Master Thesis

SUSTAINABLE SOLUTIONS IN LAST MILE LOGISTICS

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Abstract

This report addresses the current and future solutions that contribute to improve the level of environmental sustainability in the last mile of the supply chain. The increase in the trend of e-commerce together with the inefficiencies of the delivery process causes many negative externalities known as the last mile issue.

The dynamic development of electronic commerce and the era of consumers’ immediacy have increased the number of home deliveries, mostly in urban areas. Therefore, the number of delivery points increase while the quantities to deliver become smaller compared to traditional store deliveries, which challenge even more the last mile delivery sector.

On the other hand, the last mile was already one of the most expensive, inefficient and pollutant activities in the entire supply chain. Additionally, and together with the e-commerce new trend, it has increased the negative impact on traffic congestion and noise, reduction in road capacity and increase pollutant emissions. This are the reasons why there has been a concern to find sustainable solutions to overcome this issue while keeping the operational logistics efficiency. Consequently, this report introduces through a literature review, current and future sustainable solutions together with new digital technologies implemented in the last mile delivery sector.
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1. Introduction

Since the Industrial Revolution began around 1750, human activities have contributed substantially to increase the greenhouse gases concentration. The combustion of fossil fuels such as coal, oil and gas have been used as major sources of energy creating CO$_2$ and other heat-trapping gases to the atmosphere which results in an increase of the greenhouse effect that causes a general Global Warming. The consequences of global climate changes are being disastrous: cyclones, hurricanes, wildfires, droughts, floods and earthquakes are becoming more and more frequent threatening the whole ecosystem.

Decreasing substantially CO$_2$ emissions from human activities is therefore essential and urgent. Focusing on the sector of last mile deliveries, it has been the most inefficient and pollutant of the entire supply chain. Besides, the evolution of the society, the increment of the population’ density and the emergence of electronic commerce led to new ways in consuming practices. Consumers order more things online, expecting more control and faster deliveries. Living in a fast-changing world which advances with great speed, enhances the appearance of a new trend between consumers: the immediacy. This is the reason why home deliveries had increased their popularity in the recent years and, the speed and effectiveness of these deliveries have become a key driver in the logistic sector. The E-commerce is in a phase of continuous growth and it has arrived at historic sales maximum during the lockdown due to coronavirus emergency, especially in urban areas.

For this reason, the last mile has notified an unexpected big change in the distribution network. From delivering big quantities into a few points of delivery as stores or supermarkets, to many delivery points with small product quantities. The strong trend towards internet shopping will have an impact on future transportation volumes and delivery points. It means that the number of fleet of vehicles of last mile delivery service will increase, which will bring many negative externalities as pollution, traffic jam, noise and higher logistics cost.

This additional feature will challenge even more the last mile deliveries which is already the most inefficient, costly and more pollutant part of the entire supply chain. Therefore, it is necessary solve the complex problem of the distribution while at the same time mitigate the environmental damages. Consequently, this situation emerges solving this trade-off between greener environment and logistics efficiency. Many companies are investing in solutions for last mile deliveries that creates a sustainable competitive advantage based on disruptive new technologies, innovative ideas and green logistics.
1.1 Purpose of the study

During the last recent years, global concern about climate change has emerged in the past 30 years, resulting in several international agreements and population’s concerns about the idea of significantly reduce the emissions of greenhouse gases. However, although there has been a growing interest about mitigating the climate change, it has not been achieved any satisfactory result and Global Warming is still increasing.

When considering the CO₂ emissions in the transportation sector, the last mile delivery stood out as one of the worst parts in the entire supply chain. Understanding the actions that are carrying out to deal with the environmental problem together with the trend increase of e-commerce will define the future of the last mile deliveries. These are the main reasons that encourage me towards this study. Therefore, the objective of this study is to obtain comprehensive view of the last mile delivery solutions that solve the trade-off between logistics efficiency and environmental sustainability.

1.2 Methodology

The first step of the work is understanding the background by defining theoretical concepts in order to gain more contextualization about the topic. It will help to understand the parcel industry and how the evolution of the e-commerce have influenced the market in the last recent years. Moreover, sustainability and logistics definitions are presented to introduce the last mile issue.

Then, in order to provide an overview of the main solutions available for improving sustainability of package deliveries in the last mile, the work will be dedicated to a thorough literature review. Current and future innovative ideas for last mile delivery have been described to obtain a comprehensive view of the various solutions highlighted by scientific research and by companies. The solutions described will be organized in different sections: delivery points, sustainable warehouse, transportation modes, routing policies and sustainable packaging.
2. Theoretical framework

2.1 Parcel industry

The parcel delivery industry consists of carriers or organisations that transport single shipments often in small size packages. Important features of the industry are carrier pickup at origin and carrier delivery at destination usually using small trucks.

The history of the parcel delivery industry has always been correlated with the evolution of information and communication technology (ICT), transportation technology and economic climate. Before the invention of motor vehicles, delivering parcels rely on animals: from the camels in the desert to the dogsleds in the snow. With the industrial revolution, train lines, steam ships and communications technology meant larger loads of parcels and products could be transported further and quicker. As technology progressed, the transportation of goods has been using trucks, trains, ships and more recently the emerging fast-paced aviation industry. (1)

The industry is characterized by a sustained growth since its beginning. With the complementarity of mail-order shopping, also called catalogue shopping, in the 20th century and e-commerce at the beginning of the 21st century. It has allowed customers to shop from home, which impact will be discussed in more detail in a further section. Technology and globalisation have extended the logistics capabilities of companies and have unlocked new markets, which contributed to the success of the parcel industry. Since 2014, growth in the industry has been steady around 19 % per year, with the Asia-Pacific region driving it. Similar growth numbers are expected until end of 2021. (2)

With the rise of e-commerce, consumer preferences have moved more and more to the centre of attention in the formerly business-oriented parcel delivery market. Large e-commerce players as well as various start-ups have identified parcel industry services as a key differentiator vis-à-vis their competitors. In fact, the variety of delivery options and the perceived quality of the delivery service are major decision criteria for online customers and hence directly impact e-commerce players’ success in the marketplace.

2.2 Home delivery

Traditionally, customers take care of the transportation of goods from the point of purchase to their home. In some situations, such as a purchase of large or heavy products, the distribution supply chain may extend to customer’s residence. E-commerce has changed the shape of traditional supply chain and many products purchased online require physical transport to the end user. Home delivery refers to the delivery of goods to the customer’s home or another location of choice rather than the customer going to the physical point of sale for the pick-up. In addition, home delivery does not include home sales where a seller comes to a potential customer’s house with the intention to convince to buy a good.

Goods delivered to the end consumer's residence can be divided into attended or unattended deliveries. Attended home deliveries require the consumer to be available to accept the delivery. Attended deliveries set constraints for all involved actors, which have implications for energy efficiency. The recipient must wait at home, and the logistic
service provider (LSP)\(^1\) must adjust to a certain timeslot, making the routing more complex and sensitive to changes in delivery times. In the case of unattended home deliveries, the product can be left in a mailbox or, in some cases, at the door. Unattended home deliveries are normally successful because it does not require the presence of the consumer at their home, but an alternative provision for receiving the delivery needs to be in place. (3)

The most significant impact on transportation is the increase in direct home delivery of small shipments, so it generates a different transport need. The e-commerce revolution has given buyers the ability to create a virtual just-in-time delivery system and eliminate the costs associated with the retail trade. E-commerce purchases move from the manufacturer to the distribution centres, and then direct to the end users. An efficient reliable carrier delivery system is essential for gaining customer loyalty and confidence. (1)

Brwone states that the energy consumption by consumers to transport goods to their homes by car can be as high as the total energy consumption for all upstream freight transport activities combined. To counteract this, companies that offer home deliveries seek to improve route planning, aim for more efficient deliveries, and establish a more fuel-efficient transportation fleet. (4)

### 2.3 E-commerce

Nowadays, the electronic commerce or e-commerce is becoming a global tendency with the increase in the demand of online shopping. The e-commerce is just a representation of how the digital transformation continue to shape the behaviour and practises in individuals, organisations, systems and societies.

The e-commerce is a growing aspect of an increasingly digital age which continues to grow and spread to new markets and industries. During the last years, internet shopping has been noticing a constant growth, and it is expected to increase year after year as showed at Figure 1.

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\(^1\) Logistic service provider (LSP) are outsource entities shippers leverage to manage a company's warehousing, distribution and transportation of freight.
Internet has become an important business platform or tool to sell and distribute products for B2C organisations. B2C electronic commerce encompasses transactions carried out between the company and a final consumer via internet. Compared with the traditional market, B2C e-commerce opens new challenges for companies such as the customer service level which must be managed in order not to create bad company’s perception.

The main factors that drive the customer service level in the B2C e-commerce are:

- Order cycle time, that is the time it takes from a customer placing an order to them having it in their hands.
- Convenience of delivery. This is the ability of the provider to adapt the delivery mode to end customers’ needs. Schedule of the delivery time, delivery mode options, different delivery points, premium options are some examples of that.
- Delivery accuracy to be compliant with the conditions agreed with the customer purchase, for example with the number of unit loads, the delivery day or the type of product itself.
- Information about the product availability and delivery lead time.
- Management of the returns refers to the merchant capability to adequately support customers in case of returns. Cost of returns, maximum period to return products, information about how to make the return are some examples of that.
- Management of unsuccessful deliveries and after sales services.

E-commerce has changed the shape of traditional supply chain. It is true that in some cases customers can receive some items purchased online in digital form without the need of physical delivery, this is the case for example of airline tickets, music albums, etc. Nevertheless, many other products purchased online require physical transport to reach the end user. Figure 2 shows that most of the online purchases carried out in Europe involved physical goods as clothing and sporting goods, household articles and library items.
A major reason for e-commerce fast growth over the last twenty years is that it provides additional features compared to traditional commerce. Here some of the main advantages of the e-commerce are presented:

- The customer can realize transactions for a product or make inquiries about any product at any moment.
- The application of the e-commerce offers the users more options to compare products, and there exists comments of other users that can help to have an external opinion of the company about the product.
- Customer is not needed to move to the store to purchase a product.
- E-commerce increases the competitiveness between organisations and, as a result, they present significant discounts to online customers.
- No need for physical vendors and outlets anymore: website acts as a direct link between shippers and customers, withdrawing many intermediary actors.

