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Assessing the mobility needs and traffic impacts in high-density urban development

A case study in Frihamnen, Gothenburg

Master's thesis

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ABSTRACT

Urbanization is a reality all around the world, people are moving from rural to urban areas as these provide better life quality based on services, goods and opportunities amongst others. Unfortunately, derived of this urbanization, several indirect consequences arise such as pollution, reduction of green spaces or an increase in the transportation demand. To tackle these consequences, cities need to plan their growth in a more sustainable way to reach desired levels of attractiveness and safety for their citizens. The purpose of this thesis is to analyse several of the negative impacts generated by urban transportation and the improvement potential of innovative mobility solutions for this transportation. Based on this, the thesis presents a case study in which several scenarios are evaluated according to the effects the mobility solutions provide. In addition, this thesis also examines the key factors linked with urban transport demand and those related to a sustainable urban mobility.

This thesis follows a case study approach including both quantitative and qualitative research. Based on a literature study and conceptual work, an impact assessment model is developed which is used to assess the impacts of urban freight transportation in different scenarios for the case of Frihamnen in Gothenburg.

The results the thesis presents contributes to understanding the importance and the relevance of the different transportation impacts and to what extent current solutions mitigate them. Knowing that urban planning tends to focus on passenger transportation, information on how mobility solutions affect urban freight transportation is useful. The research shows the importance of tackling congestion problems, as it is the main impact derived from urban freight transportation, the benefits of using alternative transport infrastructures and the advantages management measures can imply in urban areas. Moreover, the results indicate that that current mobility solutions often affect only sectors involved in the delivery of goods but have little effect on the service sector.

The thesis contributes to the understanding of the negative impacts of impacts, their relative importance and the reduction potential of different mobility solutions. Finally, it outlines potential future research areas that have not been deeply studied within urban transportation which can be interesting when developing future sustainable urban environments.

Key words: urban transportation, transportation impacts, urban freight, city logistics, mobility solutions, sustainability

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Enric Consegal Martinez,

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1 Introduction

1.1 Background

Urbanization is a present trend around the world leading to a higher densification of urban areas as more people decide to move to cities (Browne *et al.*, 2012). Throughout the last century, this increase of urban population has grown from 13% of the world's population in 1900 to 49% in 2005 and it is expected to reach 60% by 2030. Particularly in Europe, 72% of the population live in urban areas of which 41% live in cities and 31% in towns (PBL Netherlands EAA, 2016). Because of this expansion, urban areas also experience an increase in the needs of transportation and in the delivery of goods for their inhabitants. Gothenburg is a clear example of urbanization as many new areas have been and are being developed recently (City of Gothenburg, 2014).

Given the current trend of urbanization and densification, the need of goods and services flourish for citizens. Despite this fact, many cities are implementing restrictions for vehicle access to which leads to a necessity of efficient logistic measures for both companies and city councils to be able to offer their services (Lindholm and Blinge, 2014). Unfortunately, urban freight transportation is not always considered in urban planning and causes many conflicts between these two actors. Many cities are designed and intended for passenger transportation leaving frequently aside the necessity of an efficient planning for freight transportation. Moreover, urban freight is governed by several factors generally not controlled by the public administration, which makes urban planning a much difficult mission given that it must also cope with passenger transportation (Muñuzuri *et al.*, 2005). In addition, urban planning must also take into consideration the waste collection sector, which is leading to the development and study of new feasible ways to do so (Horvath and Wu, 2017).

Even though urban freight transportation is indispensable to provide residents with goods for their daily life, freight transportation has severe impacts in urban areas. These impacts can be categorized into environmental impacts, social impacts and economic impacts (Behrends, 2016). Due to the increase in urbanization, the magnitude of these impacts has also intensified. For instance, freight transportation represents between 20% and 30% of the total trips in cities but its contribution to air pollution varies from 16% to 50% depending on the city and the pollutant analysed (Dablanc, 2007).

To deal with these negative impacts of transportation, cities have promoted the implementation of new transport modes or new collective solutions to minimize the impact of goods movement (Navarro *et al.*, 2016). Regarding urban freight transport, measures include the restriction of vehicles that do not meet certain emissions limits, a better use of the available urban space to affect the minimum the region or, as commented, the materialization of alternative transportation systems. One of the most studied and carried out urban freight measures is the creation of urban consolidation centres (UCC) designed to consolidate deliveries from several transport companies into one collective distribution system. Some examples can be found in Barcelona or Valencia (Navarro *et al.*, 2016) in which pilot tests have been done with different results. However, many pilot tests and implementations of UCCs fail at the end as they require other measures by the public authority. Measures such as subsides to carriers or access fees for other operators, have been seen to the most effective for the well-functioning of the UCC (Heeswijk, Larsen and Larsen, 2017). Additionally, these new ideas allow municipalities to develop new areas and neighbourhoods in a more attractive way, providing a better integration between citizens and urban territory.

As explained, many initiatives are being implemented in different urban environments, but some do not show the expected results or even fail at the end. It is therefore necessary to analyse the general impacts of transportation from different perspectives (society, economy, environment) and study the real implications mobility solutions have in these areas. This thesis presents some initiatives, together with the impacts generated by transportation, and evaluates the expected repercussion of some solutions to understand their actual contribution in the reduction of impacts to reach the required goals of attractiveness and sustainability in cities and urban areas.

1.2 Purpose and Research Questions

The purpose of this thesis is to explore the characteristics of urban passenger and freight mobility, and to evaluate the effect of innovative logistics solutions on the sustainability of dense urban neighbourhoods.

To break down the research purpose into research questions this thesis follows a general framework for sustainability planning, which is generally referred to as the Framework for Strategic Sustainable Development (Robèrt *et al.*, 2002). The framework consists of five interdependent but distinct levels. The top level ensures a thorough understanding of the functioning of the system in focus (System level), to be able to arrive at a basic definition of success within the system (Success level), which in turn is required for developing a strategy (Strategy level), for implementing actions (Action level) and tools which are needed to monitor the process (Hallstedt *et al.*, 2010). The first three planning levels constitute the scope of this thesis and are the starting point for formulating the research questions.

1.2.1 Research question 1 – Understanding urban mobility systems

Urban mobility is a complex system, including many interdependent elements. To handle this complexity requires an understanding of the way urban mobility systems work. Therefore, it is crucial to define the elements that determine the system and the factors and relationships that drive its sustainable performance. Hence, research question 1 is:

- RQ1: What key factors define passenger and freight mobility in dense urban neighbourhoods and its sustainability performance?

This research question has a theoretical focus and aims to develop a framework for assessing urban mobility systems, which will frame the empirical analysis of this thesis.

1.2.2 Research question 2 – Defining sustainable urban mobility

Once the key factors of urban mobility are defined, it is appropriate to determine when this mobility can be considered sustainable in dense urban neighbourhoods. Traffic intensities have different effects depending on the area studied. In high-density environments, large traffics present substantial issue as the available space for parking and for the circulation of vehicles tends to be limited. Thus, when the demand is too high congestion becomes a major problem. In addition, a sustainable neighbourhood should also present low levels of atmospheric pollutants becoming more attractive and safe for its citizens.

This is required as a baseline in order to assess both the scale of the problem of today's systems as also the improvement potential of innovative solutions (RQ3). Hence, research question 2 is:

- RQ2: What characterises sustainable mobility (passenger and freight) representing an attractive and safe urban environment?

This research question has both a theoretical (identify definitions from previous research) and empirical scope (applied concepts in city planning).

1.2.3 Research question 3 - Strategy to success

In the final step, the sustainability performance of innovative urban mobility solutions is assessed. Two research questions will be developed in this ambit:

- RQ3a: How unsustainable is urban transport in high-density areas with business-as-usual solutions?
- RQ3b: What is the improvement potential of innovative solutions?

This research question has an empirical scope, as it analyses the case study of Frihamnen and assesses the sustainability performance of innovative mobility solutions in this context. The framework developed in research question 1 and sustainability characteristics developed in research question 2 will function as a means to this end.

1.3 Scope and Limitations

Several innovative alternatives are studied with the objective of quantifying the effect on the impacts these mobility solutions have on a general scope and within a particular urban area. These alternatives will be analysed when considered alone and as a part of a general urban planning. To do so, an estimation of the generated traffic, will be done in order to be able to particularise for a certain case study area. Specifically, the area analysed will be the district of Frihamnen in Gothenburg.

The innovative mobility solutions considered in this thesis are those developed in the DenCity project, which aims to develop "innovative solutions for sustainable passenger and freight mobility in dense neighbourhoods, with high standards of attractiveness, accessibility and sustainability" (CLOSER, 2017). These are electric distribution trucks, the combined transport of goods and waste on urban waterways, as well as innovative last mile deliveries and urban services.

The geographical scope of the thesis in accordance to RQ3 is set in the city of Gothenburg particularly the area of Frihamnen in which the mobility solutions are expected to be implemented. Regarding RQ1 and RQ2 there is no specific geographical scope, but the indicators and factors used will correspond to European recommendations and guides.

The main limitation in the thesis is the fact that the analysis includes logistics solutions only; passenger solutions are not included. Furthermore, the solutions are analysed in the context of a certain area. However, the model presented to obtain the results can be adapted to other contexts or areas in which similar initiatives are to be implemented. Therefore, the analysis of the alternatives can be generalised for other cases with similar contexts.

1.4 Outline of the report

Chapter 1 (Introduction): In the introduction the background, the purpose, research questions, the scope and the limitations of the thesis have been presented.

Chapter 2 (Theoretical framework): This chapter sets the basis of the theory used in the thesis. It reviews Urban Freight Transportation (section 2.1), Urban Passenger Transportation (section 2.2), the models and factors to estimated transportation (section 2.3) and the impacts generated by transportation (section 2.4).

Chapter 3 (Methodology): This chapter presents the methodology used to reach the purpose of the thesis and provide and answer to the research questions.

Chapter 4 (Case Study): This chapter presents the case study analysed in this thesis and consists of three sections. In section 4.1 the freight demand for the area of study is developed, 4.2 presents the different scenarios to be analysed and 4.3 presents the results.

Chapter 5 (Results): This chapter analyses the results of the report regarding the research questions developed.

Chapter 6 (Conclusions): This chapter presents the results of the research questions in relation to the purpose of the thesis and suggests future areas of research in the topic of urban transportation.

2 Theoretical framework

This chapter presents the theoretical frame used in this thesis. At first, a description of both urban freight and urban passenger transportation will be done. Together with their classification or categorization, current trends related to measures and solutions for both passenger and freight transport will be reviewed. The second part of the chapter presents estimation models for passenger and freight traffic generation. Lastly, the different transportation impacts will be described together with the external costs they generate on society.

2.1 Urban Freight Transportation

2.1.1 Definition

Currently, Urban Freight Transportation (UFT) is referred to in many ways within the literature. It is often defined using different terms, such as city logistics or urban distribution, and different scopes in terms of transport types included, regulatory policies considered, their extent in the area, and other implications. At general, UFT is vital in the generation of welfare as it is required in the movement of goods along the supply chain (Behrends, 2011). From an overall perspective, freight transport is the movement of goods regardless of the area this movement refers to. In the recent years, an increasing body of research and studies on urban freight emerged and definitions of UFT were developed. For example, in the late 1970s UFT was defined as the total number of journeys into, out and within an urban area done by road vehicles in charge of the pick-up and delivery of goods (Lindholm, 2012, p 5). This definition did not consider other trips such as services or construction. Later, experts simplified the definition and presented the idea of urban goods movement in which all type of products, excluding people, were included (Lindholm, 2012).

As cities grew bigger, the expression city logistics gained importance as it described the process and set of solutions to optimise the transport activities within urban areas by private companies considering the indirect impacts of their activity. When this concept appeared, the negative impacts analysed in transportation were less than the current ones making this definition slightly deficient to current standards. Currently, the concept of city logistics includes actors such as: shippers, retailers, carriers, citizens and public authorities, given that the impacts analysed are different from those initially studied (Estrada, 2017).

Years later in 2003, the OECD (Organisation for Economic Co-operation and Development) presented their definition for urban goods transport in which they only took into consideration the delivery of consumer goods in urban environments (Lindholm, 2012, p 6). Later on, urban freight transport definitions included the movement of goods done by professionals. According to (MDS Transmodal, 2012, p 23) urban freight transportation is defined as: “the movement of freight vehicles whose primary purpose is to carry goods into, out of and within urban areas”. Moreover, there is a current trend in which the number of services required is increasing, leading also to an increase in the number of urban logistics traffic.

The definitions presented show the relevance of the stakeholder’s point of view when describing urban freight transportation making it difficult to present a general definition. A suitable definition that matches with the idea that is be presented throughout this thesis is the following: "urban freight transport is all movement of goods in to, out of, through or within the urban area made by light or heavy vehicles, including also service transport and demolition traffic, shopping trips made by private households and waste" (Lindholm, 2012).

2.1.2 Urban freight transport sectors

According to the EU Commission (MDS Transmodal, 2012), there are five traditional UFT sectors: Retail, Express & Post, HoReCa (Hotel, Restaurant & Catering), Construction and Waste. In addition, nowadays there is also the Service sector, in charge of maintenance for companies, cleaning services and other aspects that cannot be directly related with the movement of goods. In the following, a brief explanation of these sectors considering their current situation and general aspects is presented.

2.1.2.1 Retail

The retail industry can be defined as a group of individuals and companies connected with the sale of finished products to users. Therefore, retailing is the final step in the distribution of these goods, as it is the stakeholder in charge of connecting the producers with the consumers. Within European countries, the way retail functions vary according to the culture and the geographical differences between them. In northern countries large-format stores tend to dominate in the form of "hypermarkets" whereas in southern and eastern countries there is a higher presence of small, independent stores, which many municipalities try to maintain as a sign of the cities' identity (Ajuntament de Barcelona, 2016).

However, even in the countries where large-format stores dominate, there is also an observable trends towards small-format stores (MDS Transmodal, 2012). Large stores require more time for the user to compare different products and factors such as proximity and urban lifestyle are becoming key for consumers. This is encouraging retailers to design smaller stores offering a closer service to customers together with a more specialised product offering. With this, the number of deliveries needed increases as more smaller retailers enter the market and the available space to keep goods for stock decreases due to the high costs in the city centres. Small retailers are not able to control the deliveries as much as big retailers and tend to rely on several suppliers or even on own account vehicles.

Complementing the traditional retail industry, the role of e-commerce is also increasing significantly. All around Europe e-commerce is constantly growing, increasing nearly 20% in the past 10 years (Eurostat, 2018a). Moreover, the users of e-commerce platforms has grown from 26% of the EU population in 2006 to 40% in 2010 (MDS Transmodal Limited, 2012). Even though the total amount of goods of e-commerce is not comparable to traditional retailing, its effect in logistics is noteworthy as the delivery of the product itself is substantially different to that of a traditional store. Instead of being the user the ones who goes specifically to the store to purchase the goods, these are delivered directly to their home or to a previously agreed point adapting then to the user's needs. According to some forecasts, the tendency for e-commerce is to keep on growing causing a slight decrease in the number of sales done by conventional stores (Visser, Nemoto and Browne, 2014).

2.1.2.2 Express, courier & post

Two main segments can be distinguished in this sector, on the one hand the post market and on the other the parcel and express market. The post market is related with the sending and receiving of traditional correspondence and periodic publications. In terms of volume, the post market represents 56% of the revenues and due to the historical presence it has in society it is a very experienced sector (MDS Transmodal, 2012). Consequently, from a logistics point of view it is a very efficient sector that has been able to find ways to optimise its processes while experiencing a decrease of the number of deliveries. A clear example of this optimisation is the reduction of sorting centres and delivery offices.

Since its origins, express and parcel companies used to work with the distribution of documents and parcels while offering a better service compared to traditional post. The difference between the express and parcel companies is the size of the shipment. Express companies generally focus their business on delivering small and light parcels and documents between businesses and customers. Parcel companies, on the other hand, focus their work on the distribution of larger packages. The vast majority of shipments (80%) are Business-to-Business shipments in the whole sector, while Business-to-Customer represents a 15% of the total shipments (MDS Transmodal, 2012). Even though these continue to be their main activity, many national post operators also offer similar services increasing the level of competition between them.

E-commerce has also affected this sector as some express operators are sometimes hired to deliver goods leading to an increase of parcel and express services in cities. The main reason for this is the fact that these companies work very efficiently in city centres due to the variety of transport vehicles they have. Nevertheless, when restrictions are implemented in city centres, their efficiency is highly affected. Express operators tend to design optimised and schedules to achieve high levels of efficiency, when these routes are altered the whole delivery system is changed.

2.1.2.3 Hotel, Restaurant, Catering

The term hotel, restaurant, catering (HoReCa) is used to refer to the food service industry that serves hotels, restaurants and provides catering services where required. In recent years this sector has experienced a relevant growth in Europe in which small and “non-organized” stakeholder dominating the sector (MDS Transmodal, 2012). An example of these stakeholders is those that supply small bars and restaurants that do not belong to large enterprises. The sector is influenced by three main factors: human resources, regulation and new technologies. The first one refers to the problems the sector faces to recruit employers due to the particular conditions of the jobs. The second one answers the increasing presence of EU legislations regarding food safety and labelling amongst others. The third issue, technology, is having an important impact in the functioning of the industry specially in those small companies as they are not able to generate economies of scale.

Moreover, this sector needs to face the high unpredictability of the demand which hinder the possibility of an efficient logistics planning. An example of this unpredictability is the appearance of delivery apps that work under Just In Time (JIT) principles leading to higher inefficiencies compared to the retail sector (Fernández, 2017).

2.1.2.4 Construction

The construction industry is in charge of assembling buildings and within the urban area its activity is basically related to the construction of residential and commercial spaces. Therefore, in the context of UFT, the construction sector generates deliveries of all sort of materials to different sites in urban areas and the removal of other materials. Due to the variability in the dimensions of the needed elements, construction vehicles tend to be larger than those used in the before mentioned sectors. This fact can easily mean bigger impacts on citizens or urban areas. In addition, construction companies are severely affected by restriction in city centres forcing them to find new solution for the transport as larger vehicles are generally used (MDS Transmodal, 2012).

2.1.2.5 Waste

The waste sector is responsible for the collection of waste from by private, commercial and industrial activities. Although this sector is usually not considered as an important actor in the UFT, it is crucial for the well-functioning of the other sectors (MDS Transmodal, 2012). Waste collection is as a general basis a municipal obligation, but many city councils decide to outsource it offering the service to private companies that have better knowledge of logistics and optimisation.

When analysing how the sector works, it is relevant to differentiate between the collection of “recyclable” materials and the collection of “non-recyclable” materials as they are generally done by separate companies under separate contracts from the municipalities. The reason is associated with the required infrastructure and the frequency of waste collection. Organic waste needs to be collected more regularly as the processes for it to be transformed into compost demand that little time between its collection and its transformation have passed. On the other hand, materials such as glass or paper can be stored longer time periods before being collected and transported to the recycling waste collecting companies to design more optimal routes.

Around Europe the amount of waste generated per capita varies between countries. For example, Eastern European countries generate less kg of waste per citizen per year than Western European countries. In 2016, Eastern countries such as Slovakia, Hungary or Poland amongst others, generated less than 400kg of municipal waste per citizen per year, while Western countries, such as Germany, France or Austria, generated more than 500kg per capita per year (Eurostat, 2018b). On average, EU-28 countries generated per citizen 480kg of municipal waste in 2016.

