the lower cost of Cargo-Bikes as happens in the comparison between all other scenarios.

As there were no significant differences in costs generated in the different scenarios, being the traditional network always the same, also in terms of cost savings to the traditional solution there are no big differences among the scenarios. Starting from the Base case with 6 Micro-Hubs, increasing their number to 10 doesn't bring additional cost savings, while decreasing it lowers down also the cost savings achieved from 6.7% in the base case to around 6% in case of 2 Micro-Hubs.

Besides understanding how much the cost of the solution differs among the different cases, we need to understand also if there is and what is the effect on the emissions generated. Total emissions and the emission/parcel generated by each solution are displayed in Graph 51.



Graph 51 Micro-Hubs sensitivity – Total emissions and emissions per parcel

Emissions generated overall increase going from the case with 2 Micro-Hubs (54.2 KgCO2e) to 10 Micro-Hubs (54.9 KgCO2e) according to the increase in number of kilometers travelled by EVs, both Fulfilling and Returns, which is not offset by the decrease in emissions generated by the Cargo-Bicycles due to less km travelled. The case that seems to behave in a different way is the one used 3 Micro-Hubs if compared with the case with only 2 Micro-Hubs, due to a decrease in distances travelled, but that's something caused by the specific cases and it's not part of a trend.

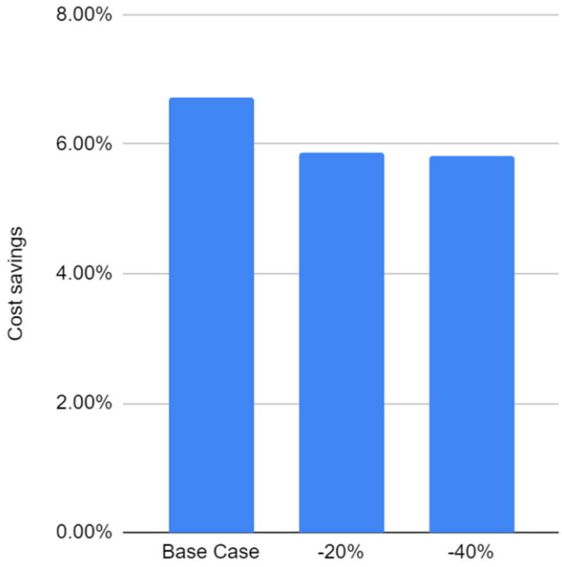
The savings in environmental impact between the traditional case and the different scenarios are follow the same comments presented above: even if emissions very slightly increase, no significant differences are obtained going from 2 to 10 Micro-Hubs. Specifically, with 2 Micro-Hubs the savings in Carbon Footprint are 94.6% while with 10 Micro-Hubs they decrease to 94.5%

5.2.4. E-Commerce Volumes

The last sensitivity analysis performed is related to e-Commerce volumes, which means to evaluate the differences that there would be if the total number of customers was different than the one considered. Specifically, we evaluated two cases in which there would be a decrease in volumes only, and no cases with an increase. The reason behind this is that increasing the volumes, the benefits of the innovative network with respect to traditional one are going only to increase, while it's interesting to see how it would perform if there was a contraction in volumes. Moreover, in as mentioned in the Introduction of this thesis work, the volumes of e-Commerce parcels delivered have increased a lot in the last years and especially due to the Covid-19 pandemic, therefore it's imaginable to have a contraction of volumes once the imposed social distancing will decrease.

In this sensitivity analysis, the only results presented will be the savings deviations in costs and emissions that there are between the innovative and the traditional network, without entering the detail of the operational results of neither of them. Because of a decrease in the number of parcels delivered, and therefore of points to be served, the number of vehicles of every kind tends to decrease, while the efficiency of the single vehicles worsens as well because of higher distances between customers. However, comparing the impact of scenarios with different number of customers gives no value, and that why operational results are not presented. What is interesting to visualize is the difference of each volume scenario with the related traditional network. Specifically, the two cases evaluated regards a decrease in volume of respectively 20% and 40%.