However, e-commerce has not totally substituted traditional one because of some disadvantages presented below:

- Customer’s inability to experience the product before purchasing it.
- Need for an internet access device.
- Risk of impatience for the high shipping times.
- Consumers are at risk of identity fraud and companies cyberattacks.
2.4 Last mile logistics

Logistics Management is the part of supply chain management that plans, implements, and controls the efficient and effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements.

Logistics management has 3 levels of action: execution, planning and strategy. Logistics execution includes the design and management of the processes that support the data and/or documents, the flow of materials, for example: handling, storage, physical transformation and transport activities along the supply chain. Logistics planning is the process that plans for the adjustment of the operational capacity and for the execution of the operational activities linking the demand and the supply sides of the supply chain. Finally, the logistics strategy and design define the distribution network, the transportation modes and the make or buy policies. (7)

Fulfilment of last mile logistics concerns logistics activities in the last leg of the supply chain, where goods arrive to the final consumer. The last mile is defined as the process of delivering a good from the last distribution centre to the reception into customer's home or pick-up point. It involves a series of activities and processes that are necessary for the delivery from the last distribution centre to final delivery point. (8)

So, it is the very last section of the supply chain, starting from the moment that parcels are picked from the distribution centre until the good is delivered to final customer. The term ‘last mile’ refers specifically to the final leg in a system involving direct-to-consumer deliveries (D2C) and so, sellers bypass any third-party retailers, wholesalers, or any other type of middlemen to deliver their products. The description of the last mile process is shown in the Figure 3.

![Figure 3. An example of delivery service flow.](image-url)
In the B2C electronic commerce, the final delivery is one of the most complex, expensive and inefficient segments throughout the entire chain due to different reasons:

- Small size of the units handled and so, the logistics activities such as transportation and warehouse activities are related to small single orders.
- The high expectations of customers in terms of service level.
- Picking and packing activities are carried out by merchant and not by customers as it happens in the traditional process.

Some scientific works acknowledge that changes within the last mile characteristics can cause significant cost effects within the entire supply chain. So, the cost of last mile delivery may represent 50% of the total cost of the supply chain. (8)

In the online purchases, the customers tend not to differentiate between the role of the company that sells the good and the carrier that brings the delivery service. The mistakes made by the carrier are attributed to the retailer. Nowadays, in the digital era is where relationships with customers are made or break. Consumers evaluate companies based on their shopping experience, not only the online store, but also the email communication, delivery options and delivery service received in terms of time and cost. Negative experiences can damage image and sales of the company and so, the last mile is critical to the customer’s overall assessment of entire company and brand. (10)

2.5 Definition of sustainability

Sustainability is one of the most popular concepts nowadays between citizens, business, and nations. Growing concerns about the environmental outcomes of human activities have contributed to increasing the importance of this concept. At the heart of the corporate level, financial profitability is no longer the only goal pursued by managers across the world. It is important to understand what sustainability is about in order to became more profitable.

One possible definition of sustainability can be: sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- the concept of needs, in particular the essential needs of the world's people, to which overriding priority should be given.
- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

A common way to make an interpretation to sustainability is to divide it in three categories using the Triple Bottom Line approach. The way to achieve a sustainable activity for any corporation, any organization or any government must satisfy three criteria: economic performance, environmental responsibility and social wealth creation. Maximizing the corporate profit of the organization is what ensures that the company will last in the long run. Therefore, economic performance is an inherent part of the Triple Bottom Line approach to sustainability. The second bottom line is focused on conserving the environment along with using resources efficiently, taking care of the greenhouse gas (GHG) emissions and concern for biodiversity preservation. In transportation economy, the improvement of environmental sustainability is strongly
linked to the reduction of CO₂ emissions, among others. The third bottom line should go linked to improve the standard of human living. In the transportation industry, this can typically refer to the congestion issues, health risk from pollution, accident risk and noise, all caused by the impact on traffic.

Contributing to sustainable development requires to do things differently or to do different things, so innovation is key to sustainability. Sustainability-oriented innovation (SOI) involves making intentional changes to an organization’s philosophy and values, as well as to its products, processes or practices, to serve the specific purpose of creating and realizing social and environmental value in addition to economic returns. (11)

Throughout this project, sustainability will be addressed with stronger focus on environmental responsibility, which is at the heart of the current issues in last mile parcel delivery and it has more potential for sustainable improvement.

2.6 The ‘last mile issue’

The economic and social life of the modern world is concentrated in cities. According to statistics from the United Nations, the percentage of the population living in cities increased from 30% in 1950 to 55% in 2019 (12). It was estimated that cities generate about 80% of total GDP (13). This means that the major concentration of manufacturing processes and trade are in urban areas and so, this concentration is the cause of the development of the urban logistics system.

On the other hand, the focus of logistics systems in cities has negative consequences for the residents’ quality of life. From an environmental point of view, it leads to the accumulation of pollutants in the air and water, but also the generation of noise and traffic jam. According to the European Commission’s report in 2014, it is widely understood that urban transport is responsible for a quarter of the total emissions of CO₂ in cities.

The concept of ‘last mile issue’ regroups all the potential problems that are specific to the last stage of parcel delivery and that have been observed in most of the main developed cities around the world. The most substantial problem occurs in home deliveries, because the increase in the scale of online shopping led to an increase in the number of rides the delivery company cars do. Therefore, e-commerce enhances the tendency to increase the volume of parcels, along with a simultaneous fall in their weight and consequently, to increase the frequency of rides.

The last mile issue has a direct negative impact on all three components of the Triple Bottom Line sustainability approach. From a financial perspective, the last mile delivery is the most expensive part of the supply chain. Lower average speed, more stops, returns and failed deliveries contribute to an increase in time and cost (14). As for environmental aspect, they mainly focus on the CO₂ produced by oil-fuelled vehicles. In logistics, last mile transportation is believed to be the stage which has the biggest impact on environment (15). Finally, the main social costs can be linked to vehicle noise in residential areas, illegal parking practices and contribution to increase traffic resulting in more pollution that cause health issues (16).
3. Sustainable solutions for last mile

3.1 Delivery points

The growth of e-commerce has caused a significant rise in direct-to-consumer deliveries. Higher volumes of direct-to-consumer e-commerce, tied to inefficient last-mile delivery systems, can lead to a substantial increase in vehicle miles travelled, especially in residential areas, which not only results in high costs, but also in increased emissions, increased congestion, and a decrease in quality of life. Additionally, the situation is worsened when multiple visits are made due to missed deliveries.

In recent years, both the distributors and parcel companies have been forced to invest in new sustainable solutions in order to reduce the inefficiencies of the last-mile deliveries. The efficiency of last-mile delivery can be improved in at least two ways: by decreasing the distance from the distribution centre to the delivery locations and by reducing the number of missed deliveries. Both can be achieved using parcel lockers deliveries, trunk deliveries and urban consolidation centres. (17)

3.1.1 Parcel Lockers

Reducing the total distance of a delivery round has a positive impact on total cost, by reducing vehicle usage, fuel cost and labour cost because distances are related to the time needed for carriers to complete the delivery round. Additionally, the lower the distance and time spent on the road, the lower the impact on traffic congestion and so, the noise for neighbours. Therefore, it is possible to act positively on the three pillars of the Triple Bottom Line of sustainability by reducing the distance needed to complete a delivery round. The idea is to reduce the number of stops that the driver needs to make regrouping the drop of several packages in a single destination, in the so-called Parcel lockers. The deliveries will not take place at the customer’s home but at other locations, which will increase efficiency in a sustainable way. An example of this type of solution is the Amazon Locker (Figure 4).

Figure 4. Amazon Locker example. (18)
The parcel lockers are self-service lockers that offer customers the possibility to collect their orders with total autonomy. They are not located at the facilities of the company, neither in the customers home, but in public spaces as parking lots, railway stations or malls meaning that parcels can be retrieved conveniently 24/7 by the customers, providing a service with more flexibility than traditional home delivery processes. As for carriers, the consolidation factor is substantial, since the driver does not have to go to the recipients’ homes and can deliver all the parcels destined to a same neighbourhood in the same location, saving a lot of time and energy. A distinctive characteristic of parcel lockers compared to traditional courier services is the significant reduction in direct delivery failures as a consequence of the recipient’s absence.

Customers are not generally assigned to their own locker. In order to optimize its usage, lockers have electronic locks with a variable opening code that can be used by different customers in many days. Once the delivery arrives, customers are notified with the ubicación, the box number and the code to open it. Customers simply add an Amazon Locker to their Amazon address book and select the location as the shipping address during checkout. The parcel lockers require the customer to complete the end part of the delivery route. All orders delivered to an Amazon Locker must be picked up within 3 days of delivery, if customers cannot pick up their order within that time, it will be returned to Amazon Hub and customers will receive a full refund. For security terms, every Amazon machine is equipped with 4 cameras and alarm system. (18)

Another example of this kind of sustainable solution for the last mile logistics is the parcel proximity delivery system carried out by the company Geeever placed in Barcelona and Madrid. They articulate the value proposition through a capillary network of micro-warehouses in parking lots distributed throughout the city with a radius of action of no more than 700 meters. A differential factor is the zero impact on city traffic, given that the van arrives at night to unload the parcels in the designed spaces and so, avoid having to leave vans in double row for delivery, with the consequent dysfunctions for the city. Then, there exist 2 different solutions for the customer. The first one is the self-pickup at the lockers located near the neighbourhood. The second solution is the final home delivery that is made on an electric scooter, taking advantage of the fact that the stations are close to the final customer, thus increasing the level of flexibility and the percentage of success in the delivery. Geeever makes the majority of its deliveries between the 6 pm to 10 pm, since the factor of being more in contact with the customer they obtain a success delivery level of almost 96%. (19)
From an environmental approach, the gains from the decreased distance would be offset by the customers’ trips to and from the parcel lockers or micro warehouses, therefore resulting in a poor performance in terms of CO\textsubscript{2} mitigation. This is only partially true because from on hand, the automated parcel lockers and other collection points are strategically located, most customers do not have to take a trip which only purpose would be the collection of their parcel. Indeed, the delivery can take place to a locker located close to their routine travels. Therefore, this substantially mitigates the travel distance of the package in its last mile, even when considering customers’ travels. On the other hand, it is also increasingly common for customers to pick up their package on bike or on foot. This results in general in a very low carbon footprint per package from the customer’s perspective as well as from the carrier’s perspective. According to a case study, the CO\textsubscript{2} impact is 21\% lower for carriers when delivering to lockers and pick-up points than when doing home deliveries. (20)

Nevertheless, locker’s delivery has some downsides as well, the main one is the lack of willingness from consumers to make the last step of the trip themselves, which can be perceived as inconvenient that offset the benefit of the online shopping. Another issue is the size limitation of the storage units of the parcel lockers, not suitable for all the deliveries. However, parcel lockers have been designed at different sizes in such a way that 96\% of all packages intended to be shipped to a parcel locker fits. (21)
A research of the usability of parcel lockers from a customer perspective has been carried out in some cities of Poland. The research shows that with a 95% probability the parcel lockers users are satisfied with the service. Also 89% of the population values the parcel locker better than using Polish Post normal services. Both price of the service and the parcel locker location are two important aspects for using the parcel locker service. Speed of the service and 24-hours availability are mentioned as well as important characteristics, though they are related to price of the service. (22)

The financial side of the parcel locker is an important aspect in terms of efficiency in relation to a standard delivery model. The comparison between a courier delivery and parcel locker delivery has been made and shows substantial differences as shown in Table 1.