Nowadays society is experiencing an increase in consumption which obviously leads to an increase in the creation of waste. Despite this fact, European legislations require the development of waste policies aiming to the reduction of waste, the re-use of products and recycling. This is leading to an increase in the recycled waste and the introduction of alternative waste treatment systems instead of landfill that has been reduced in 60% in the past 20 years in EU countries (Eurostat, 2018b). Recycling systems do not only include the reuse of materials for similar purposes, (e.g. recycling of glass), but also include the generation of energy by burning of waste. Sweden is a clear example of this, as the country recycles more than 99% of household waste thanks to an important recycling revolution over the last 40 years (Fredén, 2017).

2.1.2.6 Services

The services sector requires of a different scope in comparison to the previous traditional sectors presented. The main difference is that the actors' primary business is not to distribute or collect any physical goods. Instead, they offer their customers a human resource to complete a task. Examples can be the provision of cleaning services to businesses or homes, the maintenance of different household devices, security services to businesses or even medical visits done directly to patients.

Even though the amount of service trips varies according to the area analysed, in commercial districts is generally lower compared to the other areas. According to some reports, the total service trips in relation to the total delivery and service activity can differ from the 11% up to a 63% depending on the city (Cherrett *et al.*, 2012). These values are obtained from examining 27 freight studies done in UK between 1996 and 2009.

The vehicles used to provide these services also contrasts with the transport modes of the traditional sectors. The number of large vehicles (trucks) used by service companies is limited and they tend to work with small vans, corporate cars when necessary and occasionally with medium-size trucks. Moreover, it is also common to expect trips by bicycle or on foot (Cherrett *et al.*, 2012). Lastly, these trips also present long dwell times due to the nature of the service. This fact has a direct consequence in the use of on-street parking and the use of loading/unloading areas in city centres. Services vehicles occupy more time parking available for freight activity.

2.1.3 Urban Freight Transport measures

Given the fact that municipalities and cities all over the world are working towards more sustainable forms of transportation, it is necessary to present and analyse briefly the main solutions and measures that are normally carried out. These measures can be grouped into 5 categories: regulatory, market-based, land-use, infrastructure and management measures (MDS Transmodal, 2012). Additionally, society is experiencing a digital revolution with the introduction of new technologies. These contribute positively to many of the measures as they provide more information and allow the monitoring of vehicles and areas. Below, these actions are described and some of them, exemplified.

2.1.3.1 Regulatory measures

Regulatory measures are a set of rules intended to control private activity in order to achieve benefits for society (MDS Transmodal Limited, 2012). This collection of measures is relatively easily accepted for citizens and transport operators due to their traditional nature that helps in their implementation. On a general basis, some regulatory measures affect all vehicles such as speed limits and parking restriction, but there is also a set of regulation that affect exclusively freight vehicles. Their main objective is to encourage freight companies to use more sustainable methods for the distribution of goods reducing the impacts on citizens.

One of the most-common example of these policies are access restrictions for all sort of vehicles into pedestrian areas. This regulation usually presents some exceptions such as access permission for residents of the area or permissions for delivery vehicles under certain conditions. Another possibility of access restrictions are time-based, i.e. the establishment of time windows for freight vehicles to load and unload

(Robusté, 2012). In this case, vehicles are only allowed to enter certain areas during particular periods to develop their activity. Other forms of these ordinances are vehicle size-based (according to volume, weight or length) and emission-related restrictions. As in the other cases, only certain vehicles are authorized to access the regulated area (Muñuzuri *et al.*, 2005). These restrictions are designed to authorize only certain transportation activities within specific areas in urban districts to minimise the negative effects on citizens. Examples of these regulations can be found around Europe, e.g. Ljubljana has controlled access to the city centre and pedestrian areas in certain time windows (MDS Transmodal Limited, 2012).

Regulatory measures can also be linked with the efficiency class or the weight of the vehicles. LEZ (Low Emission Zones) are implemented in town or cities to improve air quality and can be found all around Europe (Cruz and Montenon, 2016). Depending on the city, the restriction is carried out every day, only in working days or when the concentration of harmful compounds in the air is reaching its admissible limits (Ajuntament de Barcelona, 2017). LEZ are generally related to weight restriction zones as heavier vehicles also tend to present low-efficiency engines. Gothenburg established a Low Emission Zone (LEZ) in which only all HGVs need to be meet Euro 4 standards and Prague has a weight restriction zone where vehicles over 3.5 tonnes are not allowed to circulate (MDS Transmodal, 2012).

Other strategies are oriented in the creation of special lanes promoting sustainable and public transportation. In many cities private vehicles are not allowed to use bus lanes, but some cities also have decided to allow different uses of special spaces during non-peak hours or weekends. An example is found in Barcelona where multi-purpose lanes can be found (Robusté, 2012). In these lanes, that extent for more than 5km, freight vehicles are allowed during non-peak hours and parking is permitted at night. The rest of the day, the lanes are dedicated exclusively to public transport vehicles.

2.1.3.2 **Market-based measures**

Market-based measures consist of fees and tolls to affect directly the industry and the users by rising prices of certain goods and services. These rises normally have a direct impact on the behaviour of companies as they try to remain competitive in the market. Like regulatory measures, some market-based measures not only affect the freight industry but also private transportation. These regulations can be divided into direct and indirect when applied directly to the external cost produced (direct) and when applied the causes of the external cost (indirect) which are the most relevant in urban freight transportation (MDS Transmodal Limited, 2012).

Two well-known measures are road pricing and congestion charges. The first one refers to the price private users need to pay to use road infrastructures such as motorways according to the distance they have travelled and the external costs their journey generates. On the other hand, congestion charges are oriented to control the access to certain parts through pricing. They are developed to avoid unnecessary journeys in specific areas, having a positive effect in the reduction of congestion. Well-known European examples are the London's Congestion Charge (Transport for London, 2015) and the Area C in Milano (Danielis *et al.*, 2012).

In Sweden, Stockholm and Gothenburg introduced congestion pricing systems in the past years. In Stockholm the congestion charge was permanently established in 2007, after a trial in 2006, and in Gothenburg the congestion charge began in 2013.

Both cities have a similar congestion charging system: a toll cordon around the city oriented to reduce the traffic inside the city (Börjesson *et al.*, 2012). All vehicles that enter the area are charged with a tax that varies throughout the day having a maximum total tax per day which for both cities is around 6€ (Börjesson and Kristoffersson, 2015). At night, vehicles are not charged for entering or exiting the city and vehicles can circulate freely during weekends, public holidays and the month of July. In Stockholm, the reduction of traffic caused by the congestion charge in 2011 was around 30% compared to 2005 (Börjesson *et al.*, 2012) while in Gothenburg the reduction in traffic was only 12% after the first year of implementation (Börjesson and Kristoffersson, 2015).

Additionally, some cities also offer subsides in order to promote sustainable urban distribution by helping distributors with more sustainable vehicles with some exemptions of fees or time regulations (Muñuzuri *et al.*, 2005). Examples can be found in London where zero-emission vehicles can circulate freely without paying the congestion charges and in La Rochelle (France), where low emission vehicles are able to use priority lanes when operating from UCCs (MDS Transmodal, 2012).

2.1.3.3 **Land use planning measures**

This category of measures, which is in many ways closely linked to the following set of measures (infrastructure measures), includes those that affect and change the use of existent spaces in a local, regional or national scale. These initiatives need to be planned with a long-term perspective as many actors are involved and their patterns cannot be changed in a short-term perspective (MDS Transmodal, 2012). Given that these measures require a long-term planning perspective, there are no "precise" costs associated to them due to their nature. When the infrastructure is already existent and only the use of it changes, the cost is significantly lower compared to the rest. However, when a long-term plan is needed costs increase due to its mere complexity and variety of actors involved.

One of the main measures is the transformation of parking spaces into loading zones in city centres. Nevertheless, cities are tending to reduce the number of available spaces for all traffic compromising this initiative as the number of deliveries tend to increase. In some cities, actions are being developed to integrate on-site loading zones in buildings to remove vehicles from the streets. Loading and unloading zones, if done correctly, allow an optimisation of the number of spaces and parking time required for operators to work (Dezi, Dondi and Sangiorgi, 2010).

On a mid or long-term perspective, land use strategies are oriented to the formation of large commercial spaces on the outer parts of cities in which logistics strategies can be carried out collectively as many establishments are located in areas with similar transportation needs. These measures present a bigger impact to UFT, but require stronger agreements between public and private actors and well-designed planning strategies in order to move towards a more sustainable UFT (MDS Transmodal, 2012).

2.1.3.4 **Infrastructure measures**

Infrastructure measures are often integrated with the previous category and therefore are difficult to differentiate. The main variation is the fact that these measures require a substantial public investment as new infrastructure is required. Due to their cost, thorough analysis and studies are needed to evaluate their profitability.

Some city centres do not have designated areas for loading/unloading activities and sometimes it is necessary to create them as new equipment. When this occurs, public administrations need to invest in these areas resulting then in an infrastructure measure. Another example is the development of outskirts logistics centres that can represent a significant reduction in costs when different freight operators work together in the centre (Muñuzuri *et al.*, 2005). Even though these centres play a major role in interurban transport, they have a direct effect in the total costs for operators.

Measures regarding the use or modification of existent and large infrastructures, such as railway or waterways, are also included in this category. Such alternatives intend to move, both in and out, goods from urban areas in a more efficient way (Behrends, 2017). To do so, the distances between the respective terminals should not be too large and therefore not all existent infrastructures are suitable (Behrends, 2012). Regarding rail, Paris introduced in 2007 a night train for freight between a distribution centre on the outskirts of the city and one of the major train stations in the city (Gare du Lyon). Utrecht in the Netherlands has also implemented the use of a light road train to carry containers from consolidation centres outside the city into the inner parts of it (Browne *et al.*, 2012). With reference to waterway transportation, Paris also uses the Seine river to transport some goods inside the city (Figure 1) and Gothenburg is also developing routes through the Göta river. The main problem of these solutions is the high initial investment required together with the transhipment costs between transport modes (Horvath and Wu, 2017). This last option is considered in the DenCity project to move both goods and waste from the studied area.

Figure 1: Transport of containers in the Seine river (Paris) (MDS Transmodal, 2012)

Even though these measures do not affect the so-called "last-mile" distribution, they are significant from a logistics point of view moving goods from the outskirts into the city and should therefore also be included as Urban Freight Transportation measures.

2.1.3.5 Management measures

This last set of measures refer to those oriented to a more efficient transportation and urban distribution. They are generally bottom-up actions that require the collaboration of the different actors in the distribution process. This means that the interaction between users, suppliers, distributors and public administration is essential to reduce costs and add value to the final product and service (MDS Transmodal, 2012). Consolidation strategies are the most common management measures implemented in cities to have a positive impact in UFT. Examples of these strategies are: Urban Consolidation Centres (UCCs), Hybrid UCCs, Urban Staging Areas or mobile depots amongst others (Estrada, 2017). Hybrid UCCs are urban terminals combined with other existing facilities or needs in the area. Their main advantage is that they allow the generation of synergies with other demand flows and the flexibility they present as being part of an existing facility to accommodate new demands and a new optimization process. Urban Stage Areas are temporary containers in which the cargo is consolidated close to the delivery area. From there, electric vehicles or cargo bikes are then used for the final deliveries. Mobile depots are a similar solution to Urban Stage Areas with the difference that a whole trailer containing the necessary equipment for the consolidation strategy is placed where and when required.

The most common example is the development and implementation of UCCs. UCCs can be defined as a logistics facility situated close to an urban area that it is intended to serve. This urban area can be a city centre, a whole town or a specific site such as an airport, a shopping centre or a major construction site. From this location, goods are consolidated and distributed by logistics companies using normally environmentally friendly vehicles and more efficient distribution routes and strategies (Browne, Allen and Leonardi, 2011). UCCs contribute significantly in the reduction of vehicles circulating in the city and therefore reduce congestion, air pollution and noise contamination. In addition, distribution companies benefit by avoiding entering congested urban areas and receivers benefit in terms of delivery reliability. On the other hand, they need to be carefully integrated into existing supply chains, require of a substantial demand and involve an important investment which is often the main drawback for these centres to establish (Estrada, 2017). There are two types of UCCs, those destined to retail and those to construction materials. Within urban areas and for freight transportation, retail UCCs are the most frequent.

Even though many pilot tests have been done throughout Europe, less than 20 UCCs are currently in operation due to the high investment costs needed and the unclear financial scheme they should follow. There is disparity of opinions within experts and researchers in UCC’s economic viability as some believe they should be self-funding and other believe they need of permanent governmental subsides (Duin *et al.*, 2016). In order for the UCC to survive and work, the centre should generate enough revenues to cover its costs. When the UCC operates through a private-private partnership, this is generally obtained by applying fees according to the space companies use or with membership fees for retailing companies. When the partnership is public-private, the city council usually subsides the working cost through a contract. Generally, UCCs start with public participation through temporary contracts as a transition period between the introduction of the UCC and its self-funding functioning (Duin *et al.*, 2016).

However, when the subsided period ends, the viability of the UCC is commonly affected. This is because retailers are then forced to pay higher fares to use the centre, which tend to surpass their traditional operational costs. On the other hand, when the public authority pays for the centres for a longer period, the whole system turns unsustainable. Thus, a business model to turn these centres into feasible alternatives needs to be developed. According to experts, more retailers or consumers need to use their service in order to maintain competitive fares which can only be achieved if the service is used by smaller retailers (Duin *et al.*, 2016). Other believe that an alternative would be to promote publicity for both the last-mile vehicles and the centres as a way of self-financing the facility affecting in some minor degree users (Estrada, 2017).

In 2015, Barcelona did a pilot test with an Urban Stage Area (Figure 2) in which the vehicles used were tricycles (cargo bikes). The idea was to create some spaces in the city centre to work as transhipment points for logistics companies, as the access to the inner city is very restricted and complex. They were spaces between 33m^2 and 40m^2 and the trial ran for 6 months. During the period, the service was able to reach more than a 90% in delivery success and even experienced a growth in the number of deliveries over time. A similar project was done in Valencia (Figure 3) in which a micro-distribution platform was created to act as transhipment point for logistics suppliers (Navarro *et al.*, 2016).

Both pilot tests proved the environmental and transportation benefits of this strategy in which hundreds of litres of fuel were saved monthly together with CO_2 emissions and were done to evaluate the future implementation of the centres and analyse the main problems they would face if the initiatives were finally carried out (Navarro *et al.*, 2016). The first challenge would be to reach agreements with transport operators and the second one would be the location of the transhipment terminal.

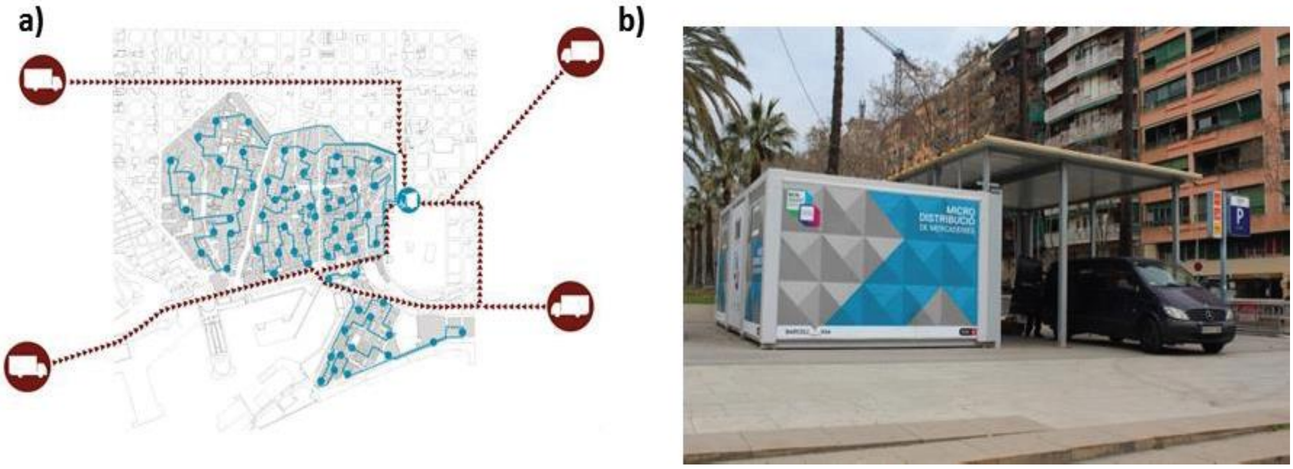

Figure 2: Schematic of the Urban Stage Area implemented in Barcelona (Navarro *et al.*, 2016)

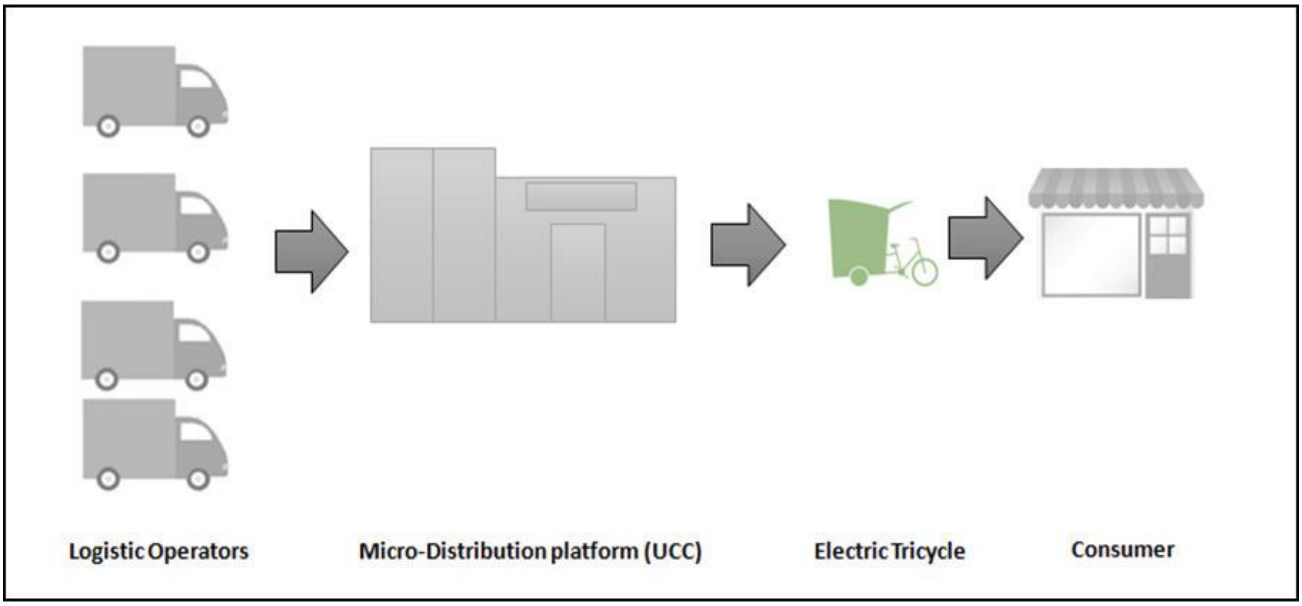

Figure 3: Schematic of the last-mile distribution system tested in Valencia (Navarro *et al.*, 2016)

Night deliveries are also promoted in some areas to avoid interference with peak hour congestion forcing freight operators to alter their working periods. This measure must be combined with the use of adapted vehicles as it has a direct effect on noise and with a close collaboration between distributors and receivers. When analysing a pilot test developed in Barcelona, many of the benefits of this action were shown. From an operational perspective, transportation time was reduced up to 90% and the investment required for silent vehicles was expected to be recovered in 3 years. However, noise pollution was not significantly reduced. The reason is that even though the vehicles themselves were more silent, the freight movement presented a higher impact on citizens at night than during day hours (Estrada, 2017).