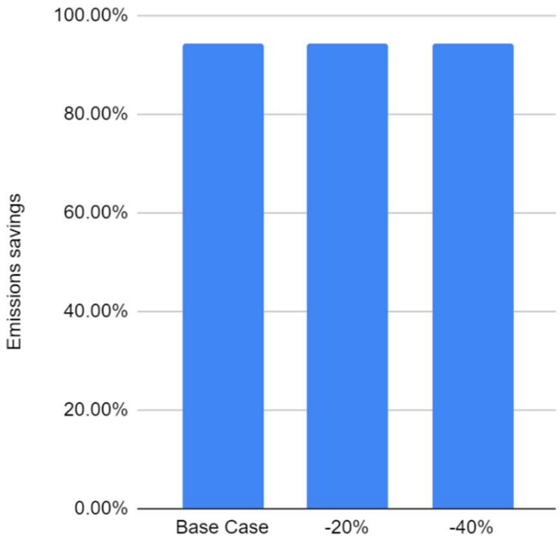
Comparison between the innovative and traditional networks in total cost and cost per parcel while varying the e-Commerce volumes are displayed in Graph 52.



Graph 52 E-Commerce volumes - Cost savings

The cost savings of the designed solution with respect to traditional network, are positive in every scenario, also with lower volumes. However, the costs savings decrease by 1% going from the from 6.7% of the Base Case to 5.8% of both the 20% less and 40% less scenarios. The reason of this decrease in savings is that once the number of customers to be served is not decreases, the effect of the customer density is lower and therefore the drawbacks of bicycles in terms of speed compared to vans are more present.

Moving on the emissions side, the comparison between the two networks for the different cases of study in this sensitivity analysis is presented in Graph 53.



Graph 53 E-Commerce volumes – Emissions savings

The emissions savings of greener solution with respect to traditional network are positive and huge in all cases with the minimum at 94.44%. Decreasing the volumes of parcels in the network, as the cost savings, also the emissions savings decrease, but in a much irrelevant intensity, going from 94.57% to 94.44%, while costs savings were decreased of almost one sixth of their value

5.3. Summary of the results

This Section sums up the main findings coming from the outcomes of the whole analysis performed.

Firstly, the second research question (RQ2) on the economic and environmental impact of the greener solution compared to the traditional network is answered. As regards costs and economic impact, the solution designed and proposed in this study with usage of Truck, Train, EVs and Cargo-Bicycles instead of ICEVs, was proved to bring benefits. The same, which was clearly expected, and in a much more significant dimension, happens for emissions generated by the two networks. These results are mainly due to the fact that Cargo-Bicycles demonstrated to be a very competitive vehicle for deliveries in city centers given the very high proximity of customers and therefore no need of vans speed, while neither needing its capacity.

According to the results obtained, the emissions generated with the greener solution to perform the daily service under our attention and based on our assumptions, are 54.71 kgCO2e. The vehicles that mainly contribute to this result are the EVs performing the deliveries to customers not eligible by Cargo-Bikes with the 71% of emissions generated, followed by Train and EVs for fulfilling Micro-Hubs, respectively 11% and 9%, and finally Cargo-Bikes, Truck and EVs transporting the returns and fail deliveries parcels from Micro-Hubs, all of them contributing of 3%). Regarding the total cost coming from the solution studied in this thesis work, the daily cost to deliver the parcels using Train, Electric Vans and Cargo-Bikes is 21,589 € and it is mainly generated by the two vehicles performing the last mile deliveries, that means Cargo-Bikes with the 79.9% and EVs Deliveries with the 17.6%, while all the others mean of transport have a minimal weight in term of costs. The reason of this is that the vehicles for deliveries are much higher in number and therefore the cost related to them is the main one.

Comparing these results with the ones coming from the traditional network, in term of environmental impact, the greener solution is far more sustainable than traditional process, indeed with the innovative network we can save the 95% of emissions generated by the last-mile delivery, but this was obvious given that we are using vehicles with a lower impact respect to diesel vans utilized in traditional process. The not so obvious outcome is that also savings in term of costs can be obtained exploiting our solution, indeed it generates 6.7% less costs compared with the traditional network, because of the high usage of Cargo-Bikes which are also less expensive than vans.

Then, through a Sensitivity Analysis performed on some of the inputs of the model, we investigated how differently the network would perform and how the comparison with the traditional network changes.

First, different scenarios of adoption rate were analyzed to evaluate what would be the results with an initial adoption of the innovative solution that is not at the maximum of its capacity. The results show that the greener network looking at the emissions generated, of course, the innovative solutions even with low adoption rate is more sustainable than the traditional network, both if the vans in the partially innovative network are to complete the total deliveries are EVs or ICEVs. Looking at the costs, the percentage of adoption of the innovative solution is relevant for the solution to be more or less expensive than the traditional one. Indeed, in greener solution with EVs, the positive cost savings are reached only with at least 80% of innovative solution adoption, while if the vans used are ICEVs, positive cost savings are reached since 60% of innovative solution adoption, given the lower cost of diesel vans compared to electric ones.