### Table 1. Parcel Lockers Sizes. (21)

<table>
<thead>
<tr>
<th></th>
<th>Medium</th>
<th>Large</th>
<th>Extra-large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (mm)</td>
<td>410</td>
<td>410</td>
<td>410</td>
</tr>
<tr>
<td>Length (Depth) (mm)</td>
<td>525</td>
<td>525</td>
<td>525</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>242</td>
<td>502</td>
<td>758</td>
</tr>
</tbody>
</table>

A research of the usability of parcel lockers from a customer perspective has been carried out in some cities of Poland. The research shows that with a 95% probability the parcel lockers users are satisfied with the service. Also 89% of the population values the parcel locker better than using Polish Post normal services. Both price of the service and the parcel locker location are two important aspects for using the parcel locker service. Speed of the service and 24-hours availability are mentioned as well as important characteristics, though they are related to price of the service. (22)

The financial side of the parcel locker is an important aspect in terms of efficiency in relation to a standard delivery model. The comparison between a courier delivery and parcel locker delivery has been made and shows substantial differences as shown in Table 2.

### Table 2. Comparison of courier delivery and parcel locker delivery daily. (21)

<table>
<thead>
<tr>
<th></th>
<th>Courier</th>
<th>InPost parcel lockers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily kilometres/ delivery driver</td>
<td>150</td>
<td>70</td>
</tr>
<tr>
<td>Parcels daily/delivery driver</td>
<td>60</td>
<td>600</td>
</tr>
<tr>
<td>CO₂ emission/parcel</td>
<td>300 g</td>
<td>14 g</td>
</tr>
<tr>
<td>Fuel consumption/parcel</td>
<td>0.23 l</td>
<td>0.01 l</td>
</tr>
</tbody>
</table>

In terms of cost-efficiency the number of parcels that can be delivered in one day by the parcel locker are 10 time higher than the home delivery. At the same time, the environmental gain and in terms of CO₂ emissions and fuel consumption seem to be significantly lower for the parcel locker. Important to mention is that the research does not mention anything about the number of parcel lockers needed, the exact locations, the size and costs of them.

Finally, another example of collection point is the use of local depots. In this case, the consumer can pick up his order from a depot or a supermarket which is located close enough from his/her home. More and more physical retail shops also develop their web shops, which is called multi-channel. Apar from the selling through physical store, some of them therefore propose a “click-and-collect”, or “clicks-and-mortar” model where the customer can come and pick up his online purchase in the nearest physical shop. The advantages of this method from the customer’s perspective are linked to the upsides of e-commerce such as customization, availability of the product and lower price. Depending on the proximity of the pick-up location, this can be considered as an alternative; however, if the customer needs to cover a long distance, then the efficiency is questionable. (23)
3.1.2 Deliveries in the car trunk

Many e-commerce companies and parcel distribution companies are implementing the service of delivering the package in the customers car trunk. Delivery to the trunk of customer’s car has recently been introduced as an alternative to home delivery, at least for customers who own a car. Real-time information about the location of the car is provided by the GPS system installed inside the vehicle. This innovative project leads to a reduction of the e-commerce missed deliveries and so, a reduction in cost and environmental impact. By delivering to the trunk of a customer’s car rather than to the customer’s home, delivery may have some advantages such as flexibility for the customers avoiding them to wait for the carriers to arrive at their homes and mitigate the missed deliveries.

The innovative idea of deliveries in car trunk dates back to the company emerging market called Cardrops, which in 2012 first attempted to address the technical challenges through the use of a device with GPS tracking capabilities, control of the trunk and a lock installed inside customers' vehicles. Soon after, the security and communication technologies that allow this delivery mode began to be seamlessly integrated as characteristics of the latest car models. (24) Not surprisingly, Amazon explored this innovative idea to improve the efficiency of last-mile delivery operations. With the trunk delivery, the orders of customers are delivered to the trunk of their cars. Amazon Key delivery collaborates with Volvo or General Motors vehicles, including Chevrolet, Buick, or Cadillac brands. This service is restricted by region at present and even if a customer resides in a region in which Amazon Key delivery is available, they must own a service-compatible vehicle. Additionally, this delivery option is not available for vehicles parked in garages with restricted entry or multi-level or underground garages due to lack of GPS signal for in-car delivery.

Users link their connected car to their Amazon account using the e-commerce firm’s Amazon Key app. No additional hardware is required, and deliveries can be made to cars parked in publicly accessible areas, such as a customer’s work or stadium parkings. Then, the carrier approaches the car, unlocks the trunk, puts the parcel in the car and then secures it, all without needing the car’s key. Users get notifications through the Amazon Key app when their package is delivered and thus, they only need to open the trunk to get the package. (25)

Amazon fixed some restrictions of the items excluded to this service delivery, there are the following:

- Items fulfilled by a third-party seller.
- Items that weigh more than 50 pounds.
- Items with dimensions that exceed 26 x 21 x 16 inches.
- Items that require a signature.
3.1.3 Urban consolidation centres (UCCs)

Due to ongoing urbanisation, the world’s cities are expanding and becoming overcrowded. A cause of this expansion, the demand for goods will continue to increase, especially the e-commerce market as explained before. This helps worsen challenges in big cities such as congestion, noise, CO\textsubscript{2} emissions and safety (27). Nevertheless, the demand for goods is a prerequisite for living and prosperous cities, so there is a need to identify viable solutions and logistic initiatives that aim to reduce this negative impact while assuring the supply of goods to citizens of congested cities.

One of the most frequently implemented and studied logistics initiatives in cities are the urban consolidation centres (UCCs). UCCs, if applied appropriately, have the ability both to improve supply chain performance and reduce environmental and social impacts of urban freight transport activity, and it can also potentially enable a change to more environmentally friendly vehicles for the last mile delivery. City consolidation centres are not new; consolidation centre initiatives were already examined some years before. For example, McDermott (1975) discusses the potential benefits and disadvantages from operating an urban consolidation terminal for carriers, shippers, consumers, society and authorities. (28)

The UCC initiative is a system including both a logistics facility for consolidation placed strategically near city areas, where different logistics service providers (LSPs) drop off their goods from the distribution centre, and then the outbound transport system executes the deliveries to final customers in the urban area. The idea of city consolidation centre is to separate the distribution activities in activities inside the city and outside the city. Transshipping at the city border makes it possible to benefit from the advantages of large vehicles for long haul transport outside the city without entering inside urban areas avoiding the negative impact such as pollution, noise, and traffic jam. After transshipment in a consolidation centre, smaller trucks transport the goods to outlets in the city. An extra
advantage is that the small vehicles in charge of the last mile can be fully loaded in the consolidation centre, which results in a minimum number of vehicles entering the city. (29)

![Figure 7. Illustration of the general scheme for UCC performance. (30)](image)

One of the major barriers concerned with making UCCs financially sustainable is the extent to which the various participants (carriers, final customers and local authorities) are willing and able to meet the financial costs of the UCC in return for the benefits that they receive. (31)

In the greater metropolitan area of Barcelona, more precisely in Hospitalet de Llobregat, the population is around 258,000 habitants, and the population density is about 21,000 habitants/km² and there is a high concentration of commercial stores of a wide variety of types. Therefore, there was a high number of commercial vehicles entering the city centre, illegal parking due to oversaturated loading/unloading places and lack of distribution regulations. The results are, low vehicle load factor, high operational costs in the last mile distribution, excessive GHG emissions, noise and pollution, as well as severe congestion. In general, in the metropolitan area of Barcelona, there is however a lack of a clear and uniform regulation to favour efficient urban delivery strategies.

To improve the performance of urban freight deliveries in Hospitalet de Llobregat, DHL Supply Chain created in 2016 a UCC to reduce the number of vehicles entering in the urban area (Figure 8) while maintaining high service levels. The shipment consolidation achieved by the UCC consisted on delivery loads of several carriers to retailers located in the commercial area of the city as well as the demand from final customers. (30)
The project involved several stakeholders: DHL, the Centre for Innovation in Transport (CENIT), provided support in the preparation and design phase, and the city council of Hospitalet de Llobregat that acted as the main promoter of the initiative. They aimed to achieve a reduction in the number of kilometres travelled by the fleet for interurban freight transport and a reduction in CO$_2$ emissions to the atmosphere. More specifically, the project had the following results:

- Transport costs in urban deliveries were reduced by approximately 25%.
- Higher handling costs of the terminal.
- The number of traffic movements were reduced with at least 30%.
- Significantly reduction in the number of truck-kilometres.
- Reduction in CO$_2$ emissions with up to 25% (based on model estimates and the expected reduction in truck-kilometres).
- Space devoted exclusively to UCC was only 42.12m$^2$.
- Load factor rose from 68% to 73%.
- Reduction in energy consumption of the fleet.
- Shorter delivery times due to the congestion reduction.
- Increased punctuality due to the proximity to destinations.
3.2 Sustainable warehouses

Decreased barriers to trade and improved technology has allowed businesses and supply chains to expand across regions and countries, and therefore increasing the need for the sustainable management of supply chains. Furthermore, it is inadequate for businesses to promote sustainability only within their own company, entire supply chains have to be managed in a sustainable way in order for business to remain competitive. One of the key components within the supply chain is warehousing because it is a driver of the cost effectiveness and customer satisfaction for companies. However, very few of them regard the environmental impacts of their actions and do not understand the social consequences of their business activities. A sustainable warehousing company would not only have to consider the economic factors, such as rent and operations costs, but also balance the social and environmental effects that occur within the warehouse compound. The term warehouse whenever it is used in this chapter refers more to a distribution centre. Although warehouses and distribution centres appear to be interchangeable terms, they do have different characteristics. A warehouse is a facility where goods are stored for periods of time, while a distribution centres tends to be associated with terms of flow, movement and fulfillment of customer orders in short period of time.