Other measures can be the definition of pick-up stations for e-commerce with the intention of avoiding rescheduling of deliveries when the customer is not available. These stations tend to be located in important sites of the city with easy access for citizens, such as shopping centres or commercial neighbourhoods (MDS Transmodal, 2012). This alternative can be also considered as an infrastructure measure as in some occasions a physical station needs to be built, but basically requires of collaboration between users and distributors.

Together with all the previous measures, it is necessary to remark the role new technologies have contributing in the efficiency of many of the measures as is it easier to control if a vehicle has entered a restricted zone, the time a vehicle has been in a loading/unloading zone and the traceability of different freight vehicles and their routes. Additionally, automotive manufacturers are actively investigating and developing low emission vehicles based on alternative fuels such as hydrogen, natural gas and the introduction of electric vehicles in the market (MDS Transmodal, 2012)

2.2 Urban Passenger Transportation

Urban Passenger Transportation (UPT), is the movement of human beings to and within urban areas. This movement can be done on two different ways: private transportation or public transportation. In public transportation, various users share the same transport facility such as buses or trains, while in private transportation people use their own vehicle for movement (Researchpedia, 2016). The purpose of this movement can be daily commuting to work or studies, leisure, migration issues or personal reasons. When a journey is completed using more than one transportation mode is defined as intermodal transportation, which is generally experienced when using public transportation (Wikipedia, 2018d).

Urban Passenger Transportation is becoming more important around the world for both urban and rural areas. New mobility patterns and the increase of population contribute to this need of transportation and cities that provide better mobility solutions for their citizens are directly benefitted from it (IRU, 2018). When planning passenger transport solutions, economic and social activities become easier, contributing to the internal development of cities.

2.2.1 Classification of urban passenger transportation

As defined previously, there are two basic types of passenger transportation: private and public.

2.2.1.1 Private transportation

Private transportation is characterized for not being able to be used by the general public. As for the costs of this transport, the user pays entirely for the direct and part of the indirect costs associated such as road infrastructure which is also financed through public taxes according to different agreements (Estrada, 2013). In addition, the user is also the owner of the vehicle. There are two categories according to the motorization of the vehicles. Motorized vehicles such as private cars, motorcycles, electric bicycles that provide higher speeds and give autonomy to users. Non-motorized vehicles such as conventional bicycles or walking, are much more limited in speed and operational range and, therefore, are usually used in shorter distances.

Passenger cars, or private cars, account for the vast majority of passenger trips in Europe and around the world. On average, in 2014 more than 80% of inland passenger trips were done by car in the EU-28. Only seven countries present values under this 80% threshold (Eurostat, 2018c). European cities are promoting the use of non-motorized vehicles for the direct benefits they have on the environment, human health and the contribution the reduce traffic congestion. Studies show that more than 30% of private car trips cover less than 3km and 50% of car trips cover less than 5km (EU Commission, 2013). Furthermore, the introduction of electric bicycles also contributes to reduce the modal share of cars as they increase speed and loading capacity of biking.

2.2.1.2 Public transportation

In comparison to private transport, public transport allows the transportation of the general public through a series of group travel systems. These systems follow defined schedules, pre-established routes and can transport more passengers in comparison to private vehicles. Unlike private transportation, some public transport modes receive subsides from public administrations offering low prices for its users. Differences in public transport modes are related to several criteria such as distance, time, speed and cost amongst other (Humphreys, 2016). From an urban perspective, the most common modes are buses, light rail or trams, underground and passenger trains. For relatively short interurban trips, trains and high-speed trains are common and for larger distances air transport is used. Lastly, ferry transportation is also common between islands and mainland where the capital cost of this modes is significantly lower than building new infrastructure (Wikipedia, 2018b).

Public transportation systems not only bring benefits to local cities, but also to local economy and municipalities in several aspects. First of all, public transport has a positive impact in local economy and society. With investment in public transport, economic opportunities flourish and communities experience revitalization (APTA, 2018). Additionally, environmental impacts are considerably reduced, and traffic congestion also decreases. In comparison to private transport, public transport is much safer considering the number of accidents and even more when analysing fatalities (National Express Transit, 2017).

2.2.2 **Mobility as a Service**

One of the current trends to improve UPT is the idea of Mobility as a Service (MaaS). This relatively new concept is used to describe initiatives and solutions using current technology and facilities to benefit passenger transportation. Due to its recent presence within urban mobility, it can be perceived as a concept (a new idea for conceiving mobility), as a phenomenon (it requires the emergence of new behaviours and technologies) or as a new transport solution (Jittrapirom *et al.*, 2017). The main difference to current transportation options is the flexibility these options provide to the user allowing a better mobility experience. MaaS could be defined as a mobility distribution model in which different transport modes are used to offer an adaptable mobility package to the user. Nevertheless, being a relatively new concept, a general definition is not yet available. Some experts believe that MaaS is currently one of the main disruptions within transportation. This is caused by the entrance of new socio-economic systems that affect the traditional functioning of the system (Holmberg *et al.*, 2016).

There are three main drivers for MaaS: societal, economical and technological. The first driver is linked with the trend of urbanisation in society and its effects on mobility. In large cities the ownership of cars is expected to decrease when the millennial generation enters the labour market resulting in the growth of car-sharing solutions. Moreover, the awareness for environmental issues is also encouraging people to find alternatives (Holmberg *et al.*, 2016). From an economic point of view, MaaS is related to flexibility and to idle transport assets which grew after the economic crisis some years ago. Car sharing initiatives contribute positively to the reduction of the total number of vehicles in cities and require less investment compared to traditional systems. Lastly, there is the technological driver of MaaS. Current technologies ease the communication between users which enables the introduction of the so-called Intelligent Mobility.

According to some examples of MaaS and from literature, there are some aspects that characterise a MaaS system. These are: integration of transport modes, tariff option, single platform (generally digital), multiple actors, use of technologies, demand orientation, registration requirement, personalisation and customisation (Jittrapirom *et al.*, 2017). Many examples of mobility services can be found around the world, but probably the most famous example is Uber, the peer-to-peer taxi service that uses a mobile app to request a trip for the user. Many other examples that can be found in Nordic countries are related with the possibility of renting car for private use managed by automotive companies or even public administrations. With today's technology, it is easier to communicate individual mobility needs, which can be met through customized mobility alternatives that often work under standardized mobility services (Holmberg *et al.*, 2016).

As mentioned earlier, there is no clear definition of the concept of MaaS, and therefore no standard categorization exists. Holmberg et al (2016) present two possible ways to categorize them. The first model (Figure 4) is based on the complexity and the innovativeness while the second model (Figure 5) defines the service according to the degree of integration and ownership.

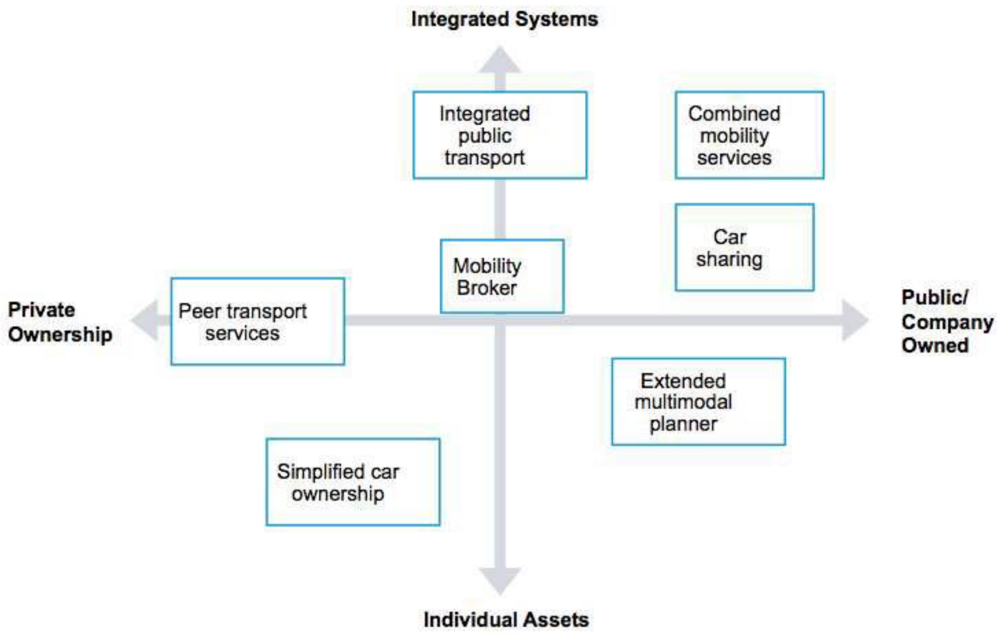

Figure 4: Model for the categorization of MaaS (Holmberg et al., 2016)

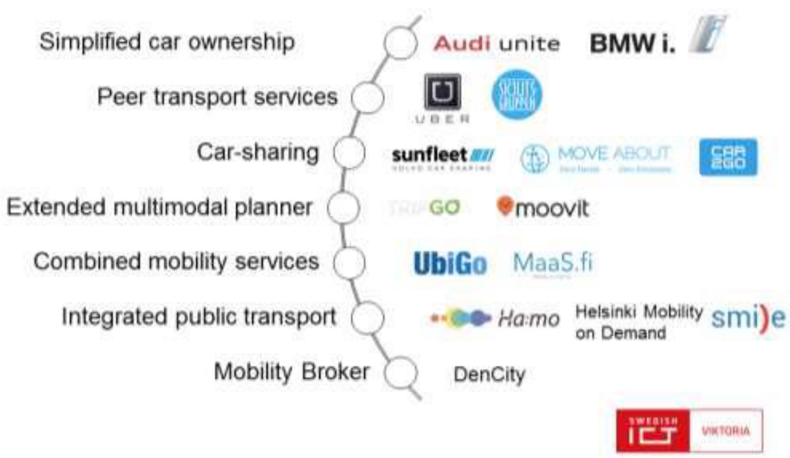

Figure 5: Model for the categorization of MaaS (Holmberg et al., 2016)

2.3 Estimation of Traffic

As previously presented, transportation in urban environments can be divided into passenger and freight transportation. Due to its historical importance, there is more knowledge of passenger transport demand compared to freight transport demand. Consequently, the models for passenger transportation are much more standardized and globally used, whereas freight transport models have not yet reached this stage.

Regarding passenger transportation, in Europe four main models are used (Visem, Cube, TransCAD and Emme) providing reliable results in many cities (Bonnafous, Gonzalez-Feliu and Routhier, 2013). These programmes present simulations of how the passenger traffic will function in a certain area as they consider physical features of the sites and psychological aspects of the drivers. In order to fully work, a reliable transportation demand is needed and therefore what elements drive passenger transportation need to be analysed.

When reviewing literature on the topic, research differentiates between two main estimations: total traffic volume and modal split. The total traffic volume estimation or total travel demand is the expected demand of transport in a region for a certain period of time. For this estimation, the parameters that are generally used are those related with population, spatial and economic characteristics of the region studied. Regarding population characteristics, key parameters are: the average income of the inhabitants, the total population, the size of households, age distribution and labour participation amongst others (Jong and Riet, 2008). Household income is the most important driver of demand of personal transport, while the total population and the household size affects the total number of tours generated in an area. Employment also influences the demand of passenger transportation as there is the need of workers to commute to their working place. However, the country and the type of labour market in the area has a direct effect on the modal split of the passenger transportation.

Spatial structure of the area also influences in the demand of passenger transportation, with the key factors of location of major activities and attraction points, population density and the integration of the area within the existent transport network. Areas in which the existent network is reliable often have a higher demand for passenger transportation. In addition, the location of activities influences the tour length and therefore, the time needed for transportation. Population density also affects the preference of transport mode as in dense areas the possibility of private vehicle is lower due to space constraints (Jong and Riet, 2008). Other models consider also the economic characteristics of the area and tend to look at factors such as its gross domestic product, the generalized cost of transport and the historical elasticity of prices and income in the region (Mittal *et al.*, 2017).

The other main estimation is the modal split estimation. For this assessment, aspects related with the modes' characteristics, its preference amongst users and their prices are considered. Some research focuses on the modes' characteristics to be able to define thoroughly the user's preference. For this analysis, key elements are: the availability of private transport or public transport, the service characteristics, the capacity (of both the mode and the infrastructure), travel costs and the travel time (Jong and Riet, 2008). Among these, the availability of private transportation is the most determining factor when choosing the transport mode to be used. Travel time has also a direct effect on the modes selected. Other models used in urban planning are based in the optimization of a cost function used to decide which mode of transport will be used based on the cost, the comfort, the safety and the convenience of the trip. Considering the passenger traffic volume, an overall estimation is then elaborated (Ma and Gao, 2016).

For freight transportation there is fewer standardization and reliable models due to the lack of information related to the difficulty in obtaining relevant data. This has encouraged many institutions to develop models and approaches that unfortunately are usually limited to academic use (Gonzalez-Feliu *et al.*, 2014). Many countries and public administrations tried to develop models to include commercial transport flows in their traffic studies to be able to evaluate impacts and understand their behaviour. However, they were often only focussed on particular areas and their use in other countries is limited.

The current dynamics in urban activities, environmental issues and logistics flows due to differences in demand increases the complexity of developing appropriate models. To define a good model, data should meet the following requirements: provide information of the locations of the economic activities, information of the management and organization of the transportation of goods and the characteristics of the used modes and vehicles (Gonzalez-Feliu *et al.*, 2014). Initially, goods transport models were derived from large scale models of road truck traffic. The approaches consisted in gravity functions of commodity flows but they did not met the reality due to two main reasons: differences between the goods traffic distribution and the vehicle distribution, and the fact that logistic choices implied the objectives of several actors (Routhier and Toilier, 2014). When analysing freight transport demand models, these are generally characterized by four parameters: level of aggregation, degree of detail, the reference values used for the estimation and the spatial resolution of the model (Thaller *et al.*, 2016).

Even though the interest in this topic is increasing, the amount of research is still small, and the data sources are also limited. These are generally traffic counts, transport operator's data and surveys oriented to establishments. However, there is a lack of relationship between these data sources that condition the accuracy of the models which tend to limit them to specific areas or cities.

When focussing on the demand of freight transportation, it is important to define some concepts strictly related to the activity of the different establishments and sectors. These are: freight generation (FG), freight trip generation (FTG), freight trip attraction (FTA) and freight trip production (FTP). FG is the result of the economic activity taking place in an establishment. And is generally measured in volume or weight according to the type of delivery unit. FTG is the number of vehicles needed to transport the FG in an area. In other words, FTG is the logistical decision on how to transport FG by an establishment (Sánchez-Díaz, 2017). In addition, FTG comprises of the sum of FTA and FTP. FTA refers to the incoming trips to an establishment delivering goods, whereas FTP is linked to the number of outgoing trips produced by establishment to other users (Guldbrand, Johansson and Westbloom, 2015). FTG is normally measured by the number of incoming delivery trips to the establishment and the outgoing trips from the establishment on a certain period. Estimating FG helps to determine the general characteristics the establishment should have to store the desired goods, while the estimation of FTG can be then related to the number of total journeys or routes needed to satisfy the demand of the establishment or of the whole area of study.

For urban establishments, FTA depends on the total freight attraction the establishment has (FA), the variety of supplies required and the ordering policy the company follows. (Sánchez-Díaz, 2017). The fact that in some cases FTA and FTP are defined by different factors, shows the importance of studying them separately to avoid an overestimation of FTG. Other relevant indicators used when estimating the average FA in a certain area are parameters such as the total population in the area, the average area of the establishments according to their commercial activity, the number of employers and relationships between them (Ibeas *et al.*, 2012).

To then estimate the total number of routes needed other models are used that consider the delivery vehicle's capacity, the dimensions of the area of study, the number of establishments to provide service and the strategy followed by the transportation company. With this, it is then possible to estimate the economic costs linked to freight transportation. (Daganzo, 1984; Estrada, 2007; Estrada *et al.*, 2011).

2.4 Unsustainable impacts of transportation

Both passenger and freight transportation contribute to the generation of impacts that can have environmental, social and economic consequences. According to many studies and regulations, these impacts are: congestion, air pollution, greenhouse gases emissions, noise pollution, accidents, other environmental impacts and infrastructure costs (RICARDO-AEA, 2014). Given the fact that urbanisation is increasing, public administrations find themselves in the need of defining the effects caused by these impacts in order to control and encourage solutions. Many relationships can be found between characteristics of urban transportation and negative impacts of urban freight transport (Figure 6) which is the sector often targeted by policy makers (Browne *et al.*, 2012). However, given that these impacts impose costs upon society, the quantification of their effects is much more complex to determine. In these cases, when the side effects of certain activities signify a cost for society they are defined as external costs (RICARDO-AEA, 2014).

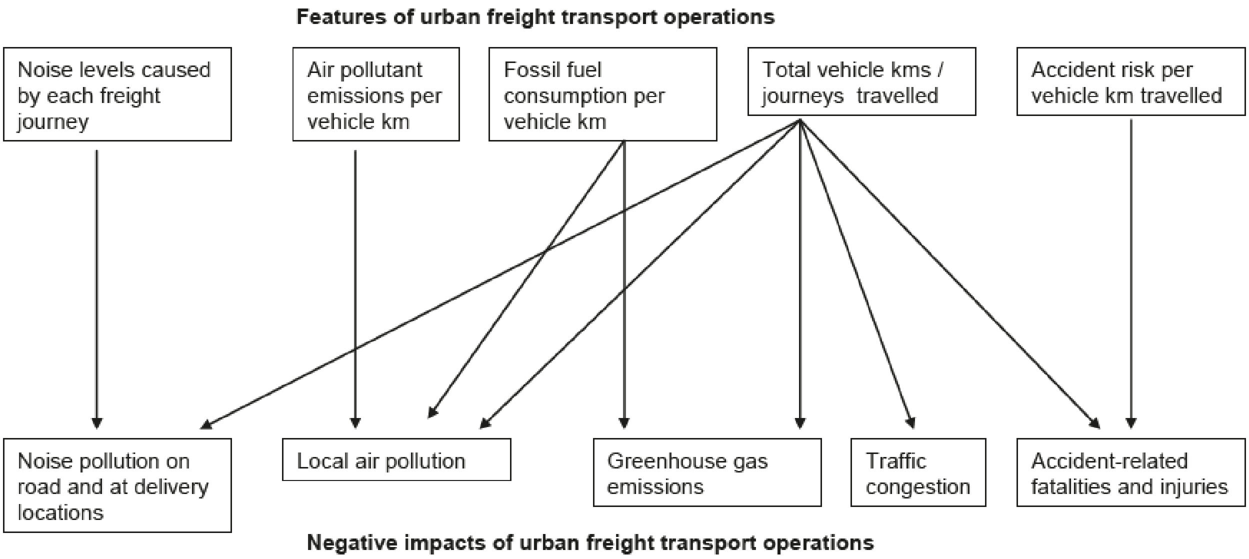

Figure 6: Relationship between features and negative impacts of UFT (Browne et al., 2012)

To quantify the effects, it is necessary to establish a methodology to determine the external costs for each category to then evaluate the real implications of the measures public administrations might carry out. It is relevant to comment that depending on the transport mode used, the external costs will vary. are linked to the transportation mode considered. In this section, the external costs for each category are described according to a report done for the European Commission, DG Mobility and Transport in 2014 (RICARDO-AEA, 2014).