The second sensitivity analysis performed considers a different for the assignment to the parcels and therefore customers to Cargo-Bicycles or EVs, moving it from 2kg to 10kg, to evaluate the benefits or inefficiencies given by a higher use of Bicycles. The results show that allowing Cargo-Bicycles to transport also heavier parcels, the savings with traditional solution are higher than in 0-2 Kg threshold situation both in term of costs and emissions. In particular, emissions are halved, with savings go from 95% to 97%, while cost savings increase from 6.7% to 9.5%.

Investigating instead the scenarios with different numbers of Micro-Hubs, the results seem not change too much both if the number increases or decreases respect to the initial assumption to have 6 Micro-Hubs. The cost savings respect to traditional network goes from 5.96% using 2 Micro-Hubs to 6.72% with 6 Micro-Hubs, decreasing then to 6.71% in case with 10 Micro-Hubs, meaning that there is an amount of Micro-Hubs after the which they may be too many. Regarding the emissions, the savings in Carbon Footprint are 94.57% with 2 Micro-Hubs and they minimally decrease until 94.50% using 10 Micro-Hubs. Evaluations on what can be the best number of Micro-Hubs to use depend therefore on the specific cases and trade-off chosen.

Lastly, we evaluated the differences that there would be if the total number of customers was different than the one considered, precisely if there was a contraction in volumes of 20% and 40%. Both the cost savings and emissions savings from traditional network decrease given the lower density of customers served derived from a lower overall number of them. However, the changes are also in this case not significant at all, with a decrease by 1% in cost savings from base case to 20% less volume scenario, which then don’t change moving to 40% volume less. Regarding the emissions savings, they decrease by 0.1 % going from base case to scenario with 20% less customers and they remain almost the same going from 20% to 40% customers less. The solution is therefore proved to be robust also to variations in number of customers, since compared with the traditional network savings in both costs and emissions are almost not even influenced by the decrease in volume.

5.4. Comparison with literature

In this Section our outcomes and findings are compared to the main contributions found in literature.

The environmental impact generated by our solution is low compared to the as-is situation, this is inevitable given the electric engine of all the vehicles used in the network. The same outcome was also obtained in all the other papers on Cargo-Bikes analyzed in Literature Review but with lower benefits respect to the ones of our greener network. For example, in the paper written by Jacques Leonardi et al. (2012) the last-mile delivery in London City Center is made by EVs, for heavier parcels, and Cargo-Bikes, for the lighter parcels, instead of Diesel Vans, generating the 83% of emissions savings, that is lower than almost 95% reached by our solution. Also, considering only Cargo-Bikes replacing Diesel Vans, like in case of S.Melo et al.(2017), the avoided emissions are 73% kg of CO2 with 100% of adoption of Cargo-Bike.

Looking at costs, our solution produces savings respect to traditional network mainly because of high exploitation of Cargo-Bikes in a very dense area. In other solutions using Cargo-Bikes as only vehicle instead of Diesel Vans, costs are higher in the proposed network compared to traditional one, as in Sara Verlinde et al. (2014) and Carlos Llorca et al. (2021). However, in both cases also infrastructures costs are considered. Indeed, as written in Chapter 3, we didn't consider these types of costs given that it was assumed that this type of network should and would be partially financed by the Municipality. Nevertheless, cost for infrastructures would change the results of our model so much, being the Micro-Hubs just some non-refrigerated sea-containers. In our paper only J. Fraselle et al. (2021) shows a positive impact also regarding costs using Cargo-Bikes instead of Diesel Vans, indeed when performing a comparison among different last-mile deliveries vehicles, the most affordable one was proved to be the Cargo-Bicycles.

As written above, the greener solution developed in this thesis work is always valuable in term of environmental impact respect to traditional network. Regarding the costs, there are some important factors fundamental to develop a sustainable network compared to the as-is situation, like the possibility to avoid investment costs of Micro-Hubs, given that they can be under Municipality responsibility as well as many other papers in literature assume.

Furthermore, some of literature review papers underline the impact of having efficient bicycle lanes to not create high issues on traffic condition, as Carlos Llorca et al. (2021), that is not developed in our thesis work and could be analyzed in future works, especially considering the focus that local governments are putting in strengthening the cycle lanes network in their cities.