According to Baker and Marchant, the framework of a sustainable warehouse or consist of three stages. The simple level of a green warehouse is the one that has energy efficiency as a hallmark in its facilities. The second stage is that the warehouse’s operations are expected to consume renewable and green sources of energy to lower carbon emissions. In the most advanced stage of green implementation, the warehouse can self-produce energy from renewable sources such as solar panels, winds turbines, and biomass. At this stage, the warehouse becomes a truly green component of the sustainable supply chain. (32)

3.2.1 Sustainable Infrastructures

Regarding the first step of a sustainable warehouse, certainly, all warehouses need to consume energy to perform daily business activities. Considering that the largest consumption of energy in warehouse comes from heating and light systems, this significant consumption can be reduced by energy saving practices and efficiency equipment. A good example of that is the Alnatura distribution centre in Lorsch, Germany. This AS/RS2 facility of organic foodstuffs is 9,000 m² of area and the structure are made of wood, from sustainable sources and additionally, the building is 2.5 m into the ground. The good insulation and ground temperature effect enables the building to operate without any heating or artificial refrigeration. (32)

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2 An automated storage and retrieval system (AS/RS) consist of a variety of computer-controlled systems for automatically placing and retrieving loads from defined storage locations.
Another example of a design to reduce embodied energy used in the production of building materials is that of Adnams warehouse in Southwold, UK. This warehouse uses lime and hemp (natural substances) in its walls as well as glulam beam from sustainable forest sources in its roof supports. It also has a soil-covered roof on which the plant sedum is grown helping to maintain a constant natural temperature for the storage of its wines and beers. This type of roof not only provides thermal insulation but also results in cooling benefits from evapotranspiration and the metabolic processes of plants.
3.2.2 Green energy consumption

Concerning the second step of the framework of a sustainable warehouse described by Baker and Marchant, it refers to the use of green energy for the consumption in warehousing activities such as the lighting systems and the mechanical handling equipment. (32)

Managing lighting efficiently in terms of its functional performance, cost, energy use and resultant emissions helps to enhance energy efficiency, helping to reduce cost in the warehouse. An example of that was carried out at the distribution centre of Lidl in Heerenveen, Netherlands. The large grocery company changed the interior lighting system of its 46,000 m² of distribution centre with the cooperation of Philips. The distribution centre is equipped with long-life LED lighting of Philips LED Industry, combined with control systems, such as presence detectors and a daylight-based dimming system that adjusts according to the light entering through the domes. Corridors are divided into sections over 10 to 20 metre stretches. A third of the corridor might be lit at 100%, while the remainder stays at 20%. Outdoors, a similar principle applies. Automatic switches can turn lights on and off and ensure that they are dimmed when there’s little activity at night. All this leads to an energy saving of 45% a year in comparison with traditional fluorescent strips. (34)

To achieve the rapid and intensive movement of goods, all warehouses use a range of mechanical handling systems for the movement and lifting of goods. There are different pallet handling trucks depending on the requirements of the activities carried out at the warehouse. The starting point for the choice of equipment lies in wider equipment characteristics related to:

- type of access to products: aisle width and lift height.
- work environment: operating outside a building, on uneven surfaces or in closed spaces.
- weight distribution: for stability of trucks, every equipment requires a heavy counterweight.

For example, a simple manual warehouse will use counterbalance forklift trucks to unload and vehicles to move and lift pallets of products into block stacks. While higher throughputs, wider product ranges and more intensive operations add further specialist electro-mechanical systems. Traditionally, there are different types of power unit depending on the truck used: for internal-combustion engine it is used diesel fuel or gas (LPG), or there are trucks that use lead-acid electric-storage batteries. Additionally, secondary motors power hydraulic pumps for lifting.

All these type of power units generates negative impact to the environment. Looking to the future there are new internal-combustion power units using biodiesel or hybrid fuel combinations and hydrogen fuel cell technologies that are all coming on the market. Others are concentrated on adopting technologies with lower energy inputs and better operational controls by relating equipment performance specification to activity and need. (32)
Since 2015, Toyota Material Handling Europe a has also improved the energy efficiency of its electric trucks. 85% of electric-powered product families are available with lithium-ion (li-ion) batteries. The intelligent design features on these li-ion batteries deliver a 13 to 25% reduction in electricity consumption over lead-acid batteries. This first energy efficiency improvement is due to a reduced energy loss in the charging process of li-ion batteries versus traditional batteries. They can be recharged quickly, and truck availability is further improved through greater storage capacity and 10-20% lower energy loss. The upfront cost of a li-ion battery is higher than a traditional lead-acid battery but, it has longer life spans and lower operating costs due to a significant reduction in energy use and therefore, CO₂ emissions. (35)

Additionally, Toyota is innovating with hydrogen fuel cells as an energy source for its trucks. Their only emissions are water and heat, refuelling with hydrogen for up to 10 hours operation is as quick as for internal combustion engines. The use of fuel cells in transport today is constrained by the lack of hydrogen infrastructure, but it reduces CO₂ emissions by 300 tonnes per year. (35)

![Figure 11. Example of Toyota Material Handling trucks. (35)](image)

Another way to reduce CO₂ emissions and increase efficiency in the warehouse handling system is with digitalization, automatization and robotization. Automated storage and retrieval systems (AS/RS) not only bring operations costs and time reduction for warehousing operations, but also optimise warehousing activities positively influencing our environment producing less CO₂ emissions. Another advantage associated to automated warehouses is the space optimisations due to it uses narrow aisles, and thanks to digitalization the waste of paper is minimized.

An example of this innovative technology is the Hub Logistics automated warehouse in Hakkila, Finland. What they offer with such automated and digitalized warehouse are process quality with high accuracy and security levels equal to almost 100%, operation speed and operational reliability with constant performance measurement and reporting. Hakkila warehouse needs only 3 hours to complete a customer order to delivery, it has picking speed of 3500 rows per day, while in an average manual warehouse order completion time would be 12 hours and picking speed would be 250 rows per day. The definite advantage of this system is that it can work during the night-time, requiring no lighting or air conditioning like humans would need, and relocating inventory according to later orders fulfilment and facilitate work productivity. (36)
3.2.3 Self-generation of renewable energy

Green energy for the consumption is an essential step for reaching a sustainable warehouse described by Baker and Marchant (2015), but to engage more actively with the need to reduce emissions moving to self-generation of renewable energy is the third phase towards achieving a sustainable warehouse.

A perfect approach to cut off emissions and greenhouse gas as well as save energy costs is the self-produce partial or nearly full energy needed in the warehouse by using renewable energy sources. Nowadays, the most used and clean sources of energy are solar, biomass, and the wind. (32)

Amazon is a company that is investing in new initiative to generate clean energy by installing solar panels on its fulfilment facilities around the world. In 2018, Amazon introduced a new rooftop solar energy system in its fulfilment centre in Tracy, California, a collaboration was carried out with the company Prologis. With 11,700 solar roof panels, the 3.8 MW rooftop installation is one of the largest in Northern California and represents the latest collaboration between the two companies. Prologis and Amazon worked together to achieve their joint goal of optimizing sustainability in the Tracy facility, the solar panels generate enough electricity to power the entire warehouse consumption. (37)
Another example that self-generates its own green energy for consumption is carried out by the Nike company. In Ham, Belgium, the company opened in 2019 a new distribution centre powered entirely by renewable energy, the latest milestone in Nike’s moved to zero carbon and zero waste to help protect the future of sport. The new facility, called the Court, expanded Nike’s logistics capabilities to meet growing consumer demand in Europe while advancing sustainability at scale. The Court is 1.5 million square feet and operates completely from wind, solar, geothermal, hydroelectric and biomass power. In addition to railways and highways, surrounding infrastructure includes a network of canals, enabling 99% of inbound containers to reach the facilities by water. This eliminates some 14,000 truck journeys each year, reducing associated carbon emissions. (38)
3.2.4 Waste Management

Once discussed the sustainable warehouse practices in terms of the energy perspective, it is also important to mention the huge volume of packaging waste managed in the warehouses. This waste generation is an inevitable consequence of daily warehousing activities. Goods are constantly on the move; inbound and outbound deliveries have to be dealt with as well as the movements of items from location to location inside the warehouse. Therefore, the volume of packaging waste, often in the form of corrugated cardboard and plastic wrappings, is left behind and needs to be taken care of. This is the reason why an innovative management of waste is an important duty in a sustainable warehouse. An appropriate strategy and implementation of waste management help companies reduce costs while comply with local environmental regulations and increase their social responsibility efforts.

The smart way to achieve a sustainable waste management solution is considering it at the very beginning of the process. A common mistake for both small and larger companies when planning a new building or an extension of an existing one, is to forget about how the waste streams will be handled. It can have expensive economic and environmental consequences and result in a less efficient last-minute solution.

An interesting approach used for implementing warehousing processes that protect the environment is looking at three main areas: reduce, reuse, and recycle. The Carlsberg group implemented an example of sustainable packaging management system.

The first idea was reducing the amount of packaging they used in shipping products. Advances in packaging materials allow a reduction in weight while maintaining efficiency. The reduction in packaging weight not only reduces shipping costs but saves energy by moving packing material and packed items around the warehouse.