2.4.1 **Congestion**

Congestion is defined as the state of being overcrowded, especially with traffic or people (Collins Dictionary, 2018). When referred to traffic, congestion appears when various users decide to use the same network or road, affecting the maximum capacity this can stand (RICARDO-AEA, 2014). As the flow of vehicles varies during the day, congestion is not a permanent problem in many roads. However, on peak hours and in small city centres, in which the access is more limited, congestion is always present.

Congestion has several direct consequences for travellers. An example is fuel and oil consumption, in the US in 2002 nearly 3% of the total fuel consumed by the transport sector was estimated to be wasted in traffic jams (Poudenx, 2008). Furthermore, congestion has also been linked to propensity to obesity (Poudenx, 2008), to stress and has a direct effect in working hour losses. As an example, in Barcelona a worker spends on average 33,8 hours stuck in traffic per year (Muñoz, 2017).

When analysing road transportation, there are several approaches for the quantification of the congestion costs, but many present several issues when applying them in practice as they only work for specific conditions (RICARDO-AEA, 2014). One approach is the FORGE model, developed by the Department for Transport (DfT) in the UK in 2005 and revised in 2012. According to this model, to quantify the external cost of congestion a set of parameters needs to be differentiated. These parameters are: region (rural to metropolitan), trip purpose, type of vehicle, type of road, congestion band and time of the day. After some corrections and considerations, it is possible to define an estimation of the marginal congestion costs in which the trip purpose and the time of the day are not taken into consideration. In appendix I, a table containing the marginal congestion costs can be found (Table 20)

Regarding the other transportation modes, few studies have been made to estimate external costs caused delays and they differ significantly from country to country. The rail sector is the one that provides more information. For air transportation the cost of congestion, and therefore delay in flights, depend on the airline. For the shipping industry, it is directly linked to the storage costs in ports and warehouses (RICARDO-AEA, 2014).

2.4.2 **Safety**

Safety within transportation is linked with the risk of suffering an injury or even death after an accident while travelling. The costs related to an accident need to be divided into direct and indirect or external. The direct costs are those covered by the insurance company the person has a contract with, depending on the negotiated policy the quantity is higher or lower (RICARDO-AEA, 2014). On the other hand, there are the external costs of the accident, which are those not covered by the insurance company. The most relevant costs are medical costs, production losses, administrative costs, material damage and the associated psychological damage. In addition, the restitution cost must also be considered. This cost is associated with the average cost the injury signifies for society caused by the impossibility of the injured person to work and/or to generate value in the future (Garola, 2008). Therefore, the external costs related to an accident are the following: expected costs due to the accident for the person exposed to the risk, expected costs for the relatives of the person exposed to risk and the accident cost for the rest of the society (RICARDO-AEA, 2014). Currently, road accidents are the leading cause of injury-related deaths around the world (25%). Moreover, it is expected to be the sixth main cause of death the next decade in developing countries (Poudenx, 2008).

When quantifying the costs, it is possible to elaborate an average of the social costs according to the country and the severity of the accident. Fatalities are the most expensive costs, with an average cost in the EU of 1.870.000€, severe injuries present an average social cost of 243.100€ and slight injuries mean 18.700€ on average. Analysing the data, there is a clear difference in the social costs between western and eastern countries in the EU; western countries present higher social costs (RICARDO-AEA, 2014). However, for the evaluation of the impact, it is convenient to establish a marginal cost based on the type of vehicle and the type of road. In appendix I the marginal costs for these impacts are shown (Table 21)

The previous information is only related to road transportation and its related accidents. For other transportation modes, the occurrence of accidents is much lower for the total km travelled. Regarding the evaluation of the other transport modes, in 2011 an important analysis of the external costs was developed that reported an average cost value of 0,5€ per 1000 pkm (passenger per km) for air transportation, 0,6€ per 1000 pkm for passenger rail and 0,2€ per 1000 tkm (tonnes per km) for rail freight (CE Delft; INFRAS; Fraunhofer ISI, 2011). For these cases, all accident costs can be considered as external, resulting the marginal costs in average costs.

2.4.3 **Air pollution**

Air pollution is defined as the introduction of harmful substances to the atmosphere. This pollution is directly caused by both natural processes and more significantly human activity (Wikipedia, 2018a). Several models and methods exist for the quantification and evaluation of air pollution effects. Nevertheless, the most recommended and used method is the Impact Pathway Approach (IPA) in order to standardise the analysis (Figure 7). This method is based on 5 key steps. The first one quantifies the burden of pollutant emissions, the second is to analyse the dispersion of the pollutant around the source. The third step is to establish the level of exposure the population and the environment have to the pollutant. Then the impacts related to the number of premature deaths, illnesses and the effect on crops amongst others are quantified. Finally, a monetary equivalence is developed for each impact (RICARDO-AEA, 2014). The following figure shows these steps:

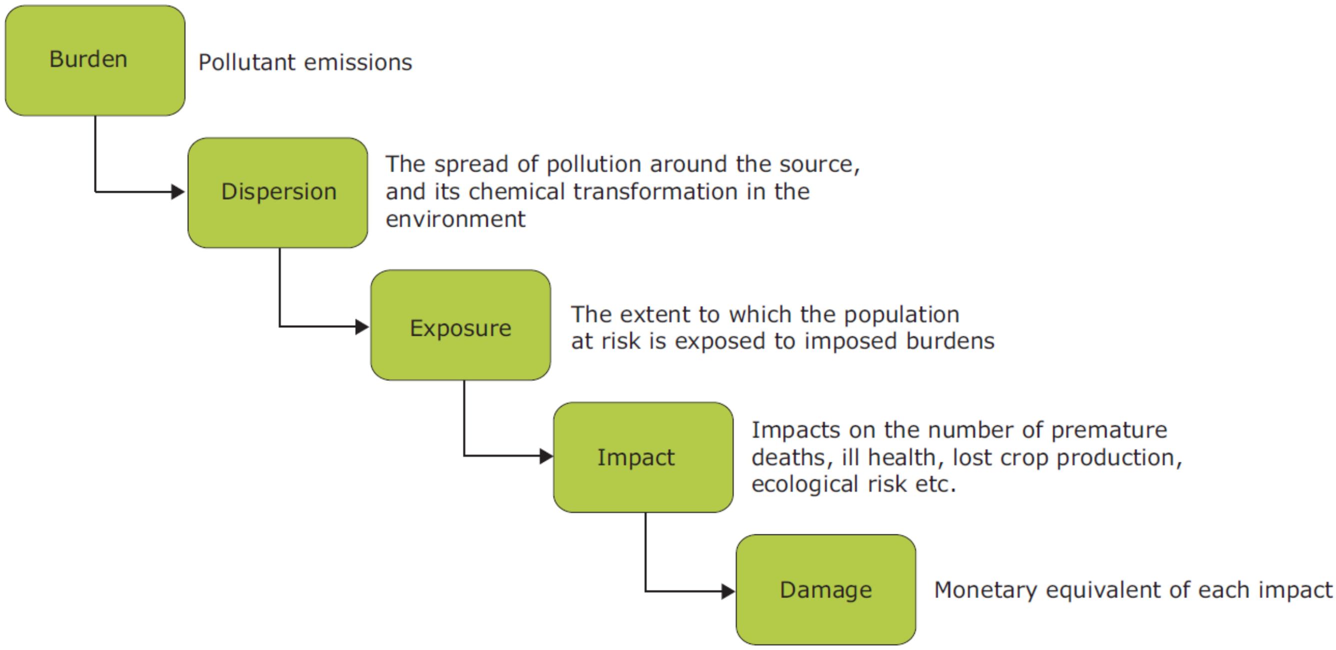

Figure 7: The Impact Pathway Approach (RICARDO-AEA, 2011)

The pollutants can be classified between primary and secondary pollutants. The first are direct products of fuel combustion such as nitrogen oxides (NO_x), sulphur dioxide (SO_2) and carbon monoxide (CO). Secondary pollutants are generated through atmospheric chemistry when certain elements or pollutants combine themselves in the atmosphere. The main ones are ozone (O_3), and different types of sulphates and nitrates. To these, Particulate Matter needs to be added, being PM_{10} and $PM_{2.5}$ the most relevant ones (Wikipedia, 2018a).

Regarding the impacts of air pollution, it was estimated that more than 20.000 premature deaths were caused by road transport pollution in 1999 in France, Austria and Switzerland (Poudenx, 2008). On average, urban freight is responsible for 15%-60% of the air pollution in cities depending on the pollutant considered (15% for CO and 60% for PM) (Robusté, 2012). In addition, primary pollutants can affect children and adults in different ways. Particulate Matter for example, can cause asthma in children but it is more linked to cancer risk in adults. Secondary pollution, on the contrary, have the same repercussion in both adults and children when analysing their effects in health. These effects can then be monetized, and different studies have been developed.

The unit cost for this impact is directly related to the health injuries they produce, together with the technology used in the vehicles. Therefore, a distinction must be made between cars, light commercial vehicles (LCV), heavy goods vehicles (HGV) and buses. Moreover, the type of engine and its efficiency (EURO0 – EURO6) and the road type is also considered when defining air pollution costs. Thus, the cost is evaluated in €/vkm according to the vehicle's category (size or weight), the EURO-class efficiency and the road type (RICARDO-AEA, 2014). The full marginal costs for air pollution can be found in appendix I (Table 22 and Table 23).

For rail transportation, a similar approach is done to evaluate air emissions from diesel-driven trains. As for road transport, a differentiation must be done regarding the type of train and the area this travels to (urban, suburban or rural). Air transport, inland waterway transport and maritime transport also are contributors to air pollution and have their own marginal costs based on researches done in each sector (RICARDO-AEA, 2014).

2.4.4 Noise pollution

One of the transportation impacts which is more studied recently is noise pollution. Not only it affects people's comfort, but also is linked with health impairments, loss in productivity and stress. Therefore, two main impacts can be related to noise: personal disturbance and health impacts. As for air pollution, a method to determine the marginal costs of noise has been developed based on similar steps to those of the IPA method (RICARDO-AEA, 2014).

This impact has only been considered recently and according to the World Health Organization (WHO), it is a major factor in decreasing life quality. Moreover, it is the only environmental impact for which the number of complaints have increased since 1992 (Poudenx, 2008). Noise pollution is directly caused by the vehicle's engine, the contact between infrastructure and the vehicle, and the freight movement itself. The recent concern for this impact is linked with the little number of studies done oriented to understand clearly its consequences and define its economic costs. The main reason is the lack of comparable data amongst different countries related to noise exposure.

As in other impacts, the environment considered is relevant in the evaluation of the impact (rural or urban environment) together with the vehicle analysed. However, for noise pollution the time of the day is also relevant when defining the consequences (RICARDO-AEA, 2014). During the night the background noise is considerably lower, and therefore the impact of noise pollution is significantly higher. This fact is sometimes used as a drawback for the development of polices related to night deliveries in cities. Even though many tests show that the noise levels remain the same, the impact is much higher which in many cases leads to the non-implementation of the alternative (Estrada, 2017). Recently, the WHO recommends two noise limits according to the time of the day. During day time (7:00 – 23:00) outdoor noise should not exceed 55 dB. During night (23:00 – 7:00), this value should be under 40 dB (Mueller *et al.*, 2017).

With all these stated, the marginal cost for noise in the EU is defined according to the type of vehicle studied, the time of the day, the traffic type (thin or dense) and the road type (urban-rural) in €/vkm. When comparing the same transportation mode, the highest values for the external cost are those at night for urban areas when the traffic is thin (RICARDO-AEA, 2014). When freight trains travel through urban areas, their impact is the most severe. In appendix I the table containing all marginal cost can be found (Table 24).

When analysing other transportation modes, the air transport industry is the one in which mores studies have been done to define the marginal costs for airports when considering the landing and take-off cycle (LTO). In these cases the costs are measured in €/LTO and differ between countries and airports making difficult the definition of a standard value (RICARDO-AEA, 2014).

2.4.5 Climate change

Greenhouse gases (GHG) are defined as those atmospheric gases that absorb and emit radiant energy in Earth's atmosphere. Currently, they have a direct effect in climate change and their emissions are a key topic for global research and environmental policy measures. These gases are mainly carbon dioxide (CO_2), methane (NH_4), nitrous oxide (N_2O), water vapour and forms of fluorocarbons (Wikipedia, 2018c). Of these, CO_2 is basically emitted through human activities and transportation is a major actor in it (Wang, Chen and Fujiyama, 2015). To estimate a unit cost for the impact this phenomenon means, a similar method to the IPA has also been developed based on the quantification of the GHG emissions per vehicle, the valuation of climate change costs and the marginal climate change costs per vehicle (RICARDO-AEA, 2014).

When considering freight and passenger transportation, several studies have been done to assess their global impact in climate change. In 1990, carbon emissions from passenger transportation were 0.8 GtC (Giga tonnes Carbon) and by 2050 they are expected to be 2.7 GtC (Poudenx, 2008). According to (Wang, Chen and Fujiyama, 2015), of all greenhouse gas emissions in 2012, which accounted for 34.5 billion tonnes, 22% were generated by the transportation industry. When comparing different studies, the values of the total carbon emissions from transportation vary between 20% and 25%, depending on the scope of the analysis, resulting therefore in a significant proportion (Piecyk and McKinnon, 2010; Girod *et al.*, 2013). As urban transportation is a multi-modal system, including cars, buses, and rail trains amongst others, the impact of different transport modes is variant. As an example, private cars in carbon emissions (gCO_2/pkm) is three times that of regular buses or even more compared to metro or light trains (Wang, Chen and Fujiyama, 2015). Consequently, passenger transportation is expected to be one of the potential sectors to reduce carbon emissions.

One of the major threats of the GHG emissions is the possible increase in more than 2ºC in Earth's atmosphere and the severe consequences this would have. This fact results in the establishment of a limit of CO_2 emissions allowed by countries around the world and the agreement to control the global emissions. For the evaluation of the external costs linked to the impact, two main approaches exist. A damage cost approach, an evaluation of the costs considering that no actions are done to reduce climate change, and an abatement cost approach. This second approach considers also the costs of achieving certain reduction in the GHG emissions. The differences in global pathways make it difficult to have a full estimation of the costs. Despite this, the calculations of climate change costs approved from a European perspective are those based on the abatement cost approach (RICARDO-AEA, 2014).

To finally estimate the marginal climate change costs for road transportation, the same parameters as for air pollution are used: vehicle type, engine efficiency (EURO type) and the road type (urban, rural and motorways). These marginal costs are in €/vkm, and therefore do not consider the capacity of the vehicle which is relevant in the transportation sector when comparing cars and buses. This approach is done based on the concept of equivalent g of CO_2 (eq. gCO_2), as other gases contribute to the greenhouse effect such as N_2O and NH_4. The full table of marginal climate change costs can be found in appendix I (Table 25).

2.4.6 Infrastructure costs

These external costs correspond to the increase of maintenance and repair transport infrastructure need during their lifetime due to high traffic levels. When defining the external costs, only the economic effects of the repairs are considered and not the consequences a bad infrastructure can have on vehicles or travellers. When analysing roads, differences in materials, external conditions, infrastructure design and total traffic, provoke variations in the unit costs according to the country examined. However, all studies show the same relation between vehicles and infrastructure wear, consequence of the fourth power law that states that the damage caused by a particular vehicle is generally related to its load by a power of four (Pavement Interactive, 2012), resulting in HGVs being those that damage the infrastructure the most.

For road transportation, the definition of the unit cost for this impact is then linked to the vehicle type and the road type. Similar approaches for maintenance costs are done for rail transportation in which the traffic type is considered (passenger or freight) (RICARDO-AEA, 2014). The full table of infrastructure costs can be found in appendix I (Table 26).

2.4.7 Other environmental impacts

There is a group of other environmental impacts which are sometimes neglected for a set of reasons such as: complex impact patterns and uncertain valuation approaches, complex relationship between the impact and the infrastructure, and difficulty associating the impact to the transport system (Maibach *et al.*, 2007). Of these, the most relevant and often considered impacts are the following: costs for nature and landscape, costs for soil and water pollution, costs of up-and-downstream processes and additional costs due to land use planning (Litman and Steele, 2017; RICARDO-AEA, 2014). These impacts are seldom examined when a cost-benefit analysis is done for transport investments. Swedish and British guidelines for example only discuss very briefly these effects (Börjesson *et al.*, 2014).

Costs for nature imply the habitat loss, fragmentation or quality loss for flora and fauna in areas were transportation infrastructure is developed. Some approaches for the quantification of these impacts depending on the precise impact evaluated and the transportation mode (road and railway) are used (Maibach *et al.*, 2007). Traffic has also a negative effect on the surrounding water and soil due to the emission of heavy metals and hydrocarbons. To evaluate the costs, approaches related to the repairing costs are followed. However, few studies for its evaluation exist and the unit values differ significantly.

Transportation itself has indirect effects linked to the need for the energy production and additional costs linked to the production of vehicles and infrastructure. Energy production causes externalities due to extraction, transport and transmission of the energy. Moreover, when developing vehicles and transportation infrastructure, maintenance and environmental costs are linked with its creation (Maibach *et al.*, 2007). The costs of these effects are determined in a similar way to the other major impacts as many pollutants are the same helping the evaluation.

The last impact in this section are land-use impacts. The way in which urban spaces are designed and planned, has direct consequences on the transportation impacts generated in the area. Many factors can be analysed for land-use planning (Litman and

Steele, 2017). Table 1 shows the main land-use factors and its main effects in transportation:

Table 1: Land-use factors and impacts in transportation

Factor	Impact
Regional accessibility	Decrease in the travel distances
Density	Increase in congestion and decrease in travel distances
Centeredness	Increase in public transport efficiency
Roadway design	Increase use of other transport modes
Parking supply and management	Vehicle ownership and total distance travelled
Transit accessibility	Total trips and use of alternative modes

The impacts land-use generates for users and travel behaviour have been thoroughly analysed by many authors and studies, as a correct land use can clearly have positive effects for society (Soria-Lara, Aguilera-Benavente and Arranz-López, 2016). However, little has been done to quantify them numerically as many external conditions surround all the situations. Even though its analysis is complex, the definition of indicators would be interesting and useful in order to facilitate the establishment of a unit cost. These impacts are becoming more relevant in dense urban areas and a correct management of some factors can signify a big difference.