What however cannot be compared is the result of a solution that considers also the entrance of the goods into the city in a greener and innovative way, which is the gap in which our study wants to fulfill. Also, this can be one of the reasons why the savings obtained in our case are higher than the papers studied, because our study also compares the entrance of goods inside the city from the outside with ICEVs or with the Train.

6 Conclusions

This thesis work is focused on the impact of the urban logistics around last-mile deliveries, proposing an innovative solution capable of acting on both economic and environmental impact of the network used. In particular, the context considered is the e-commerce deliveries, a phenomenon that is growing at a very fast pace, 20% from 2020 to 2021 in Italy in value and deliveries, and that has many drawbacks in urban logistics efficiency.

The network developed considers the point of view of a single Courier in Milan, and the usage of Truck, Train, EVs, and Cargo-Bicycles as vehicle types for delivering goods from outside the city to customers' locations in the very center of the city. The model built is a simulation model on ArcGis, through which the vehicle routing is solved and optimized given the data inputs and the parameters inserted. Then, costs and emissions generated are calculated based on the operational results of the model.

Looking at the results obtained, there are clear and significant benefits in the usage of the innovative network suggested in our study and this is due to the huge efficiency of Cargo-Bicycles in performing last-mile deliveries. Indeed, being neither the capacity nor the speed of vans differentiating, the decrease in emission generated and in cost obtainable implementing the proposed network can be huge, especially on emission side.

As a matter of a fact, 95% of emissions produced by the last-mile delivery can be saved if using the network as it is in the Base Case proposed, and moreover, also on cost side benefits are achieved, with 6.7% lowers costs generated.

It was then interesting to study what would change if changing some of the inputs or assumptions to the model, in order to gather as many insightful outcomes as possible and also evaluate the robustness of the results obtained.

First, different scenarios of adoption rate were analyzed to evaluate what would be the results with a partial initial adoption of the innovative solution and on the cost side, savings are achieved only with 60% of adoption at least, while emission savings are huge even with very low adoption rate. Another interesting outcome from the adoption analysis regards the case with EVs and 0% adoption, which means the traditional deliveries performed with EVs, in this case, costs are around 6% higher, but 80% of emissions savings are achieved compared to the traditional with ICEVs. Then it was studied the possibility of assigning to Cargo-Bicycle deliveries parcels until 10kg, and the results are that with higher usage of bikes emissions would be halved, with savings going from 95% to 97%, while cost savings increase from 6.7% to 9.5%. Investigating instead the scenarios with different what emerged is that cost savings versus the traditional from 2 to 6 Micro-Hubs vary from 5.9% to 6.7%, staying then 6.7% also in case of 10 Micro-Hubs, while emissions produced and therefore savings almost do not change. This proved 6 Micro-Hubs to be a reasonable number of Hubs to have since there is no need to have more of them, but also that if space availability would be a problem, having fewer Micro-Hubs would just bring a slight contraction in cost savings but nothing more. Lastly, also on delivery volumes was performed sensitivity analyses, specifically to evaluate if lower demand would bring to inefficiencies. The results are that emissions savings would be not affected by a lower demand while cost savings would be 1% lower in the case of 20% or 40% contraction of volumes.

The solution proposed proved therefore to be hugely effective in decreasing the impact of urban logistics in environmental terms, but also ensuring a lower cost faced, which is not common in sustainable solutions. Indeed, the case of EVs only with no Cargo-Bicycles reached the 80% of emissions savings but was more expensive than the traditional network. With the usage of Cargo-Bicycles both economic and environmental sustainability can be achieved. Moreover, while the Base Case studied is already very worth to be implemented and reach huge benefits, increasing the threshold of parcels weight for Cargo-Bicycles, significantly higher results can be achieved, and the solution would still be feasible in terms of capacity.

Potential limitations on the model may be given by the assumption performed, even if most of these are coming from discussion with the couriers or other studies analysed. Moreover, each of the most relevant assumptions, for example the definition of the fixed delivery time, is affecting both the proposed innovative network and the traditional one. Being the comparison performed always comparing to the two networks, and given the sensitivities performed on the inputs, the results are therefore considered quite robust.

As last remarks, a very insightful study we consider could be performed with a view on the future could be based on autonomous vehicles. These indeed, drones or robots, not needing any driver, once regulated and operatively feasible, will bring a huge disruption in the field of last-mile deliveries.

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