In addition, Carlsberg warehouses adopted the concept of returnable packaging, items such as wood pallets and plastic totes are constantly reused. Working with their suppliers, they increased the life-cycle of this material, and so they can be reused a number of times, reducing waste and saving money.

Additionally, in 2013 they implemented glass bottle collection systems in 11 cities across Russia, with the aims of improving the recycling rate of its bottles, an expensive package. As part of the initiative, they cooperated with regional government and provided containers for separate waste collection, such as PET packaging, glass, aluminium cans, cardboard, etc, that were submitted for recycling. Over 60% of the aluminium and glass waste collected as part of the project were recycled and thus, their cans and bottles contain up to 30% of recycled materials. (39)

![Carlsberg Icon of sustainability.](39)
3.3 Current sustainable transportation modes

Identifying the type of vehicle fleet for the last mile delivery is crucial for companies because it plays an important role on many different cost influencing parameters or factors such as fuel consumption, load capacity, security and safety practises, methods for loading and unloading, time of the delivery, cost of transportation, etc.

Less obvious is the choosing of the type of information and communication technologies used for delivery, although it plays an important role in the efficiency and cost structure of the last mile. For optimal routing, it is important the communication with the couriers to inform them where they have to pick up or deliver parcels when they are driving on a specific moment or in case a consumer has changed the delivery address or reception point at a late moment. By using communication technologies, in most cases, a significant amount of time and fuel can be saved. When the level of information technologies was significantly lower, much more paperwork had to be done, more manual checks and sub-optimal routes were more common. By using the situation-specific information technologies, in most cases, a significant amount of time, fuel and paperwork can be saved. Another good consequence of increasing use of IT is the increased level of reliability of deliveries. (40)

Rethinking the fleet of vehicles used in the last mile can sometimes impact the efficiency of the deliveries themselves, but mainly their fuel-efficiency. The impact on cost is uncertain, as investment needed for the ecological transition may result in higher costs, cancelling out a part of the efficiency gains and cuts in fuel expenses. Some of these alternatives can also have a positive impact on congestion reduction, contributing to an overall improved sustainability.

The literature review shows that the results indicate a trend for the implementation of smaller and lighter vehicles for last mile deliveries in urban areas: 47% of the studies suggest, among other alternatives, the use of bicycles and tricycles, while 53% of the articles support the use of light commercial vehicles. Another trend observed in this type of distribution, indicated in 64% of the studies, is the shift from conventional (fossil fuels) to alternative sources of energy (electricity). (41)

3.3.1 Electric vans

The standard delivery vehicle is the diesel van because it is the cheapest source of energy for such vehicles but is not sustainable. Growing concerns for the environmental impact of GHG emissions from fossil fuels have caused carriers to search for alternative energies for their motor vehicles. Nowadays, some companies are planning to operate in last mile delivery market by electric vehicles, however they cannot stand alone without government intervention because there are many drawbacks such as:

- Long-time of charging
- Low number of charging stations. Additionally, not all cities have invested in these infrastructures.
- Battery price is still high.
- Short driving ranges
Nevertheless, as part of its zero-emission commitment, IKEA Retail aims by 2025 for 100% of home deliveries to customers to be done by electric vehicles (EV) solutions in all its 30 countries that it operates. At the beginning of 2019, IKEA said it already had accomplished that goal early in Shanghai. Every IKEA delivery in Shanghai is being made by an electric vehicle.

Angela Hultberg, IKEA’s head of sustainable mobility thought that being able to accomplish this task happens to find a way around the existing conditions and look for partners willing to work with them to develop new prototypes. So, a coalition of global corporations, including the shipping giant DHL, launched a global campaign to accelerate the shift to electric vehicles. (42)

![IKEA Retail electric van](image)

*Figure 16. IKEA Retail electric van. (42)*
With truck carrying 20 m³ box enables the company to load its orders with full carton pallets specific for IKEA. This way of working means faster loading as well as minimising the number of vehicles on the streets by fully utilising the space of each truck. Finally, the new vehicles have the range to reach most of IKEA city customers from its stores and logistics units.

Hultberg said also that there is a return on investment to this because maintenance costs and operational costs of electric delivery vans are lower than traditional diesel-powered ones. Indeed, a report published last year by the North American Council for Freight Efficiency found that a medium-duty urban delivery van that has a stable route of between 50 to 100 miles per day could be one of the earliest commercial vehicles to economically go electric. That is because charging can be done predictably, stop-and-go traffic can tap into regenerative braking and there is a sweet spot of miles driven. (43)

Additionally, it exists also the cost of not doing this change because many of cities in Europe are planning to prohibit fossil-fuel-powered vehicles from entering certain city centres. So, if IKEA have not zero or low-carbon vehicle delivery options, it might not be able to deliver goods in certain European zip codes.

On the opposite hand, Schöder, Ding & Campos (2016) highlight the difficulty to operate a shift from a type of vehicle to another due to the “lock-in effect”. Indeed, the current high market price of electric vehicles is a substantial barrier because the investment needed is important and so, not all the companies specially the small ones, they usually do not have the financial leveraging power necessary to operate a significant shift. (44)

### 3.3.2 Cargo bike or Cubicycle

In order to deliver small packages, Cargo bike is a solution. It is an electric delivery bike fitted with three or four wheels that can deliver small packages. This means that the driver must pedal to move forward but the electrically assisted commercial cargo bike is fitted with an additional engine that constantly helps the driver. It also is equipped with a rear trunk giving it a large load capacity. Normally, an electric cargo bike for deliveries offers a load capacity of about 1 m³. It is aimed at local traders who want to put in place a home delivery service for their customers, all while growing their visibility in their district. (45)

DHL Express has introduced a new vehicle to its fleet in some cities in the Netherlands, Belgium and Germany that will further enhance its efforts to improve its carbon efficiency. The Cubicycle is an electric four-wheeled cargo bike fully equipped with a special container. It can transport up to 125 kg of goods. It is intended for parcel deliveries in the city and the courier departs from a service centre on the outskirts of the town.

DHL Express aims at a double goal. First, this fits perfectly into the DHL Go Green program, which aims for a more environmentally friendly last mile delivery. By 2025, the company wants to reduce its CO₂ emissions by 30%. Secondly, the Cubicycle facilitates delivery in the city centre since the launch of circulation plan implemented in some cities. Therefore, the cargo bikes can reach every district of the city. Once all packages have been distributed, the vehicle returns to pick up a new load of parcels. This delivery method proves to be very efficient. It is also more productive than delivery by vans thought Danny Van Himste, General Manager of DHL Express in Belgium. (46)
Other examples more common on the food delivery industry are the cargo bikes. Companies such as Glovo, Deliveroo or Uber eats delivers fresh food products in urban zones using cargo bikes. The **Figure 18** shows the block diagram of the proposed solution for delivery of food products in urban zones using cargo bikes. The users of the system are all participants in the chain of distribution of food products: the producers and sellers of food products (restaurants, bars and supermarkets), the deliverers of food products and final consumers.

The server application is linked to a database that contains user data (their names, locations for pick-ups and deliveries of food products) and enables interconnection between final consumer and producers. Through these server applications, producers and sellers of food products are connected online. Deliverers bring the package from the producers and sellers’ position to customers’ home. Consumers can have an insight of the status of the product and the actualised location.
These solutions could help to improve the quality of air and reduce pollution in the big cities with high population density and, it helps to solve congestion problem. The low speed of the vehicle and the small loading capacity are the principal barriers. However, to overcome them, the use of Urban Consolidation Centres has been considered as an efficient combination, as it would allow a bike to refill in a location close to its delivery area. Even if in some concentrated areas, many companies may face high cost to acquire places to allocate hubs, the low initial cost and variable cost of this mean of transport could counterbalance the high facility’s investment cost. (47)

3.3.3 Electric scooters

Electric scooters began as vehicles primarily intended for leisure and entertainment. However, nowadays they are being used for the distribution of goods in the last mile delivery. In the city of Barcelona, it is already being implemented taking advantage of the fact that with current batteries and electric engines technology, a delivery route can be perfectly covered within the range of the autonomy of these vehicles. Not only saves money, but also reduce pollution levels in urban areas and they are ideal for activities that involve the transport of small sized goods.

Additionally, the carrier brings a backpack on his back where he carries the packages and they also have a loading platform on the front which is used also for transportation of packages; however, the volume and number of packages are limited. On the other hand, this solution has an excellent manoeuvrability due to the facility of use and operate arriving at locations where other modes of transport cannot arrive. It is also a fact that for accelerating the growth and adoption of electric scooters in last-mile deliveries, cities must provide adequate charging facilities, and safe infrastructures for the circulation of these type of vehicles.

An example of this mode of transport for the last mile delivery has been mentioned before with the company Geever in the parcel locker section. Behind the final home delivery innovative project, there is an underlying vision of the neighbourhood seeking that the delivery person to become someone who customer can trust. In this sense, when hiring personnel, residents of the area in question have been chosen, who are offered a part-time contract. (48)

Figure 19. Example of electric scooter for deliveries from Greever. (48)
3.4 Future sustainable transportation modes

For urban freight transport in last mile delivery, the electric vehicles for transportation described before are used as an alternative of the traditional transportation methods powered by fuel fossil energy. Such scenario could reduce CO₂ emissions by 30%, congestion by 30% and delivery costs by 25% on 2030 when compared to a “do nothing” baseline (49). In addition, despite the sustainable solution they represent in terms of economic, social, and environmental perspective, some problems are associated with them. Loading capacity and speed limit constraints are some examples of that, especially in urban areas or when the load weight is exceeded. Other limitations of these transportation modes include the inability to climb steep slopes and the potential risks due to extreme weather conditions. In addition, consumers order more things online, expecting more control and faster deliveries. This are the reason why the last mile solutions are scouting new sustainable methods.

Digitalisation and robotisation are already having an impact on the production, packaging, picking and sorting processes in factories and warehouses, and will be also at the heart of urban freight solutions of last mile deliveries. Soon, disruptive technologies, such as droids, robots and driverless cars, will be able for ever-shortening delivery times, allowing for more efficient last mile solution and the launch of an alternative in transportation modes. Nevertheless, the use of the new solutions presented below is currently technically feasible but with numerous barriers that still must be overcome to make it a good alternative to the problem of capillary distribution in large cities. (50)

3.4.1 Drones

In the last recent years, Drones have been increasing its popularity for its huge applications and uses it could perform. Drones refers to an aircraft that flies without a crew, which performs its function remotely. The unmanned aerial vehicles (UAVs) are capable of autonomously maintaining a controlled and sustained flight level powered by electric batteries.