2.5 Chapter summary

This chapter presented theoretical concepts that are relevant for answering the research questions presented in the purpose of the thesis. Research question 1 is linked to the information explained in section 2.3 (Estimation of traffic) as it shows the key factors that define passenger and freight mobility in urban areas. To answer research question 2, information from section 2.4 (Unsustainable impact of transportation) linked with the effects of transportation impacts to human health is used. In addition, finally, research question 3 is linked with theory presented in section 2.1 (Urban Freight Transportation) regarding possible mobility solutions and to then evaluate their effects, data from section 2.4 is also used.

Given the fact that the thesis analyses only solution linked with the logistics sector, theory linked with Urban Passenger Transportation, section 2.2, is not used for answering any research question specifically.

3 Methodology

This chapter presents the research methods that will be used to answer the research questions of this thesis. To start, a background on the research approach and its process will be presented. Then, the case study relevant for some of the research questions will be introduced followed by the data collection methods used in this thesis.

3.1 Research approach

The basic aim of this thesis is to quantify the environmental improvement potential of new mobility solutions in urban areas. To do so, it is necessary to determine the parameters influencing the character and scale of passenger and freight traffic. Moreover, it is crucial to compare the consequences of the proposed solutions with the current situation and with an "ideal sustainable objective". These comparisons will aid to evaluate the real benefits these measures have. To do so, the thesis has three main research questions and to answer these research questions this thesis uses a case study approach combining quantitative and qualitative research.

Qualitative research can be defined as exploratory research in which the problem or topic is described in detail while quantitative research is oriented to quantify the problem by generating data that can be used for its evaluation (De Fanzo, 2011). Moreover, qualitative research is also linked with the development of interviews and observations, as qualitative researchers tend to study everyday life environments (Näslund, 2002). For case studies, the combination of both approaches is normally done as theoretical knowledge and real application is crucial.

This thesis has 3 research questions, each oriented to a different analysis according to their scope. RQ1 is focuses on the factors that define passenger and freight transportation in urban areas and therefore will be based on literature review regarding the topic. Therefore, the approach will be more quantitative. On the other hand, RQ2 and RQ3 require qualitative research to define certain thresholds and establish the effect of certain policies. Thus, these questions will combine knowledge provided in the literature review and information obtained from interviews, observations and external documents provided by actors involved in the project and public administrations. Table 2 shows the resources used for the different research questions.

Table 2: Relationship between research questions and used resources

	LITERATURE REVIEW	INTERVIEWS	OBSERVATIONS
RQ1: ANALYSIS FRAMEWORK	RESEARCH PAPERS		
RQ2: SUSTAINABLE TRAFFIC VOLUMES	RESEARCH PAPERS	CITY & TRAFFIC PLANNERS	EXAMPLE URBAN AREAS
RQ3a: TRAFFIC WITHOUT DENCITY SOLUTIONS – CURRENT SITUATION	RESEARCH PAPERS; EXTERNAL DOCUMENTS	TRAFFIC PLANNERS, TRANSPORT COMPANIES	EVALUATION OF SIMILAR AREAS, CURRENT DISTRIBUTION SYSTEMS
RQ3b: IMPACT REDUCTION WITH DENCITY SOLUTIONS	RESEARCH PAPERS; EXTERNAL DOCUMENTS	DENCITY PARTICIPANTS	

3.2 The case study: Frihamnen, Gothenburg

As previously commented, case studies are considered both qualitative and quantitative studies as they focus on understanding the dynamics present within single settings (Eisenhardt, 2011; Näslund, 2002). In addition, case studies are preferred when examining contemporary events and are normally done for a variety of aims such as descriptive analysis or generation of theories. Due to the particular working process case studies follow, Benbasat et al. (1987) defined a set of characteristics they share, the most relevant of which are (Näslund, 2002):

- Data are collected by multiple means
- Phenomenon is examined in a natural setting
- Changes in data collection methods could take place as the investigator develops new hypotheses and analysis
- The results derived depend heavily on the integrative powers of the investigator

The case study for this report will be the future development area in Frihamnen, Gothenburg, based on the mobility solutions developed in the DenCity project. This new area is expected to have a similar urban structure to existing ones in the city of Gothenburg. Using data from other studies and observations, relationships will be adopted to get a more realistic approach. The area used for the comparison will be Vasastan.

The City of Gothenburg is recently involved in the development and growth of all the areas close to the Göta Alv in the project known as the RiverCity. One of these areas is the former free port 'Frihamnen' in which the idea is to promote a sustainable and attractive neighbourhood combining public spaces, housing areas, office buildings and a variety of shops (Gothenburg City Council, 2012). All the innovations and solutions implemented in this area will then be applied, if possible, in other parts of the city aiming for a more sustainable future for the whole city.

The DenCity project, which is financed by Vinnova (the Swedish government agency that administers funds for research and development), is oriented to design sustainable solutions for passenger and freight transportation in dense and attractive urban neighbourhoods. DenCity reviews solutions and services that will be tested under real conditions to understand their consequences (CLOSER, 2017). In the project several entities work together in 5 different focus areas that are:

- Zero Emission Distribution: Electric vehicles for distribution of groceries in cities, opening up for efficient zero-emission deliveries in terms of noise, emissions and particles and enabling new ways of delivering goods - for example silent deliveries during off-peak hours which means more space for people during the day.
- WP2 Urban Waterways: Development and test of a multimodal transport chain including barge, cargo-bike and small electric vehicles in order to make use of the largely un-utilized infrastructure (waterways) in Swedish cities
- WP3 Enabling Infrastructure for Dense Cities:
    - Digital platform integrating mobility and delivery services for people living and working in dense urban areas

- Business model and blue-prints for a City Consolidation Centre (CCC), servicing an entire urban area with consolidated goods and waste transport
- Development of mobility solutions and their integration in the urban planning process

- WP4 Urban Deliveries and Services: Consolidated e-commerce distribution and return flows through the development of neutral delivery infrastructure in real-estates
- WP5 System integration and effects: Integration of the different solutions into a collective transport system as well as integrating of freight issues into the urban planning process. Collective solutions require an urban logistics infrastructure which in turns requires an urban planning process, which takes considerations to freight in the long-term development plans.

This thesis is linked with focus area 5 as an analysis of all the other mobility solutions is used in the evaluation of the impacts they will present. To do so, information and data from all the other work packages is used.

3.3 Research process

Since the thesis is based on a case study, it follows an abductive research approach. The abductive research process (Figure 8) is characterized by a combination of theory development and data collection (Kovács and Spens, 2005). The other main approaches are inductive or deductive but neither of them is suitable for case studies. Deductive approaches are oriented to evaluate existing theories or ideas, while an inductive approach is done for generalizations of new phenomenon. Case studies normally combine multiple data collection that alters slightly the orientation of the data collection methods used or the information wanted. In other words, this approach allows the researcher to take advantage of flexible data collection adjusting to the real needs of the analysis (Eisenhardt, 2011). Consequently, the data collection methods may differ from those initially planned but his should not be seen as an inconvenience. According to building theory, this is crucial to understand better the problem that wants to be considered.

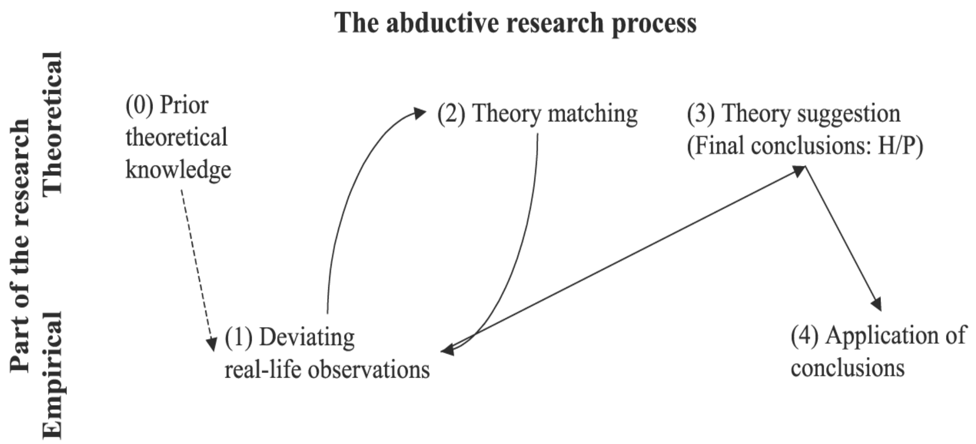

Figure 8: The abductive research process (Kovács & Spens, 2005)

Given the different data sources used in this thesis, Figure 8 can be recreated in a similar way considering their nature and their results (Figure 9).

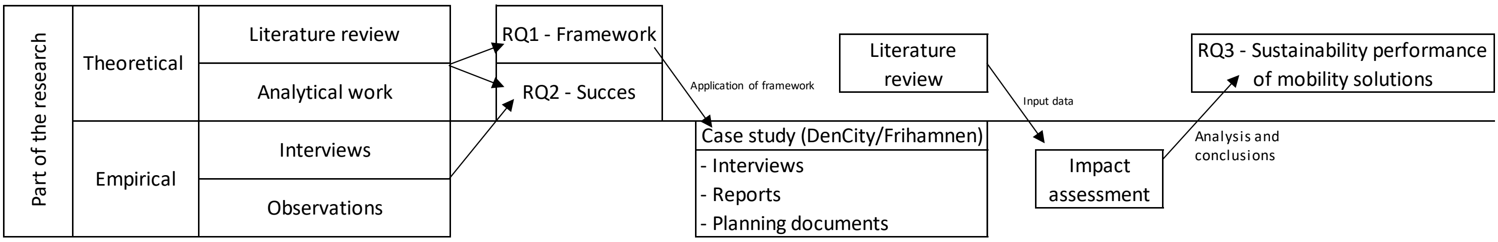

Figure 9: Research process for the thesis

3.4 Data collection

Data collection is crucial to have a strong theoretical background and to be able to describe the reality presented in the most accurate way. Data can be classified in primary or secondary data. Primary data refers to data collected by researchers to solve and understand the problem to be analysed. On the other hand, secondary data refers to data obtained from other researchers oriented to a problem different from the analysed situation.

As this report is linked with a case study, it is usual to have data from different sources (Kovács and Spens, 2005). Therefore, in this report both types of data are collected, for the theoretical analysis secondary data from research papers, institutions' websites and other governmental documents is used. Primary data is obtained from interviews with the different actors directly and indirectly involved in the project and observations of similar sites for comparison. In addition, throughout the thesis it has been possible to attend some meetings to have a better view of the progress and updates in the project.

3.4.1 Literature review

The literature review presented in chapter 2 is oriented to create a valid theoretical background for the reader about urban transportation, its estimation and its consequences. Due to the nature of case studies, literature review and empirical analysis are developed alongside as new areas of knowledge arise while exploring the reality of the case.

Furthermore, secondary data is obtained from public reports to determine values such as nº of residents and businesses for the case study. In some occasions relevant data for some topics is obtained via interviews.

3.4.2 Interviews

Interviews, together with observations, are the most common source of information for qualitative research. They can be categorized into structured, semi-structured or unstructured interviews (Jamshed, 2014). Structured interviews have well-defined questions and predetermined techniques, semi-structured interviews tend to have a less defined guide in which the topics that want to be explored are stated. Finally, unstructured interviews resemble more to a "controlled conversation" oriented towards the interests of the researcher. To capture all the information presented in the interview, it is highly recommended to have them recorded as long as the respondent accepts.

In this thesis, two sets of interviews were conducted. Initially semi-structured interviews were done with several participants in the project to have a prior perception of the role of work packages and the vision public administrations had of the case. Later, more structured interviews were made with transportation actors to facilitate the estimation of the parameters used in the estimation of traffic and impacts. Table 3 presents the different people interviewed, their role in the company they work for and the date of the interview.

Table 3: Interviews done during the thesis

Name of the interviewee	Organisation	Role	Type of encounter	Date of the interview
Fredrik Cederstav	AB Volvo	Project Manager	Face-to-face interview	15/02
Lina Olsson	Closer	Project Leader	Face-to-face interview	15/02
Mia Edström	Stadsbyggnadskontoret	Project Leader	Face-to-face interview	20/02
Martin Svanberg	SSPA	Project Manager	Conversation	22/02
Magda Collado	RISE Viktoria	Researcher	Face-to-face interview	08/03
Fredrik Widman	Trafikkontoret	Project Leader	Face-to-face interview	20/03
Linda Andersson	AB Ramböll	Traffic planner	Conversation	23/03
Peter Arnes	Goteborg Stad - Kretslopp och vatten	Process leader	Face-to-face interview	03/04

3.4.3 Observations

Throughout the thesis, there was the possibility to attend group meetings linked with the progress of the DenCity project. Moreover, and given the fact that the future area of Frihamnen is intended to have similar characteristics to those some areas in Gothenburg have currently, commercial observations and traffic counts in existent areas were also considered. These observations were case studies oriented to characterize the transport and the commercial activity in the area of Vasatan in the Master level course ‘Sustainable Transportation’ at Chalmers University of Technology.

In 2016, in the course “Sustainable Transportation”, a survey was performed to get information from the different commercial establishments around Vasastan. The survey focused on defining the total area the shops and businesses occupied, the average number of employers a regular day together with general information regarding the deliveries received and the patterns followed in these deliveries. More than 90 establishments participated in this survey and relevant data was retrieved from it.

In 2017, a traffic count was done in the same academic course oriented to define the total traffic in the area. The traffic count was done for all transport modes and was performed in two different days to obtain reliable data. The traffic count was carried out from 7am to 6pm, and passenger vehicles (both public and private), freight vehicles, pedestrians and bicycles were analysed. Regarding freight vehicles, the commercial sector, the vehicle’s size and its engine’s efficiency were analysed.

3.5 Impact assessment model development

Research question 3 is based on elaborating an estimation of the expected logistics traffic in Frihamnen and after that, elaborate scenarios based on the different mobility solutions proposed in the DenCity project and evaluate their external impacts. To do so, a model was developed using Microsoft Excel consisting on 3 different steps. The model is only for freight transport demand and does not consider passenger transportation in the area.

The first step is the estimation of the amount of demand from and to the area. Three types of demand generators are considered: 1) commercial establishments (retail, restaurants, hotels, etc.), 2) apartments and 3) offices. For each demand generator, four types of freight demand are considered: 1) parcels, 2) pallets & roller cages, 3) waste and 4) services. Based on the total number of establishments, offices and apartments in the area, the total demand is calculated. The second step consists on the traffic generation to satisfy this estimated demand. Each demand type is transported by several vehicle classes differing in terms of vehicle size, load factors, etc. The outcome of the second step is the amount of vehicle tours to and inside the area needed to meet the expected demand from step 1. In the last step, the external impacts of the estimated traffic from step 2 is quantified in monetary units (€) (external costs generated by each sector and each type of vehicle). For this step a default tour for each vehicle and/or sector needs to be defined, as well as the marginal unit costs units of the different types of externalities.

In this section, these3 steps are explained in detail, followed by a discussion of the limitations of the model.

3.5.1 Step 1: Estimation of the demand

As seen in the literature review, an FTG model was developed (Sánchez-Díaz, 2017),in which FTA and FTP for commercial establishments were studied. According to the model, FTA and FTP can be calculated using the following equations:

$$FTA = 3.94 + 6.30\gamma_{RP} + 0.76A - 0.56(\gamma_{HC}A) - 0.53(\gamma_{PS}A)$$

where:

A: area of the establishment (for $100m^2$)
γ_{RP}: binary variable denoting if the establishment belongs to the retail perishable sector (1 if it belongs, 0 if not)
γ_{HC}: binary variable denoting if the establishment belongs to the health care and other services sector (1 if it belongs, 0 if not)
γ_{PS}: binary variable denoting if the establishment belongs to the public and education sector (1 if it belongs, 0 if not)

$$FTP = 4.50 - 4.02\gamma_{RN} - 2.78\gamma_{HC} + 1.08(\gamma_{RN}A)$$

where:

A: area of the establishment (for $100m^2$)
γ_{RN}: binary variable denoting if the establishment belongs to the retail non-perishable sector (1 if it belongs, 0 if not)

The unit of the resulting values is number of individual freight trips or the total number of deliveries. As an example, considering a food retailer store (retail perishable) of 100m^2 would receive 11 deliveries per week (FTA) and produce 4.5 deliveries per week (FTP). As a whole, it would generate 15.5 freight trips (FTG)

Regarding freight demand of households, only the e-commerce market is considered, i.e. the number of deliveries of online purchases to private addresses. According to a report presented by Eurostat in 2016, 67% of Swedish citizens had bought or ordered online goods in the previous 3 months (Eurostat, 2018a). In addition, the same report provided information on the number of times European citizens had purchased online, resulting in an average of 5.3 times in the last 3 months. Considering this, for the model it is supposed a total freight demand of 0.3 items/week per inhabitant. A trip is accounted for each item delivered.

For the freight demand in offices, no detailed studies were found when developing the model. However, it was possible to contact Mr Michael Browne, who has a strong knowledge in urban freight transportation, who proposed the value of 0.3 trips/100m^2 of office per day. Therefore, an estimated value of 1.5 trips/100m^2 per week for offices.

The model also takes into consideration the waste generated in the area by its citizens and the different establishments. From the interview with the waste company in Gothenburg, it was possible to obtain information related with the general and food waste collection. Thus, the model does not estimate the amount of paper, glass, plastic and other recyclable waste in the area of study.

It was not possible to elaborate an analytical estimation of the waste generation for all commercial establishments. Nevertheless, the following supposition was made in accordance to data retrieved from a study in British cities (Allen *et al.*, 2008):

Table 4: Supposition of the number of waste containers generated by sector

Sector	***Nº of general waste containers/week***	***Nº of food waste containers/week***
Accommodation and food	5	3
Public services and education	2.5	-
Health care services	2.5	-
Retail perishable	4	-
Retail non-perishable	4	-

Lastly, an estimation of service trips is done. Again, few studies have been made which include service trips, and those that have generally only analyse commercial establishments. Therefore, service trips to households and offices were not included in the model and for commercial establishment an average of 7.6 service trips/weeks was made (Cherrett *et al.*, 2012).

3.5.2 Step 2: Traffic generation

The second step of the model is to estimate the total traffic generated to satisfy the total freight demand calculated in step 1. First of all, it is necessary to distinguish which vehicles and which sectors supply each type of demand. Generally, 3 different vehicle sizes are distinguished.: light duty vehicles with a maximum weight less than

3.5 tons (L), medium-duty vehicles with a weight less than 26 tons (M), and heavy-duty vehicles with a weight bigger than 26 tons (H). The different sectors considered are transport companies, retailer with own vehicle fleet, HoReCa companies with own vehicle fleet, waste collection, and construction & service companies. In addition, the split of each vehicle also needs to be defined to then calculate how many vehicles will be needed according to each freight transport sector. The initial split considered will be presented when the BAU scenario is defined in chapter 4. The type of vehicle and the transport sector supplying each delivery unit or service used in the model are shown in the Table 5.