The idea of using Drones for last mile delivery has been gaining popularity during last years. The ability to travel from an origin to a destination in a short time and with the help of the GPS on board, could have many advantages. Its use may have the potential to decrease delivery costs because of the fast speed they could have due to the fact that drones are not constrained by road infrastructure and congestion; they can also deliver packages faster than a car/van from a close-by storage location. In addition, they have the ability to reach difficult terrain or remote locations and fly over obstacles on the ground. Furthermore, delivery drones should also have a reduced environmental impact, as they will eliminate urban congestion and air emissions. (51)

On the contrary, while drones certainly offer several advantages compared with more traditional delivery methods, many limitations still lie ahead for drones to scale. For example, because drones work with batteries, its flight distance and lifting power are limited, which means that are restricted in both the maximum travel distance and the size of the package. Furthermore, there is also a need to invest in infrastructure to relocate or build new distribution centres and define the new points of delivery where drone could leave the package to customers. Finally, drones can lead to injuries to people who are subject to having drones flown over them so, regulations might also be defined. Given
the risks, insurance costs for drone systems may further increase operating costs. With all of that, many delivery providers are testing drone delivery for its future implementation. (52)

Two main types of electric drones have been tested for delivery: multirotor drones (quadcopter and octocopter) and hybrid drones. The multirotor drone is the most popular type given its manoeuvrability, and it runs on batteries. Depending on the model, multirotor drones have an average maximum carrying capacity of 2 to 5 kg, a maximum flying distance of 15 to 40 km, top speed of 50 km per hour; these types of drones need to land for each delivery. Otherwise, hybrid drones are equipped with propellers and wings, they can take off and land like a copter and can glide like a plane. This design increases the distance the drone can reach. In 2015, Amazon unveiled a new hybrid delivery drone, which uses eight rotors to take off vertically, then switches on an extra rotor to fly horizontally, and finally lands vertically to a given location. (53)

Figure 20. Hybrid delivery drone from Amazon. (53)

The first example of an unmanned aircraft that has been exceptionally authorized to deliver goods in Europe was carried out by the logistic company DHL in 2014 to get urgently needed goods such as life-saving medicines to Juist, an island in Germany’s North Sea where more traditional delivery options such as ferries or trains were not always available. The roughly seven-mile flight to the island took about 15 to 30 minutes as the drone hits speeds of up to 40 mph. So once the drone had arrived, bicycle couriers delivered the medicine to residents of the island.

Another example of that is carried out by the Wing drone’s delivery company supported by the big company Google. In 2019 Wing has built delivery drones and navigation systems that can deliver small packages directly to home in minutes, in addition to an Unmanned Traffic Management (UTM) system that helps drones navigate the skies safely. Now is currently testing its operations in Australia, Finland and USA bringing products from pharmacy, coffee shop and hardware stores. Furthermore, and due to the coronavirus situation, Wing has seen a significant increase in requests for deliveries since the outbreak began.
Regarding the operation process, it is quite similar as the traditional method, in summary, once a customer submits an order via the Wing mobile app, the drone flies to pick up the package at the delivery facility. The drone then climbs to a cruise height above ground, flying to the designated delivery destination in several minutes. Once at the customer destination, the drone slows down, hovers, descends to a delivery height of 7 metres above ground, and then lowers the tether and automatically releases the package in the desired delivery area. (54)

Amazon has also invested in the solution of drone deliveries with the launch of Amazon Prime Air. The service is supposed to deliver with drones small packages to customers within 30 minutes of ordering. It is estimated that around 20 percent of Amazon’s e-commerce orders meet these criteria. The operations were expected to begin in select cities starting late 2019; however, the service has yet to materialize. Apart from the investments in drones, Amazon has already found two solutions for the future distribution centres that operates with drones’ deliveries and made the patterns public in 2016: the Multi-level fulfilment centre and the Airborne fulfilment centre.

The Multi-level fulfilment centre (Figure 21) was designed to accommodate landing and take-off of unmanned aerial vehicles (UAVs). These skyscrapers would allow them to pick up and drop off packages from all floors of the building, which would significantly increase delivery efficiency. By locating the fulfilment centres within urban setting, such as densely populated areas, items may be more quickly delivered to the growing population of people that live in the cities, as well as the large population of people who work there. Finally, these hubs will also include central command centres to essentially serve as air traffic control stations like those found at an airport. To sum it up, this solution would replace the traditional warehouse model in favour of modern, drone-friendly versions that could serve as both charging hubs and convenient pitstops for delivery drones to pick up and drop off packages efficiently. (55)

The Airborne fulfilment centre (AFC) (Figure 22) may be an airship that remains at a high altitude and UAVs with ordered items may be deployed from the AFC to deliver ordered items to user designated delivery locations. As the UAVs descend, they can navigate horizontally toward a user specified delivery location using little to no power. What Amazon pretends with this solution is providing the distributions centres with mobility and so, it would drastically lower the energy required to deploy delivery drones to their final destinations. These aerial warehouses would stay afloat with helium or hot air and store the inventory that corresponds with whatever metropolitan city. Additionally, customers could even browse the specific list of items the Airborne distribution centre above them has in stock. In addition to these, it will allow the online retailer to have items delivered within minutes when a user place an order, decreasing drastically the operations costs for Amazon while improving the purchasing experience for its customers. (56)
Figure 21. The Multi-level fulfilment centre by Amazon. (55)

Figure 22. The Airborne fulfilment centre by Amazon. (56)
Ultimately, like many other patents, it is difficult to tell how tangible this idea is and will move toward reality. It should be emphasised that, while the development of drone-beehives for last mile delivery may already be viable, the setup of such distribution centres would require important industry and public involvement. Such consultations would be particularly important, considering the novelty of drone delivery, to address concerns and policy implications in terms of safety, environmental nuisance, urban planning, air traffic, city logistic, and employment in the delivery industry. (57)

3.4.2 Autonomous vehicles

Increasingly, autonomous cars, or vehicles capable of sensing their environment and navigating without any human input, are being visualized as a key transportation mode of the future for human and package deliveries. Most major automakers such as Tesla, as well as technology companies including Google, Apple, and Uber, are working on autonomous driving technologies of varying degrees. However, recently a debate of their utilisation has been opened due to the accidents they have provoke, some of them fatal ones. Even though it may take more time before this technology is widely available, it is likely to also have an impact on the last mile delivery market.

Autonomous vehicles for deliveries consist of autonomous vehicles that deliver the product to customer’s doorstep without any human intervention in the entire process. Self-driving cars are powered by electric batteries and use also multiple technological innovations to figure out where they are, what is around them, and a software that can interpret common road behaviour and signs in order to reach their destination. These vehicles could have substantial benefits in terms of fuel consumption and CO₂ emissions because its efficient driving performance. When it is used for long haul transportation, they can also operate for longer hours, thus providing greater flexibility in delivery times and increasing operational efficiency. Concerning the last mile delivery, autonomous vehicles would only be useful for deliveries to remote areas. Since driverless vehicles are not limited by such constraints as driver fatigue and so, it would be easier for them to drive longer distances to deliver items. (58)

On the other hand, there are some studies focusing on urban last mile deliveries involving the so-called Sidewalk Autonomous Delivery Robots (SADRs). They are pedestrian sized robots that deliver items to customers without the intervention of a delivery person. Since SADRs travel on sidewalks, they have been the subject of increasing regulations. Some studies analysed the regulations of the SADRs in the USA and its potential time and cost savings. (59)

The idea behind this solution is to bring many SADRs in a common van, each of them with an urban delivery point. Once the van arrives to the urban area, the SADRs get out of the van and split to reach the delivery point. They use sensors and navigation technology that allow them to travel on roads and sidewalks without a driver. When compared to a conventional human-driven delivery van, SADRs can reduce cost, time, and vehicle travel in some instances. Road delivery robots are also more economical when delivery routes are relatively short. However, due to their limited range, vehicle miles tend to increase in most scenarios.
Amazon launched in 2019 an electric ASDR vehicle called Amazon Scout. The small six-wheels vehicle can navigate around pedestrians and other objects on the sidewalk as it rolls to deliver the goods. It can withstand adverse conditions from an unexpected rain shower to the infrequent sun, and even the biggest snowstorm. Nowadays Amazon has started to test this service in some cities of USA, but it is not clear when they will be consolidated as a last mile delivery solution. (60)

The company FedEx is also investing in the robots for the delivery of products to their customers. The Roxo project is being tested and developed since 2019. It is a delivery robot that, thanks to artificial intelligence and the various sensors it has, it can follow a marked route to deliver the requested order at the customer's door. It offers safe navigation since it detects any obstacle with its sensors. This vehicle can roll on almost any type of terrain and going up and down slopes and stairs. In addition, it is designed to transport all types of cargo within logical size limits. Compared to the Amazon Scout, it has more capacity, but its speed is lower. (61)

Furthermore, Mercedes-Benz has created a prototype van containing individual SADRs stored inside. It has the capacity to store 8 delivery robots from Starship Technologies. When a van stuffed with the robots and the deliveries for households arrives at a central location, it will then be able to unload the delivery vehicles, through a drop-down ramp, which will complete the last leg of the journey to avoid city centre traffic. At designated delivery stops, the van's driver takes the load carriers for the impending deliveries from the racks according to the pick-to-light process and inserts them into the robots. Instead of driving door-to-door and doing stop-and-go deliveries with the vans, it can stop in a location, and wait for the robots to come and load-up the goods and do the last mile of the delivery. (62)
In summary, autonomous electric delivery vehicles can significantly reduce carbon emissions; policy makers and regulators should seriously consider their benefits. Potential cost savings brought about by driverless technologies can accelerate the growth of e-commerce as well as package and grocery deliveries. One of the biggest technical challenges in the development of autonomous delivery systems is the difficulty of reaching any area without disturbing traffic and pedestrians. Additionally, the delivery of products with less human contact and proximity could have negative impact in human daily life due to program mistakes, however some consequences may also be positive which is appealing during pandemics. In addition, future research efforts can evaluate the impact of these new vehicles and technologies on last mile delivery.

3.4.3 Subway automation system

The last example of future innovations in the transportation modes for sustainable last mile delivery presented is the tube transport or underground system. The sustainability trends, such as environmental impact, reduce traffic jam and taking profit of public space, lead to this concept applicable in different areas and within the delivery phase. The basic principle is the transfer of goods inside capsules through an underground pipe network within urban areas, so the occupation of public areas such as streets and sidewalks can be minimal.

In the late 19th and early 20th century, underground tubes were used in many cities to speed up the transport of mail between post offices and government buildings. Letters were put into capsules, the capsules into the tubes, and compressed air was then used to push the capsules from one station to the next. However, the air compressors are expensive to operate and maintain, and the energy they produce dissipates quickly, so capsules can cover only short distances. But technology now exists to overcome those limitations. In 2003, Franco Cotana, an engineering physicist at the University of Perugia patented a system based on a network of metal pipes. Instead of using air pressure, it uses magnetic fields. These fields, generated by devices called linear synchronous motors, both levitate the capsules and propel them forward. The capsules are routed through the network by radio transponders incorporated within them. At each bifurcation of the pipe, the transponder communicates the capsule’s destination, and the magnets pull it to the left or the right, as appropriate. (63)
The evolution of this new technology inspires some companies in defining a new transportation system based on moving capsules through an underground network until reaching the final customer. The German company CargoCap defied a new alternative for the urban transportation of goods for the last mile delivery. Transportation as such is executed by individual intelligent vehicles, the Caps. Each Cap is designed for the transportation of two euro-pallets, and they can thus be directed through pipelines with a diameter of 2 metres.

The Caps call at many stations in an extensive underground transportation pipe network 24 hours a day. At their destination, one or more Caps arrange themselves automatically into the station to be reloaded or unloaded. Because of underground transportation pipes, the system is unaffected and uninfluenced by other transports, traffic routes and traffic jams and so, it leads to a significant decrease of transport time, noise, and exhaust fumes. (64)

Figure 25. CargoCap System delivery scheme. (64)

The laying of additional transportation pipes next to, under or over existing pipes, subway tunnels and other underground buildings would need an investment and collaboration of the regional government. If the demand for transport with this mode increases, the underground transportation network would grow with it. Because of using pipe jacking for building the underground network, and the relatively small diameter of the transportation pipes, the picking stations can be laid in existing infrastructure facilities without problems.
One of the main limitations is the low level of flexibility in terms of access points by users. Nevertheless, British start-up Magway is planning an alternative, they want to build narrow tunnels and tracks that could run underground next to metro lines of the most crowded cities in the United Kingdom, carrying parcels and groceries. The company’s idea is similar to the one described by CargoCap. Building a series of pipes, less than 1 meter wide, that could transport items traveling along a track powered by a magnetic motor, connecting distribution centres to final consumers, who live close to the area around the particular metro line. Once the vehicle arrives to the allocated station, there would be a horizontal automation system on the pavement of this station that will retrieve the packages. (65)

Finally, the aim of the idea is to make the last mile distance much shorter, especially with the huge network in big cities. Additionally, there would be a huge reduction in the pollution and congestion in cities due to the reduction of transportation vehicles in the road. Nevertheless, to apply this idea, it would be necessary a huge initial investment to integrate the automation system in the network and the government and other stakeholders would be involved for using public space.
3.5 Optimizing routing policies

A large proportion of freight distribution in last mile delivery is carried out by road vehicles. Assigning customers’ demand to the vehicles, followed by routing and scheduling them, involves a set of decisions that can have a significant impact on the costs and service level provided. Currently, trends call for integration of environmental management with ongoing operations. This not only increases complexity in the chain but also may equally lead to conflicting interest between economic and environmental requirements.

Environmental issues can impact on numerous logistic decisions throughout the supply chain such as location of distribution centre, sourcing of raw material, transport planning and transportation modes, among others. Many companies are exploring ways to achieve environmentally sustainable logistics practices while considering the most cost-effective solution. Therefore, decisions regarding these activities at strategic, tactical, and operational level will determine the environmental impact. In this section, it will concentrate in the reduction of environmental impact by optimising the fleet planning in the last mile deliveries. (66)

When the set of customers and their demands change little, then the experience can lead to good sets of routes that meet constraints concerning the vehicles, such as their capacities, and service requirements, such as time windows for deliveries at customers, all of them aiming at minimizing the economic costs of the operation. However, when the customer base and demands are constantly changing, for example in the e-commerce market, then it is often advantageous to make use of a computer technology to solve such problem. It has been suggested that the use of computerized procedures for the distribution process planning produces substantial savings in the global transportation costs. (67) The objective is to find out the optimal number of trips that minimize the total amount of kilometres driven by the vehicles for the deliveries. It is expected to increase the fleet efficiency and, consequently, reduce the unnecessary distance travelled that can lead to a reduction in fuel consumption, and hence a reduction in greenhouse gas emissions. Furthermore, a reduction in empty running vehicles would also yield significant environmental benefits. (68)

In 1959 Dantzig and Ramser were the first to introduce the Vehicle Routeing and Scheduling Problem (VRSP). It consists of minimize the total distance driven by the vehicle fleet while satisfying all the customer orders when a set of customer deliveries must be made from a central depot. Within the denomination of these routing problems, there is a wide range of variants and problem customizations. From the simplest to some much more complex that even today are the subject of research. Nowadays and despite the technology advances, the computation time required to find the optimum solution for any known method increases exponentially and so, the optimum solutions can be only found for problems of limited size. For the other cases, heuristic methods are usually applied even though they do not guarantee to find the optimum solution. (69)
Several companies, especially in the fast-moving consumer goods industry and in e-commerce, have realized that for implementing the optimal routing policy in the last mile delivery, it is necessary some advances in data analytics and technology. The possibility to achieve real-time visibility by using telemetry systems\(^3\) through advances in sensor technology, vehicle connectivity and delivery data from individual routes, allow to develop a more precise picture of the company’s last-mile operations. Therefore, it helps to adjust the last-mile distribution approach to changing market dynamics and becoming more cost-efficient and reduce environmental impact.

With the rise of the Internet of Things, it is now possible to obtain system-wide insights into the number, status, location and expected trajectory of products and shipments along their entire journey. This new level of detail and dynamism enables companies to substantially reduce the number of blind spots in their distribution networks, maximize service levels and minimize cost inefficiencies due to inaccurate planning.

In addition to the reduction of the environmental impact, the use of telemetry systems also takes importance as a measure to monitor and evaluate the driving of goods transport vehicles in order to improve road safety. In Spain in 2017, goods delivery vehicles were involved in more than 16% of accidents with victims in urban areas, and vans alone accounted for almost 4,800 of these accidents (70). As a result of the installation of one or more devices in the delivery vehicles, data such as average speeds, use of brakes, pollution levels and time at the wheel can be measured. The effective management of this data will allow to improve security in the performance of distribution activities in urban areas. (71)

An example of the optimization of the routing policies was carried out by the big package transport company UPS. Each business day, UPS drivers make an average of about 100 delivery stops. To ensure UPS drivers use the most optimized delivery routes in regard to distance, time and fuel consumption, UPS developed On-Road Integrated Optimization and Navigation (ORION). It uses expansive fleet telematics and advanced algorithms to gather and calculate countless amounts of data to provide UPS drivers with optimized routes. The technology helps UPS drivers to determine the optimal way to deliver and pick-up packages within a set of stops. Start time, commit time, pick-up locations and traffic jam are used to calculate miles and travel time to plan the most cost-effective routes. ORION saves UPS about 100 million miles per year. That is a reduction of 10 million gallons of fuel consumed and so, a reduction in carbon dioxide emissions by about 100,000 metric tons. (72)

\(^3\) Telemetry systems are the automatic recording and transmission of data from remote sources to a system in a different location.
3.6 Packaging and Recycle management

In several steps of the supply chain, goods are transported. For example, from the supplier to the manufacturer, from the manufacturer to the distributor and from the distributor to the final customer. Instead of transporting loose goods, transport packaging is often used for the transportation. Frank Albert Paine provides a broad and well-established definition of packaging in the three following statements:

- Packaging is a coordinated system of preparing goods for transport, distribution, storage, retailing and end-use.
- Packaging is the means of ensuring safe delivery to the ultimate consumer in sound condition at minimum cost.
- Packaging is a techno-economic function aimed at minimising costs of delivery while maximising sales and hence profits. (73)

The fundamental functions of packaging are the following: protection, containment, preservation, apportionment, unitisation, convenience, and communication of the product. Packaging influences several business and management-related areas. In logistics, packaging is recognised as having a significant impact on the costs and performance of the logistics system. The better the size of the transport packaging, the more efficient space can be used. This will increase the utilisation of trucks and vans which can lead to a reduction of CO2 emissions. Not only the size but also the material of the transport packaging can be of importance. Packaging is a strategic supply chain component that contributes to the overall supply chain performance. (74)

Focusing on the last mile delivery, the e-commerce uses more package for home deliveries than when it is transported from the distribution centre (DC) on a pallet to a retail store. This is because in each delivery to a customer, the product is packaged individually and so, in many cases it increases the environmental impact depending on the material used and the recycle management system. Consequently, the need to investigate the potential of logistics-driven packaging innovation seems to be of importance for the industry. It can lead to find new unexplored areas of competition and sustainability while assuring customer satisfaction. (75)

The definition of sustainable packaging from the Sustainable Packaging Coalition (SPC) as the most accepted definition for sustainable packaging states that it must consider the next characteristics to be sustainable (76):

- Be beneficial, safe, and healthy for individuals and communities throughout its life cycle.
- Meet market criteria for performance and cost.
- Be sourced, manufactured, transported, and recycled using renewable energy.
- Maximise the use of renewable or recycled source materials.
- Be manufactured using clean production technologies and best practices.
- Be made from materials healthy in all probable end-of-life scenarios.
- Be designed to optimise materials and energy.
- Be recovered effectively and used in biological and/or industrial cradle-to-cradle cycles.
Research into the environmental impact of e-commerce and traditional in-store shopping have revealed that the main problem as regards delivery in urban cities arises in the last mile, where several factors including package type, material and size are all major contributors to carbon emissions. The fact that packaging materials have a direct impact on energy used, and hence on logistics and waste production, is arousing increasing concern. Although packaging made from non-renewable materials such as plastics continues to be widely used on the grounds of its recyclability, too strong a dependence on these sources should be avoided at any rate. (77)

At present, global e-commerce is being led by Amazon, eBay and AliExpress companies. For example, Amazon dispatches more than 10 billion packages each year and have recognized that their carbon footprint in 2018 was 44.40 million tons. Additionally, the situation of the Covid-19 increased the number of virtual visits to online purchases, and therefore this supposed a material and a massive wastage of energy. This section examines various strategies that companies are using to reduce CO₂ emissions and energy wastage in e-commerce packaging while ensuring that products arrive intact and undamaged to final customer. (78)

However, first it is important to understand the different layers of packaging to therefore, know which level of packaging a company is bracketed at in order to determine its total obligations. There are three main levels:

- Primary packaging, which encompasses the wrapping or containers handled by the end user and serves to protect and advertise the product.
- Secondary packaging, usually in the form of large cases or boxes that are used to group quantities of primary packaged goods for distribution and for display in shops.
- Tertiary packaging, which comprises the containers used to gather packaging groups into larger loads for transport in order to facilitate loading and unloading of goods.