Table 5: Relationship of supplying vehicles and delivered items or service visits

Delivery unit/service to be delivered	Supply vehicle
Parcels to commercial establishments	L vehicle from transport company L vehicle from retail company
Parcels to households	L vehicle from transport company
Pallets/cages	M vehicle from HoReCa company M vehicle from retail company H vehicle from retail company M vehicle from transport company H vehicle from transport company
Other	L vehicle from HoReCa company L vehicle from transport company M vehicle from transport company H vehicle from transport company
Service visit	L vehicle from construction company M vehicle from construction company L vehicle from service company M vehicle from service company
General waste container	L vehicle from waste company M vehicle from waste company H vehicle from waste company
Food waste container	L vehicle from waste company M vehicle from waste company H vehicle from waste company

After defining these relationships and the vehicles' split it is possible to calculate the number of tours and trips needed for each vehicle and each transport sector. In the model, a tour is defined as the journey done by the vehicle to reach the area, whereas a trip is defined as the journey done by the vehicle to each receiver within the area. To calculate the total number of tours and the number of trips per tour the following equations are defined:

$$\#tours\ vehicle_i = \frac{total\ demand\ of\ the\ category}{\sum_i^n \frac{split\ vehicle_n}{split\ vehicle_i} \cdot \frac{trips}{tour} vehicle_n \cdot \frac{items\ or\ service}{trip} vehicle_n}$$

$$\#trips\ vehicle_i = \#tours\ vehicle_i \cdot \frac{trips}{tour} vehicle_i$$

*: i and n refer to vehicles supplying the same delivered item or service visit

For service vehicles the demand is the number of service trips expected, and for waste vehicles it is linked with the number of containers they collect in each stop.

Given the hourly presence of each logistics vehicle throughout the day, it is then possible to calculate the number of tours and trips done per hour by multiplying these values together. The number of trips expected per hour is then used to determine the Passenger Capacity Unit (PCU) demand throughout the day. The PCU is parameter used to determine the degree of congestion in a road and within urban areas it is useful to evaluate the use of available parking spaces. The PCU equivalence factors adopted for the traffic generation are the following (RICARDO-AEA, 2014):

Table 6: PCU factors for freight vehicles

Vehicle type	***PCU factor***
LDV or vans	1.0
MDV	2.0
HDV	3.0

All in all, this second step allows the calculation of the number of tours and trips in the area throughout the day for each vehicle category as defined in Table 5.

3.5.3 Step 3: External impacts evaluation

The last step of the model consists of the estimation of the external impacts caused by the traffic generated in the area. The impacts are calculated for the network, linked to the number of tours, and within the area, linked to the number of trips. As explained in the literature review, the indicators of the external costs for the studied impacts depend on the total vehicle-kilometre (vkm). Therefore, the impacts depend on the length of the tours in the network and inside the area. The length of the tours obviously varies a lot depending on type of sector and vehicle used. However, in this thesis one default tour is defined which is used for sectors and vehicles.

The model evaluates the following impacts: congestion, accidents, air pollution, greenhouse gases, noise and infrastructure wear. To calculate the impacts several input parameters are needed. Table 7 depicts the parameters used for the calculations in this thesis. The value of the indicators can be found in the appendix.

Table 7: Key parameters for the calculation of external impacts

External impact	**Definition of the indicator**
Congestion	- Region: metropolitan city - Road type for the network: main road - Road type for the area: other roads
Accidents	- Country: Sweden - Road type for the network: motorway - Road type for the area: urban roads
Air pollution	- Road type for the network: suburban - Road type for the area: urban

GHG emission	- Road type for the network: motorway - Road type for the area: urban
Noise pollution	- Road type for the network: suburban - Traffic type for the network: dense - Road type for the area: urban - Traffic type for the area: thin
Infrastructure wear	- Road type for the network: motorway - Road type for the area: other roads

From the indicators defined above, air pollution and GHG emission are linked with the engine's efficiency of the vehicles and therefore these costs need to be calculated separately for each vehicle size and emission efficiency class, in order to achieve a more accurate evaluation. In addition, for congestion costs a differentiation in terms of traffic conditions on the route has to be made, i.e. free-flow, near capacity and over capacity conditions, which are defined based on the relation between traffic volume and capacity of the road (RICARDO-AEA, 2014).

With all this stated, the external impacts are calculated by multiplying the number of tours and trips with the default tour in the network and the value of the indicator of the external impact. This calculation is done for all vehicles in all the sectors and the unit value is €.

3.5.4 Limitations of the model and impact assessment

The model described presents some limitations in three main aspects: scope of the model, data quality and model behaviour. Regarding the scope, the model does not consider passenger transportation, nor the impacts generated by it. In terms of data quality, some traffic types are not included due to lack of data, e.g. service trips to households and office, as well as waste from offices. Due to lack of waste generation models, waste generation for commercial establishments is based on the author's assumption instead of primary or secondary data. Finally, the model does not work as a dynamic simulation. In a realistic situation, larger volumes in step 1 (demand) would lead to higher transport efficiency in step 2 (traffic generation). However, the model cannot reflect these changes. The input data in each step is defined independently.

Due to the limitations of the model and data, the outcome of the model should not be taken literally, i.e. the amount of external costs calculated most probably differ a lot from reality. However, it is assumed that the model and data used is accurate enough in order to compare different scenarios and by this to assess the relative performance of and systemic difference between the alternatives analysed.

4 Case study – Frihamnen, Gothenburg

This chapter presents the results for the evaluation of the external impacts caused by freight transportation for the case study according to the model previously described. 4 different scenarios are defined: the BAU scenario in which no changes in current mobility trends are included, and 3 scenarios for the year 2030 in accordance to the initiatives promoted in the DenCity Project. First the scenarios are described and later the evaluation of the external impacts presented.

4.1 Freight demand in Frihamnen

Before presenting the scenarios, it is useful to calculate the expected freight demand in the area as it will be the same in all cases. According to the model used for the freight traffic generation, to calculate the freight demand in commercial establishments their total number and average area needs to be reckoned. For this study, it is assumed that the commercial establishments in the Frihamnen area will have the same pattern as in residential areas in the inner city of Gothenburg, which are similar to Frihamnen in terms of density and type of land use. Hence, for the estimation of commercial establishments in Frihamnen, data from a survey in the area of Vasastan done in 2016 is used to define the average area for each type of commercial establishment and distribution (Table 9).

Table 8: Commercial establishments' data from Vasastan

Commercial sector	*Nº of businesses*	*Average area (m^2)*	*Distribution (%)*
Accommodation and food	40	156,2	43,0%
Retail perishable	5	42,6	5,4%
Retail non-perishable	15	133,1	16,1%
Education and public sector	2	-	2,2%
Health care and other services	31	209,7	33,3%

As Frihamnen is expected to be of the same character as Vasastan, scaling up the data from Vasastan is possible to obtain a good approximation of the expected number of establishments in Frihamnen. Maps and planning documents from the city planners of Gothenburg provide information on the planned space for housing (apartments) and businesses (offices and commercial establishments). Based on these documents, the expected space for businesses in the bottom floor on street level ('verksamheter bottenvåningar' is 28 800m^2, 129 000m^2 for offices ('verksamheter') is and 310 000m^2 for apartments ('bostäder'). Considering the commercial distribution in Vasastan it is possible to extrapolate the data based on the total area used for commercial activity, the number of businesses for each sector can be calculated Table 9.

Table 9: Estimation of the commercial establishments in Frihamnen

Commercial sector	*Nº of businesses*	*Average area (m^2)*
Accommodation and food	99	156,2
Retail perishable	12	42,6
Retail non-perishable	37	133,1
Education and public sector[1]	2	9925,0
Health care and other services[2]	77	209,7

1: According to data from city planners there will be 2 education centres (schools) in Frihamnen
2: A hospital is planned for the area. FTG for this centre will be estimated separately due to its size (27.000m^2)

In a study for the city of Gothenburg (Sánchez-Díaz, 2017) provided information on the average number of delivery units (parcels, pallets/roll cages and other) each sector receives per week (Table 10).

Table 10: Distribution of delivery units according to the commercial sector

Commercial sector	*Parcels (%)*	*Pallets/roll cages (%)*	*Other (%)*
Accommodation and food	73.5%	26.5%	0%
Public services and education	63.6%	13.6%	22.7%
Health care services	60%	10%	30%
Retail perishable	16.8%	72.6%	10.6%
Retail non-perishable	27.1%	10.4%	62.5%

Combining the expected number of commercial establishments (Table 9), the trip generation model (section 3.5.1) and the distribution of delivery units for each commercial sector (Table 10), the estimation of FTG is calculated (Table 11).

Table 11: Weekly FTG estimation in delivery units for commercial establishments in Frihamnen

Commercial sector	*Nº of parcels*	*Nº of pallets*	*Nº of other delivery units*
Accommodation & food	700	253	0
Retail perishable	30	131	19
Retail non-perishable	75	29	174
Public services and education	40	9	14
Health care and other services	270	45	135
Hospital	36	6	18
Total	1151	473	360

For the estimation of the freight demand of households, which is linked to e-commerce, the total number of residents is needed. For this case, the same number of people per apartment as in Vasastan is considered, which are 1.9 people/apartment (Göteborgs Stad, 2017). The freight demand is based on a total of 3.000 apartments which mean 5.7000 residents. For the delivery units delivered to households, a split of 65% for parcels and 35% for other is considered. Regarding offices, a split of 90% for parcels and 10% for other delivery units is considered

With all these considerations, the expected freight demand for households and offices is the following:

Table 12: Weekly FTG estimation in delivery units for apartments and offices in Frihamnen

Demand generator	***Nº of parcels***	***Nº of other delivery units***
Households	1097	591
Offices	1742	194

Regarding waste generation, data about the waste collection (total kg and total number of containers collected in 2017) in Vasastan is used for waste generated in households. Combining this data with the total population in the area given by Gothenburg's municipality (Göteborgs Stad, 2017), it can be estimated that every citizen generates 8.3 kg of general waste and 1.3 kg of food waste per week.

For commercial establishments, estimations are done based on a report in which several freight studies were reviewed (Allen *et al.*, 2008). For accommodation and food establishment one full container is estimated per working day, for retail establishments the estimation is of 4 containers per week, for the hospital the estimation is of 15 containers per week and for the rest of establishments a full container of waste is believed to be generated every two days.

As commented when defining the model, waste generated by offices was not assessed in the studies. Given that the waste generated by citizens is estimated in kg and for the other actors in containers, it is crucial to transform the kg of waste into containers. Thanks to the data from the waste company, it can be estimated that when collected a container destined to general waste weights 33kg and one used for food waste 15kg.

Bearing in mind the previous considerations, the total number of containers generated per week can be calculated (Table 13):

Table 13: Weekly estimation of the total waste generated in Frihamnen

Waste generator	***Nº of general waste containers***	***Nº of food waste containers***
Households	757	266
Accommodation and food	495	297
Retail perishable	48	0
Retail non-perishable	148	0
Public services and education	5	0

Health care and other services	193	0
Hospital	15	0
Total	1661	563

The last aspect needed for the estimation of the external costs is the definition of the default tour for each vehicle. The default tour for the network was established in 20km for all sectors. Regarding the length of the journeys of the area, thanks to the maps provided by the city planners, the total street length for the area analysed is approximately 2.75km. For vehicles belonging to transport and waste companies, it is assumed that they cover the whole area as they serve many receivers. Hence, the default tour of each trip is established by dividing the total street length by the number of trips per tour each vehicle does. For other sectors, it is assumed that they serve only a few receivers and hence do not travel through the whole street network. Their default tour for the trips was assumed to be 1km. When evaluating the congestion impact, it was necessary to fix a distance under free-flow and near capacity conditions. Due to lack of data the following hypotheses were done: On the access roads to the area (the network) 80% of the tour is under free-flow conditions and 20% under near capacity conditions; within the area 90% of the tour is under free-flow conditions and 10% under near capacity conditions.

In addition to the estimation of the total traffic to evaluate the external impacts, another interesting aspect to analyse is the space demand of freight vehicles. To do so, it is necessary to establish an average parking time for each logistics service type. These were assumed as 5 minutes for parcel deliveries, 10 minutes for pallets and other items, 4 minutes for waste collection and 1 to 1,5 hours for service vehicles. The resulting total demand for parking space (measured in ‘passenger car equivalent units’ hours (PCU hours) is useful to estimate the expected occupancy of the available parking spaces in the area. For this calculation, the PCU parameter defined for each logistics vehicles is used to determine the volume of parking space used.

4.2 Scenario definition

This section presents the different scenarios analysed in the case study. Figures 10, 11, 12 and 13 show schematic illustrations of them.

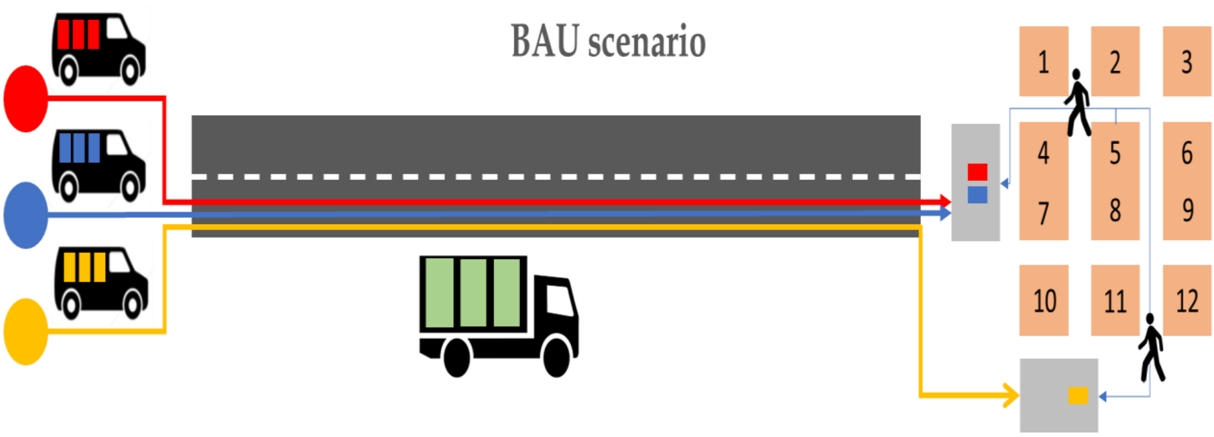

Figure 10: Schematic illustration of the BAU scenario

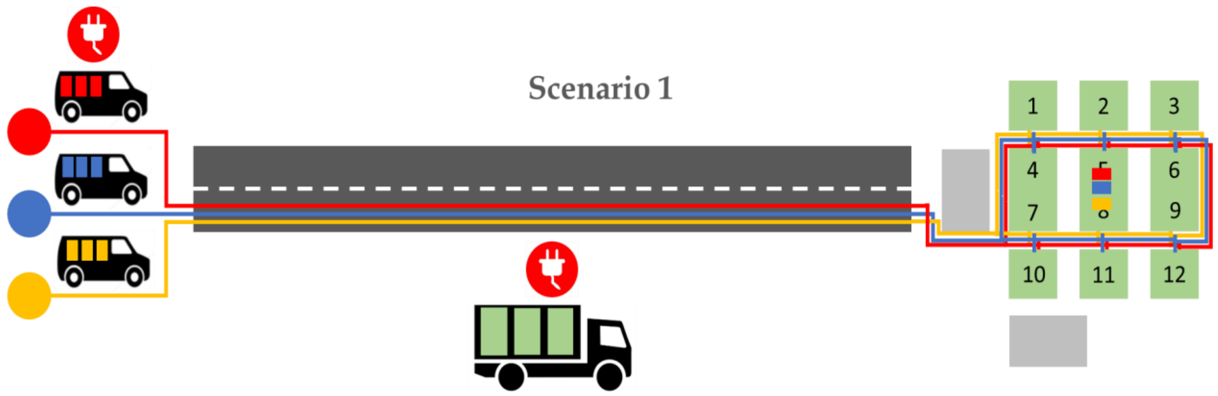

Figure 11: Schematic illustration of scenario 1

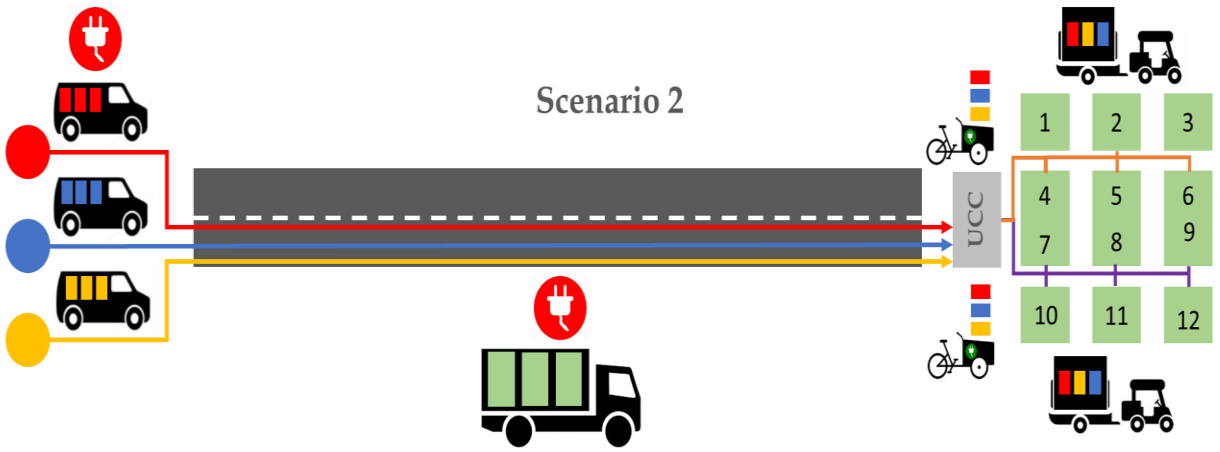

Figure 12: Schematic illustration of scenario 2

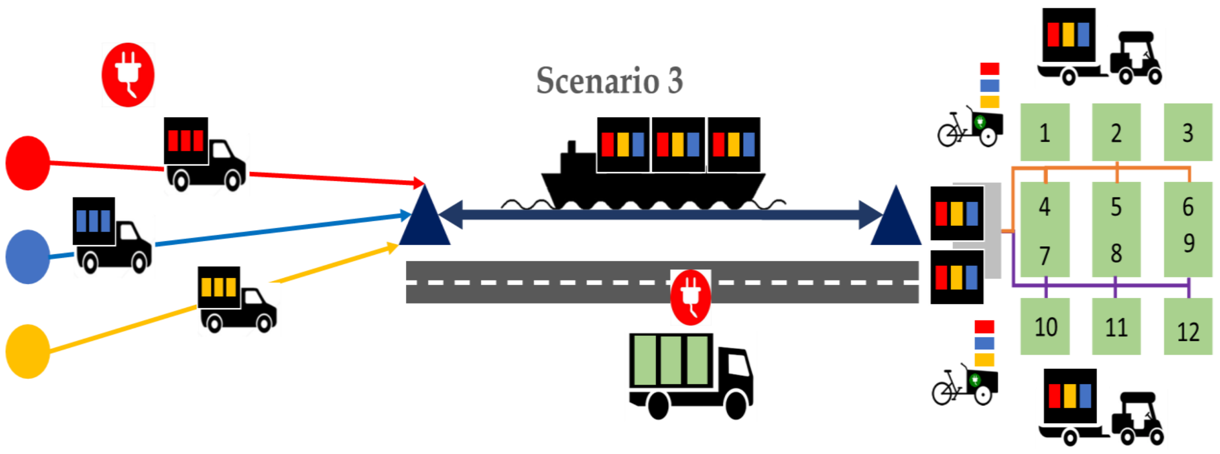

Figure 13: Schematic illustration of scenario 3

4.2.1 Scenario 0 – BAU

The BAU scenario considers the current behaviour of freight transportation based on the observations performed in Vasastan. From the traffic count, it is possible to acquire the split of the vehicles in accordance to the delivery unit they deliver (Table 13).