For the last mile delivery packaging, this section presents real sustainable packaging solutions and materials for e-commerce focusing on the first two levels of packaging, primary and secondary.

The first example concerns the big company Amazon. Since 2007, it has been working on the concept of material reduction for packaging with the Frustration Free Packaging programme (FFP). Nowadays, and after different updates, this initiative set the guidelines for all its vendors to became more sustainable in the use of packaging, it must protect the product, minimize the amount of material used in each pack and maximize its recyclability in order to reduce waste production. The objective of Amazon is to be able to send the packages as they are received from the seller, without the need to use more elements to complement the packaging, thus reducing waste throughout the chain and improving the user’s shopping experience when receive an easy-open package.
Amazon’s certification requirements include using rigid hexahedral boxes of the following minimum dimensions:

<table>
<thead>
<tr>
<th>Region</th>
<th>Length</th>
<th>Width</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>6” (152.4mm)</td>
<td>4” (101.6mm)</td>
<td>0.375” (9.5 mm)</td>
</tr>
<tr>
<td>EU</td>
<td>8” (203.2mm)</td>
<td>4.72” (119.9mm)</td>
<td>0.375” (9.5 mm)</td>
</tr>
</tbody>
</table>

*Table 3. Packaging boxes requirements of Amazon packaging.* (79)

In addition, another requirement for the certification is making its boxes with corrugated cardboard and other cellulosic materials as plastics (PET, HPDE and PP). All must be 100% recyclable and airtight sealed with a long enough piece of masking tape so that no material will be wasted during shipment. For additional printing and/or treatments, they must not affect the recyclability of the package. Furthermore, Amazon recommend that all packages must be labelled with appropriate information, the volume of each product should not exceed the holding capacity of its container and packages must be easy to open by customers. (79)

One example of the application of this initiative in a real project is with the popular Baby Alive doll, which, in its retail pack, included several packaging components, along with multiple twist ties to hold the doll in place. To reduce packaging waste and increase ease of use for its e-commerce products, they reduced the footprint of the package and used a recyclable corrugated box with a slide-out corrugated insert to hold the doll. They also reduced packaging material by 50% with FFP and, in addition, as for ease of use, the doll can be accessed within 14 seconds versus three and a half minutes for the retail pack. (80)

*Figure 27. Frustration-Free Packaging retail pack example by Amazon.* (81)

Another example of the Frustration Free Packaging program application was the one carried out by the company Philips for packaging Philips Hue, the intelligent bulb that allow to control the house’s lights in distance mode. With the FFP program, the products delivered with Amazon, are reduced the volume in 74% and the package is easy-to-open by the customer with minimal use of scissors or box cutter. (80)
Figure 28. Frustration-Free Packaging light bulbs pack example by Amazon. (81)

The second example concerns an innovative sustainable solution for the primary and secondary packaging of wine company Garçons Wines. They redesigned original flat wine bottle (Figure 29) to be delivered in a letterbox. The bottle is manufactured from 100% recycled PET, so it will not break in freight deliveries and it is 100% recyclable after the use. At only 63g, it is 87% lighter than a standard glass bottle, so the environmental impact of its transportation is much smaller. However, this new form of packaging can alter consumers’ perception and lead them into believing that the wine it contains is of lesser quality.

Eco-flat wine bottles were developed originally to facilitate the seamless delivery of wine into UK homes via the letterbox. They set out to improve consumer convenience, cut the costs of failed deliveries which in the UK alone are estimated to be £1.6 billion, and help to reduce the near 1 million kilograms of carbon emissions associated with missed deliveries in the UK. The solution not only created a product that respects the heritage and tradition of the wine industry, but also combines the emotional benefits of an elegant glass bottle, with the functional benefits of bag-in-box and sets a new sustainable benchmark. (82)

Figure 29. Flat wine bottle packaging by Garçon Wines. (83)
Another innovative example for a sustainable is the project called Winepack presented by the company Total Safe Pack to protect glass bottle during their delivery such as wine or oil bottles. Its main function is to offer a safe and reliable system of packaging for glass bottles, ideal for transporting and handling bottles to reach the final destination without incident. Its packaging system \textit{(Figure 30)} has a special folding that reduces bottle breakage by 95%.

The cardboard bottle boxes are unique in the world. They are made of corrugated cardboard and their design and cut has been conceptualized by experts with the aim of minimizing the risk of breakage in the glass bottle transport packaging. The outer box consists of a double layer of 8 mm thick and the inner piece of a single layer of 3 mm thick corrugated cardboard. In addition, it is easy to assemble, in just a few seconds it is ready to use, and it is not necessary knowing how the system works. Nevertheless, the Winepack uses a fair amount of recyclable material and thus, it is expensive for e-commerce, but avoiding bottle breakage, reduces losses and costs, and as a result, the Winepack is a cost-saving, environmentally friendly solution. (84)

\textbf{Figure 30.} Safe packaging for glass bottles by TotalSagePack. (85)

The last real sustainable project presented is related with the company Dell. They introduced an eco-friendly bamboo packaging to cushion some of its lightweight products. This material of the grass family, found in everything from food to flooring, is now also a sustainable packaging solution. Bamboo is a renewable resource from the family of grass, and it is not a tree. It matures quickly in as little as three to five years, much faster than hardwood trees which can take upwards of twenty years or more to reach maturity. Bamboo grows in a variety of conditions, it can grow in arid regions where droughts cause other crops to fail and since the roots are left in place after harvesting, it helps to preserve vital moisture in the soil. From low wetlands to higher elevations in the mountains, bamboo thrives in a wide range of climates. This is the reason why Dell uses the bamboo that grows close to the facilities that manufacture the products. This reduces the packaging-related carbon footprint. To sum up, bamboo grows quickly and in different conditions, it is strong and durable and friend for the environment. Adding to its environmental credentials, bamboo packaging ensures that the compost resulting from the packaging’s degradation process is of good quality and can sustain plant growth. (86)
4. Conclusions

Last mile delivery is a complex part of the supply chain and it has been affected by the new trend of the e-commerce. Consequently, it can be treated as a relatively new field of application with still several potential aspects to be studied to improve efficiency, especially because it really affects the economic and financial part of the supply chain. Nevertheless, as the last mile delivery stood out as one of the worst parts when considering economic and environmental problem, there is therefore a need to find efficient and sustainable solutions. This thesis provided, through a literature research, an overview of the main last mile sustainable solutions that are currently used or will be applied in the future.

This project helped me to understand the motivations behind the sustainability principles that are being introduced in the last mile deliveries sector. Investing in green logistics for last mile delivery activities will reduce the operational cost for companies maximizing the corporate profit. However, at the same time it will improve environmental and social responsibility linked to the reduction of CO₂ emissions, so less health risk from pollution, lower accidents and noise caused by the traffic jam reduction. In addition, many companies are also pushed to shift into sustainable solutions motivated by the need to comply with the laws which seems more and more aligned to mitigate the climate change, and as a marketing campaign to attract consumers concerned about the environmental problem.

Different sustainable solutions of last mile that combine sustainability with profitability have been reviewed in this thesis and presented in different sections: delivery points, sustainable warehouse, transportation modes, routing policies and sustainable packaging. Some insights resulted from the literature research.

- An alternative in case of home delivery failure are parcel lockers located in crowded public places or using the customers car trunk; both offer more efficiency by decreasing the deliveries missed rate. On the other hand, another initiative mostly used in big urban areas are the Urban Consolidation Centres (UCC) which are logistics facilities for consolidation, and they are placed strategically near city areas with the aim of reducing distance to final delivery locations.

- Distribution Centres (DC) are one of the key elements of the supply chain and sustainability is a driver for its efficiency and profitability. It can be achieved with innovative infrastructures which help saving energy, also using self-generation of green energy for consumption and operational activities, and finally taking care of an efficient waste management system.
Growing concerns of GHG emissions impact from fossil fuel combustion, have been increasing the demand of electric vehicles for transportation. In last mile delivery, some electric vehicles are being used as vans, cargo bikes and sooters depending on the urban infrastructure of cities. In addition, some companies are investing on innovative ideas as deliveries by autonomous vehicles or drones, and a subway system for automatic deliveries.

The use of advanced routing systems to show the driver the most efficient route to follow is put forward by research, providing them a suggestion by ordering the parcels into the delivery vehicles. The implementation of advanced routing systems is depending on technology advancement which will help to develop advanced real-time routing software in the future.

Packaging is a fundamental component for the efficiency of the transportation of goods in the last mile delivery, even more within the e-commerce trend. Sustainable packaging must ensure safe deliveries while at the same time it should be made by recyclable material and optimise the quantity of material used.

Disruptive innovation and cutting-edge technology unlock the avenues for a broad range of sustainable solutions in last mile deliveries of the future. This can culminate in uncountable applications at any part of the last mile, from the distribution centre to customers hands.
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