Table 14: Distribution of logistics vehicles according to their delivery activity

	Supply vehicle	***Split (%)***
Parcel delivery to stores	L vehicle transport company L vehicle retail company	72% 28%
Parcel delivery to households	L vehicle transport company (direct delivery) L vehicle transport company (indirect delivery)	52% (*) 48% (*)
Pallets	M vehicle HoReCa company M vehicle retail company H vehicle retail company M vehicle transport company H vehicle transport company	13% 13% 3% 61% 10%
Other	L vehicle HoReCa company L vehicle transport company M vehicle transport company H vehicle transport company	38% 42% 17% 3%
Service trips	L vehicle construction company M vehicle construction company L vehicle transport company M vehicle transport company	47% 1% 50% 2%
General waste	L vehicle waste company M vehicle waste company H vehicle waste company	20% 67% 13%
Food waste	L vehicle waste company M vehicle waste company H vehicle waste company	20% 67% 13%

*: According to a survey performed by PostNord (PostNord Sverige, 2017) 52% of Nordic residents preferred to receive their online purchases directly to their homes while the remaining 48% preferred collecting themselves the goods in pick-up points.

To complete the traffic generation, the values for the expected number of trips per tour and items delivered per trip need the be defined. Initially, the following values depicted in Table 15 are considered for all freight vehicles.

Table 15: Trips/tour and items/trip for each freight vehicle

	Supply vehicle	***Trips/tour***	***Items or services/trip***
Parcel delivery to stores	L vehicle transport company	40	1.5
	L vehicle retail company	4	1
Parcel delivery to households	L vehicle transport company (direct delivery)	40	1.5
	L vehicle transport company (indirect delivery)	3	15
Pallets	M vehicle HoReCa company	2	1
	M vehicle retail company	1	1
	H vehicle retail company	2	1
	M vehicle transport company	10	1
	H vehicle transport company	5	1
Other	L vehicle HoReCa company	3	1
	L vehicle transport company	20	1
	M vehicle transport company	10	1
	H vehicle transport company	5	1
Service trips	L vehicle construction company	2	1
	M vehicle construction company	1.5	1
	L vehicle transport company	2	1
	M vehicle transport company	2	1
General waste	L vehicle waste company	5	1
	M vehicle waste company	10	2
	H vehicle waste company	30	2.5
Food waste	L vehicle waste company	5	1
	M vehicle waste company	10	2
	H vehicle waste company	30	2.5

Lastly, for the evaluation of the external costs cause by air pollution and GHG emissions an initial split of the vehicles' emission-efficiency classification is used. As commented, this split is done based on the data retrieved from the traffic count in Vasastan and is presented in Table 16.

Table 16: Emission-efficiency classification for logistics vehicles in Vasastan

CLASS/SIZE	***L***	***M***	***H***
EURO 3	1,6%	2,3%	0,0%
EURO 4	12,1%	2,3%	0,0%
EURO 5	58,5%	44,2%	66,7%
EURO 6	27,2%	39,5%	33,3%
ELECTRIC	0,6%	11,6%	0,0%

4.2.2 Scenario 1 – Full-service apartment

The first scenario takes into account the introduction of electric vans and medium-size trucks for all freight vehicles. It is expected that when the Frihamnen area is fully developed the presence of electric vehicles will be higher than currently. In addition, this scenario studies the effect of direct deliveries to households. The DenCity project is promoting the use and creation of storage areas in apartment buildings in which transport companies can have access to leave parcels that are forwarded to citizens (full-service apartments, FSA). This increases the logistics service for the residents, who do not need to go to a pick-up point anymore to retrieve their deliveries. Therefore, the main differences this scenario presents respect to the BAU scenario are:

- Introduction of electric L and M vehicles for all sectors
- Change in the split of the parcel deliveries to households: 100% are delivered directly to household with L vehicles from transport companies
- Change in the number of items/trip for direct deliveries to households: 2 items/trip as more items are expected to be delivered to the buildings

When evaluating the external impacts, it is assumed that the electric L and M vehicles have zero air pollution and GHG emissions. All other indicators remain the same as in BAU. Note that there is no change in the noise pollution indicator as many studies show that the reduction in noise is only significant for very low speeds (under 30km/h) (Maffei and Masullo, 2014; Iversen, 2015).

4.2.3 Scenario 2 – Urban Consolidation Centre

In addition to electric vehicles and FSA, Scenario 2 also includes an UCC in the outer part of Frihamnen. This centre is designed to receive all parcel deliveries to the area, i.e. all parcels originally destined to stores and to households. From there, the deliveries are consolidated and delivered by cargo bikes and electric to the receivers in the area. Thus, L vehicles from transport and retail companies only reach the UCC to deliver the parcels there but do not travel inside the area distributing them.

In this scenario, 2 new freight vehicles are presented: cargo bikes and electric vehicles. Compared to electric vehicles, cargo bikes have a smaller cargo capacity but are easier to operate in high density areas with many stops. Hence, cargo bikes are used for the deliveries to households and electric vehicles are in charge of distributing to stores which tend to receiver bigger and heavier parcels. Table 17 shows their logistics characteristics, while the values for the other vehicles remain the same as in the BAU scenario.

Table 17: Logistics characteristics for the UCC vehicles

Vehicle	*PCU*	*Trips/tour*	*Items/trip*
Cargo bike	0.25	20	3
Electric vehicle	1	50	3

When evaluating the external impacts, cargo bikes do not contribute to any of the impacts while electric vehicles behave as regular vans for all impacts. Their default tour inside the area is shorter than that for transport company vehicles in BAU: As the UCC enables sorting and consolidating deliveries allowing more optimised routes, each vehicle does not need to supply the whole area. In this case, it is assumed that each vehicle only needs to cover half of the area of Frihamnen. Therefore, the default tour is half as long as in BAU.

4.2.4 Scenario 3 – Urban Waterways

This last scenario is based on an UCC in a suburban location closer to the origins of the deliveries and the use of the Göta river as a urban waterway. All parcels will be transported to the UCC from warehouses located along the upstream of the river and on the way back the vessels will load waste containers from the area to a recycling centre along the river. For this scenario, ideal conditions are considered for the functioning of the vessel. This means that the vessel is operational everyday under all sort of conditions and that it is always available. Moreover, considering that this is a future scenario, the vessel will be full-electric and designed to load parcels and waste containers. Consequently, the external impacts of the vessel are neglected to ease the calculation of the transportation impacts.

The logistics characteristics of all the vehicles operating in the area are the same as in scenario 2.

4.3 Discussion of the results

In this section, the results from the impact assessment are analysed and discussed (see appendix II for detailed results per scenario). First, the impacts in the business as usual scenario are analysed, followed by an analysis of the changes of impacts in the scenarios.

4.3.1 Impacts in the business-as-usual scenario

The most relevant impact in the network is congestion, which represents 88% of the total impacts. All other impacts have a relative small contribution to the external costs, from which GHG emissions has the highest share with approx. 7% (Figure 14). When looking at the different sectors, service (34%) and construction (30%) companies are the major contributors to external impacts (Figure 15).

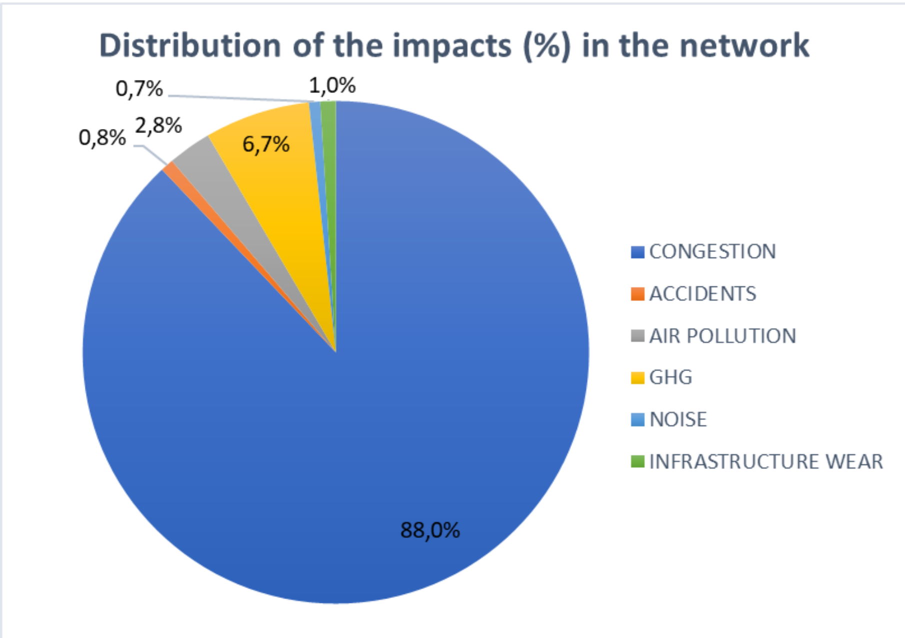

Figure 14: Distribution of the impacts (%) in the networks for the BAU scenario

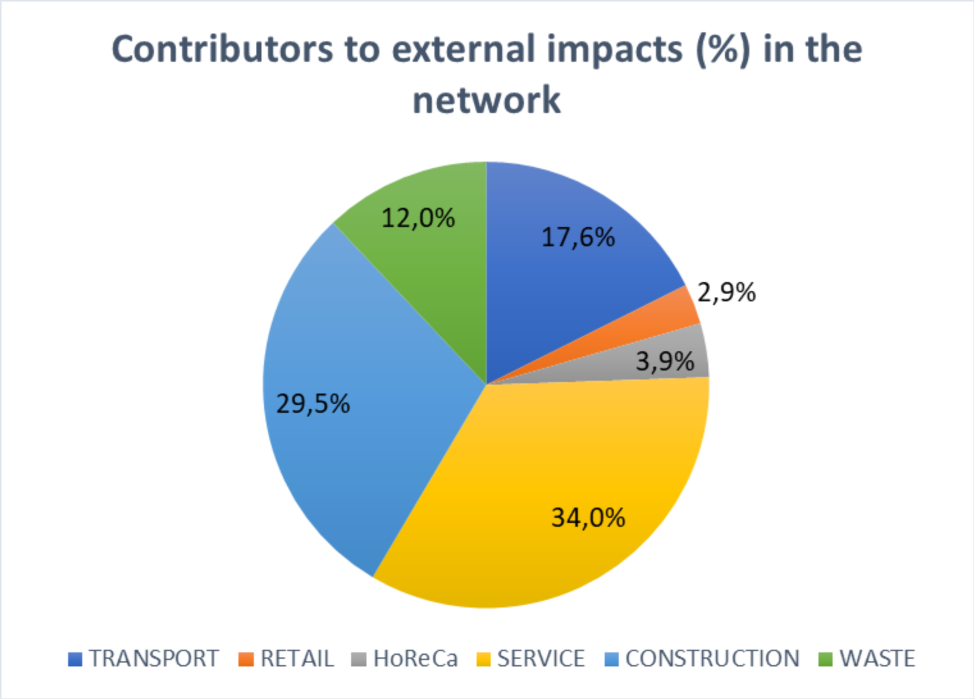

Figure 15: Contributors to the external impacts (%) in the network for the BAU scenario

When analysing the impacts in the area of analysis, congestion is still the main external impact caused from transportation accounting for more than 50% of the impacts. However, noise pollution also has an important role (29%) and is the second impact that should be addressed (Figure 17). As explained in the literature review, noise pollution is a growing negative impact in society and issues related to the acoustics sector are currently under thorough and deep studies. Regarding the different freight sectors, service and construction are also those that generate more transportation impacts in the area, followed by the transport and the waste sectors (Figure 16).

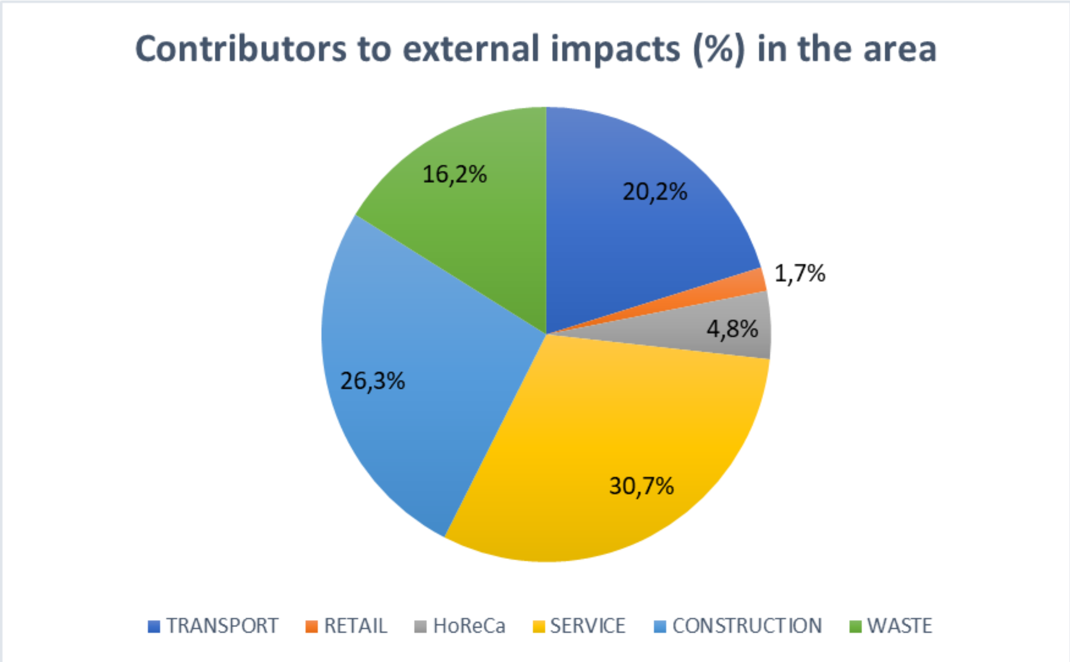

Figure 16: Contributors to the external impacts (%) in the area for the BAU scenario

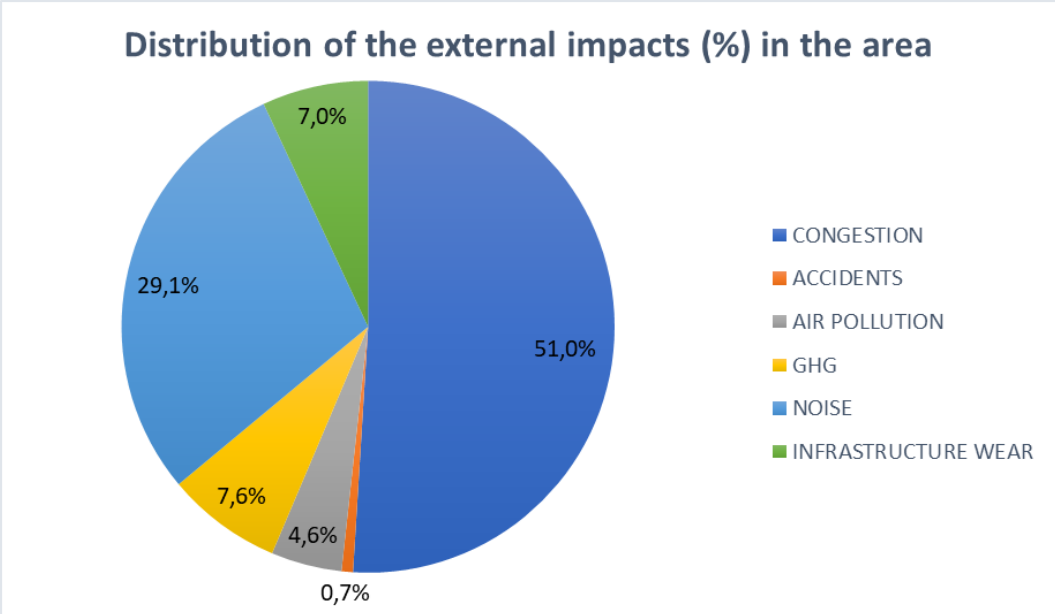

Figure 17: Distribution of the external impacts (%) in the area for the BAU scenario

4.3.2 Effect of scenarios

Analysing the reduction of external impacts of the different scenarios, scenario 1 (Figure 27: Total external impacts in the network for scenario 1Figure 27 and Figure 28) presents a reduction of the external costs when the network is evaluated in terms of air pollution and GHG emissions caused by the introduction of electric vehicles. However, when having direct deliveries to all apartments, transport companies will experience an increase in the number of trips inside the area. This leads to an increase in the number of trips affecting congestion, accident, noise and infrastructure wear in the area increasing the external costs.

In Scenario 2 and 3, there is a clear reduction in the number of trips in the area that have direct consequences in the external impacts (Figure 31 and Figure 34). With the introduction of the UCC, the total trips in the area by L vehicles from transport companies is reduced from 637 to 168 as some items are still delivered with these type of vehicles (other items). This reduction in the number of trips implies a reduction of 25% in the congestion costs in the area caused by the transport sector. However, for scenario 2, the total tours in the network remain the same as the vehicles still need to arrive at the UCC and no changes in the external impacts in the network are experienced (Figure 30).

Lastly, scenario 3 shows the biggest reduction of external impacts for both the network and the area (Figure 33 and Figure 34). In this case, waste vehicles do not travel through the road network as the containers are transported using urban waterways. Furthermore, all parcels transports are also moved from the network roads to vessels on urban waterways. This case would require retail companies to use the new transport system for the distribution of parcels to obtain the maximum benefit of this alternative. Even though the reduction of tours generated by L vehicles used for parcels deliveries is not very large (18 compared to the BAU scenario), the introduction of the vessel also takes out from the network 16 tours generated by waste vehicles. These vehicles tend to be larger than those used by transport companies and therefore their effect is more relevant. This combined reduction in the number of tours represents a reduction of 18% of the congestion costs in the network (Table 18).

Table 18: Reduction of external costs in the network

REDUCTION OF TOTAL EXTERNAL COSTS IN THE NETWORK

SCENARIO	CONGESTION	ACCIDENTS	AIR POLLUTION	GHG	NOISE	INFRASTRUCTURE WEAR	TOTAL
BAU SCENARIO							
SCENARIO 1	0,5%	0,6%	91,7%	95,8%	0,5%	0,5%	9,5%
SCENARIO 2	0,5%	0,6%	91,7%	95,8%	0,5%	0,5%	9,5%
SCENARIO 3	18,2%	16,7%	96,0%	98,0%	17,6%	20,7%	25,8%

Table 19: Reduction of external costs in the area

REDUCTION OF TOTAL EXTERNAL COSTS IN THE AREA

SCENARIO	CONGESTION	ACCIDENTS	AIR POLLUTION	GHG	NOISE	INFRASTRUCTURE WEAR	TOTAL
BAU SCENARIO							
SCENARIO 1	-0,2%	-0,2%	92,4%	93,4%	-0,2%	-0,1%	11,2%
SCENARIO 2	3,7%	4,2%	92,4%	93,4%	3,8%	1,8%	14,5%
SCENARIO 3	3,7%	4,2%	92,4%	93,4%	3,8%	1,8%	14,5%

The other externality analysed in this study is the demand of parking space (Figure 26, Figure 29, Figure 32 and Figure 35). According to indications from the handbook of external costs of transportation (RICARDO-AEA, 2014), when the ratio traffic volume/capacity is under 0,25 the road is under free-flow conditions. Then, between 0,75 and 1 near capacity is defined and when the ratio is larger than 1, the road is under overcapacity conditions. For Frihamnen it has been considered that 40% of the total street length provides zones for parking and each parking space is 8m long. To the be able to compare it with PCU, each space is considered equivalent to 1 PCU. With these values, it is possible to define the thresholds that define the three capacity conditions and see if they are exceeded during a regular day. Overcapacity condition are observed when the demand of parking space is higher than 138 parking spots per hour, near-capacity conditions when the demand is over 103 parking places per hour and free-flow or no parking problems when this demand is under 34 parking places per hour.

When calculating the parking space demand throughout the day for each scenario (Figure 18), it can be noted that over capacity conditions are never experienced, but early in the morning conditions close to near capacity conditions are observed. Given that the calculation is based on an even distribution of parking spaces in all the area, it is expected that some parts of Frihamnen will face capacity problems, especially between 7am and 9am which is the period with most freight activity. These results aid to corroborate the hypothesis that 90% of the trips in Frihamnen are under free-flow conditions. It is important to remark that only freight vehicles are accounted for this analysis, which means that the occupancy will most probably be higher as passenger vehicles will also occupy the parking spaces.

When analysing the parking space demand in the area by logistics sector (Figure 19), construction (44%) and service (30%) are clearly the ones that occupy most of the parking space. Even with the introduction of the mobility solutions defined in the scenarios, the initial evolution of parking space demand presented in Figure 18 does not vary significantly, as the total share of the sectors involved with delivering goods is rather limited compared to the share of the service & construction sector.

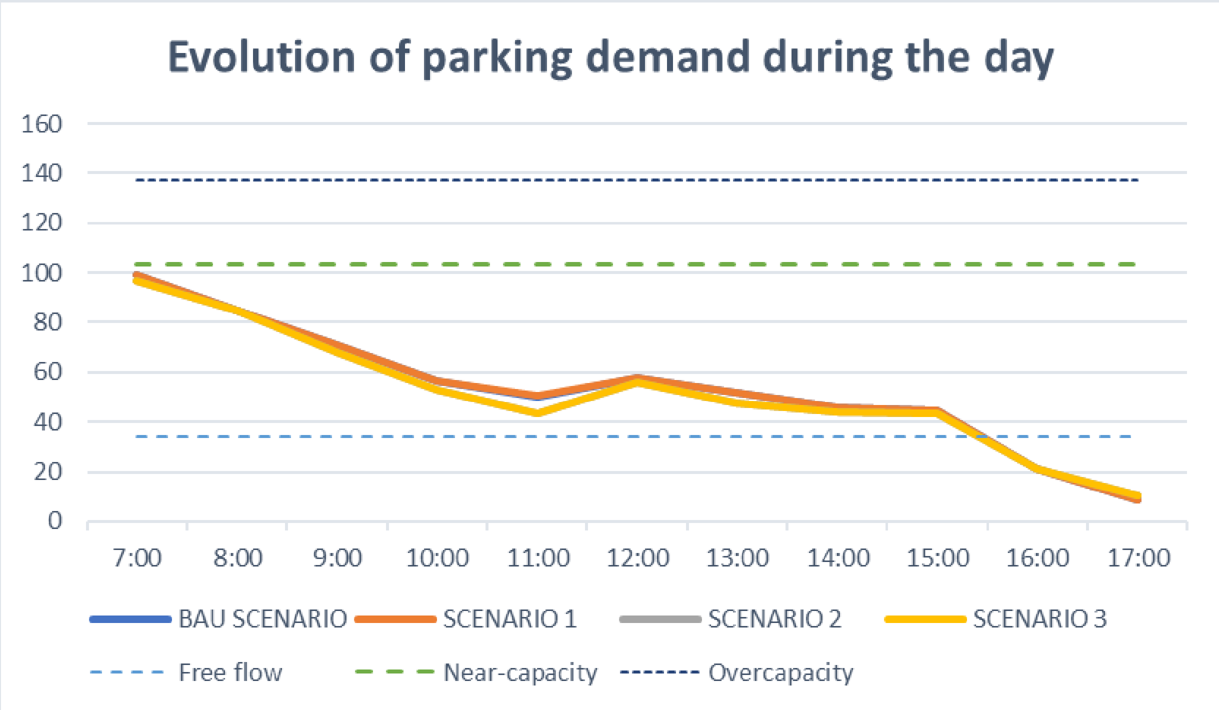

Figure 18: Evolution of the parking space demand during the day in Frihamnen

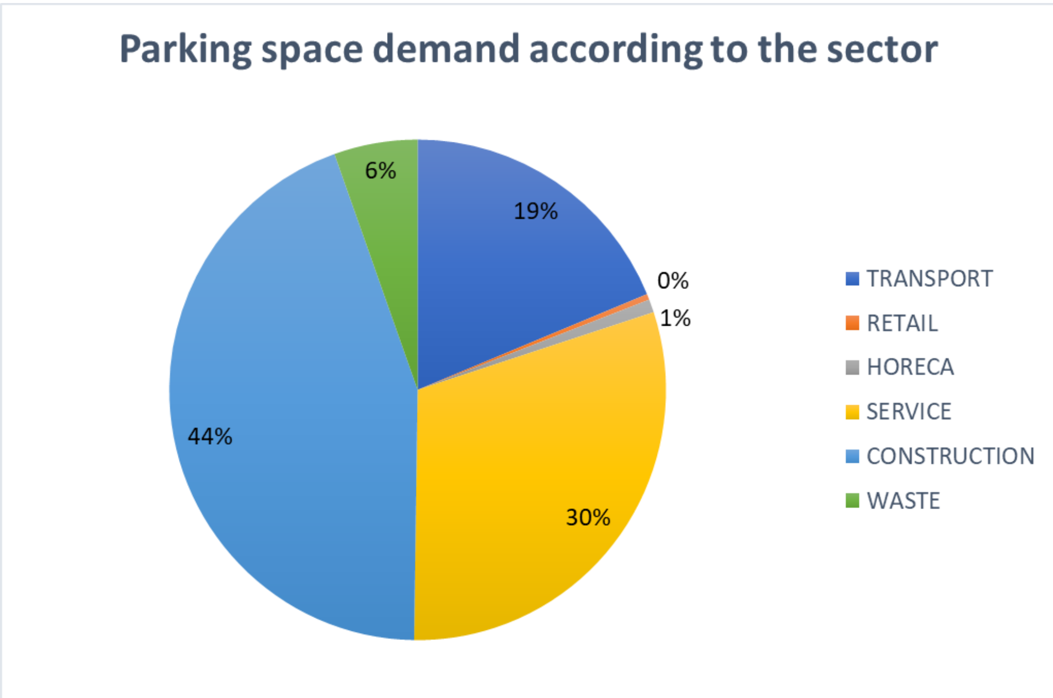

Figure 19: Parking space demand according to the sectors in Frihamnen in the BAU scenario

When focussing on the evolution of the externalities in the area (Figure 20), it is interesting to include the reduction of parking space demand to visualize that the mobility solutions do not tackle very much this issue. Regarding to the external costs (Figure 21), the BAU scenario is the most unsustainable one, as it presents the highest external costs. The introduction of a UCC contributes very positively to the creation of a more attractive environment and helps to tackle transportation impacts as the vehicles used by the centre tend to generate the minimum impacts possible. These vehicles contribute positively to the reduction of air pollution and GHG emissions but do not tackle the other transportation impacts. Congestion, infrastructure wear and external costs caused by accidents remain the same unless the total number of vehicles is reduced. Regarding noise, electric vehicles only show a noticeable reduction in noise pollution if they travel at very low speeds (under 30km/h) that are not considered for regular traffic (Maffei and Masullo, 2014).

As soon as consolidation solutions and low-emission vehicles are introduced in the area, external costs are reduced considerably. All three scenarios suggest a more sustainable neighbourhood based on the reduction of less pollutant technologies. Scenario 1 slightly increases the traffic in the area resulting in slightly higher noise, accidents and congestion impacts. Scenario 3 presents by far the biggest potential if the innovative solutions proposed are put forward. The total costs (area and network) are reduced more than 24% in this last scenario.

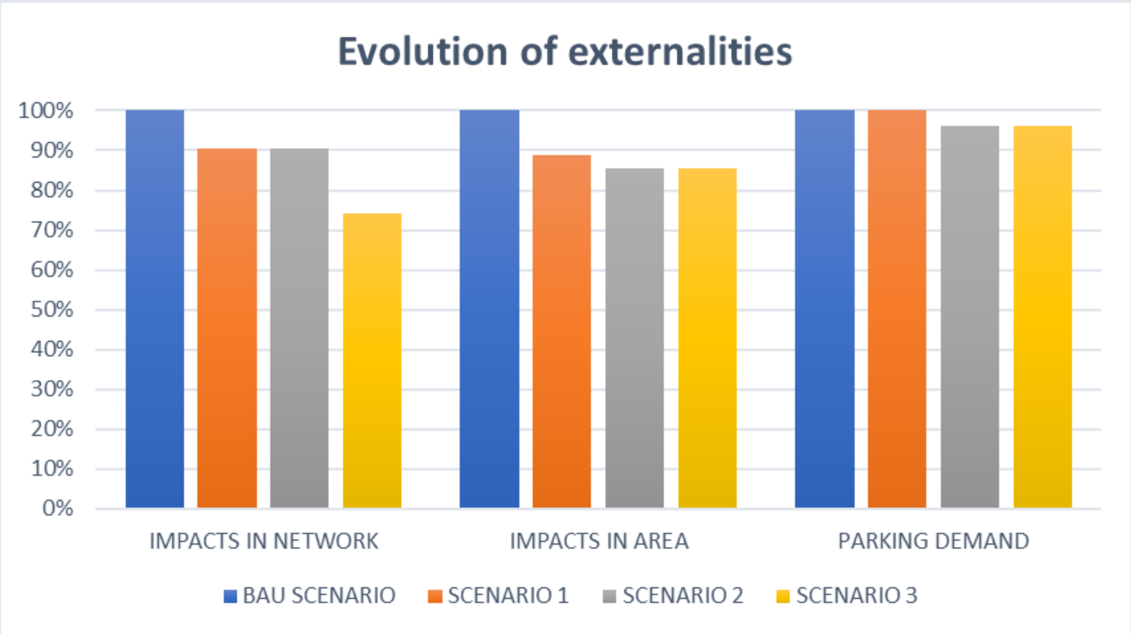

Figure 20: Summary of the reduction of all externalities according to the scenario analysed

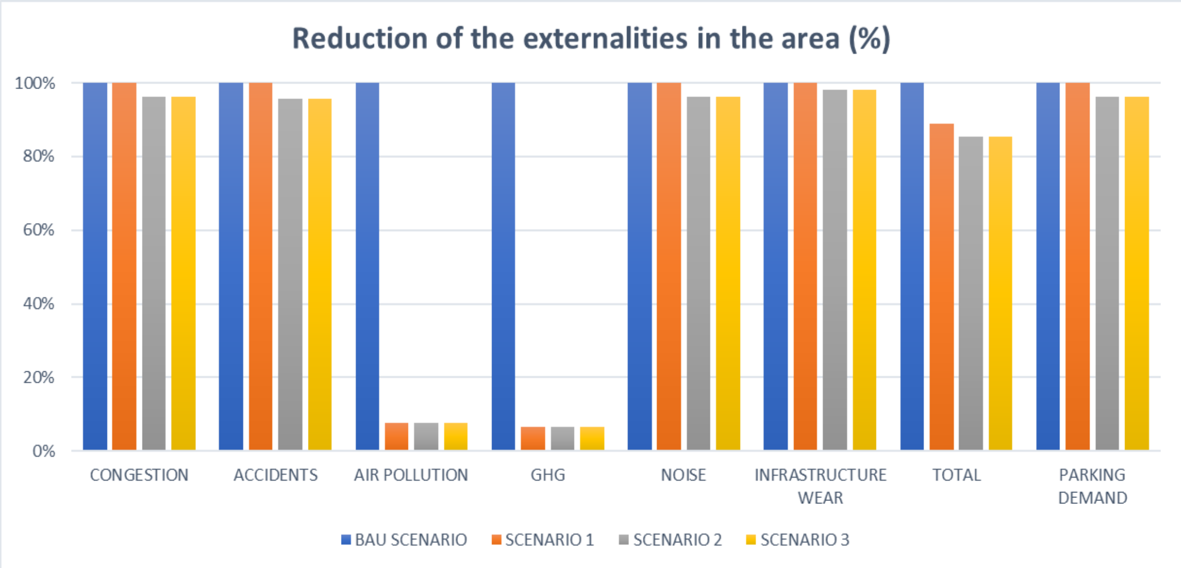

Figure 21: Reduction of the externalities in the area (%)

Nevertheless, it is important to comment that the initiatives considered in the case study, based on those promoted and developed in the DenCity project, do not affect the behaviour of vehicles belonging to the service and construction sector. Their total number of tours and trips remain stable throughout all the analysis. The change from conventional L and M vehicles to electric ones is what reduces the external impacts from air pollution and GHG emissions these vehicles generate. Therefore, it is important to encourage energy efficient vehicles and try to develop optimised routes to contribute the least possible to the environment and society. This has a direct relationship with the parking space demand throughout all the analysis, the variations are minimum and are only seen when the UCC is introduced as smaller and more efficient vehicles are used.

With all this stated and considering that the demand of freight transportation will very likely increase in the following years, it is crucial to evaluate the impacts that sustainable solutions for the freight transportation present. As seen in the analysis, the introduction of a UCC helps to reduce traffic inside urban areas, while taking advantage of other modes of transportation, such as vessels, can contribute to reduce substantially the traffic in the whole network. Given that congestion is the main external impact, this results in an important reduction of the total external costs. For urban areas, the second most important challenge is noise pollution. In relation to these impacts, air pollution, climate impact and accidents are of minor importance in the context of urban areas.

5 Results

This chapter analyses the results of this thesis by answering the three research questions based on to the data collected and in the literature review and the case study.

5.1 Research question 1 – Analysis framework

- *RQ1: What key factors define passenger and freight mobility in dense urban neighbourhoods and its sustainability performance?*

The aim of this research question was to establish the key elements to be used in the estimation of urban traffic and the evaluation of its impacts. As presented in the literature review, a clear distinction between passenger transportation and freight transportation needs to be made when analysing the factors that define them. For the sustainability performance, the defining factors are common for all transport modes.

As commented, passenger transportation has received more attention from researchers, planners and policy makers than freight transportation. This can clearly be observed in the elements that define passenger transport demand models compared to freight demand models. Passenger transportation models tend to consider the same factors, while for freight transportation the key factors differ more between models and areas of study. When defining passenger transportation two main estimations are done: the total passenger transport demand and the modal split. Figure 22 presents the key factors defining the demand and Figure 23 shows the factors defining the modal split.

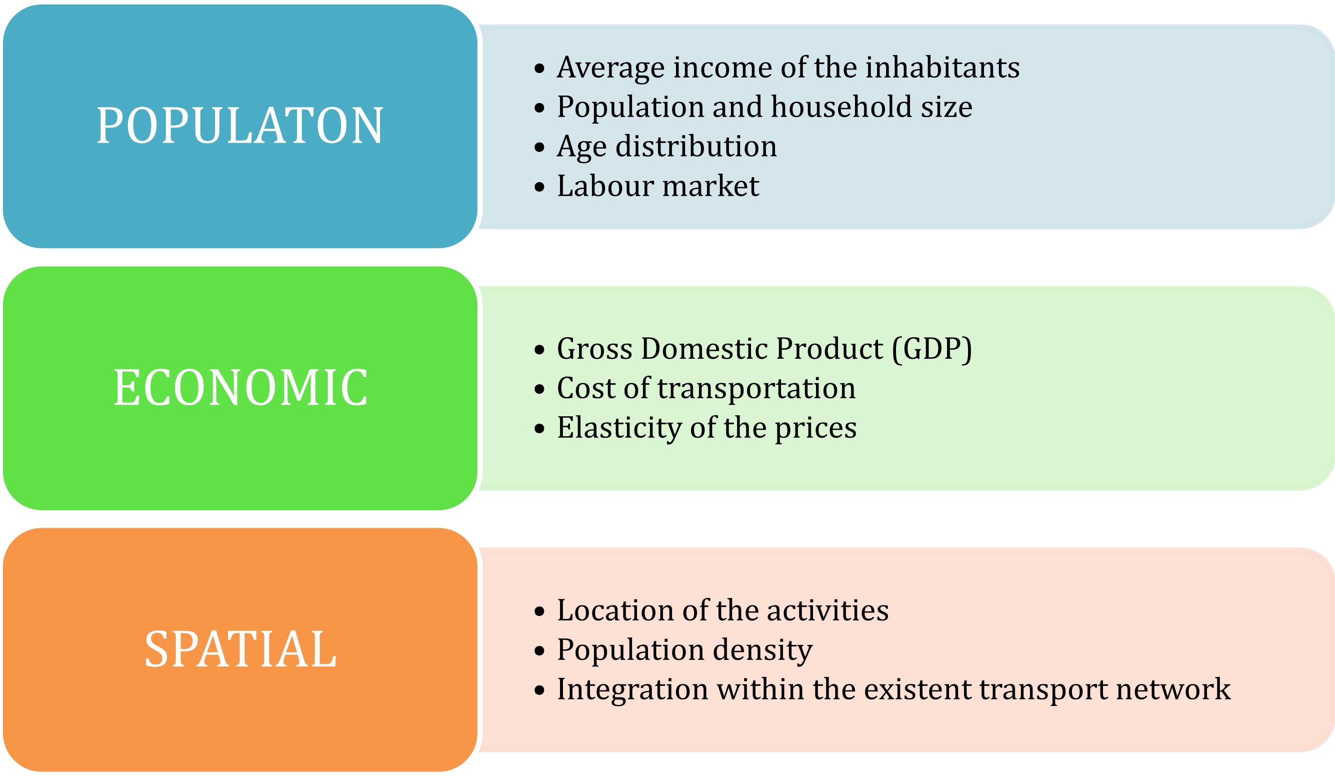

Figure 22: Key parameters for the total passenger transport demand

Figure 23: Key factors for the modal split of passenger transportation

Even though there are no general models for freight transport, some factors are generally considered in many studies and estimations. Apart from the global economic activity in the region and its total area, other key components are linked to particular characteristics of the establishments that are expected to generate freight shipments. Below, the most used reference factors are displayed:

- Sector of the business
- Variety of products offered in the establishment
- Area of the establishment
- Average number of jobs in the establishment
- Ordering policy
- Logistics decisions

The second part of the research question focusses on the sustainability performance of the transport activities. In order to evaluate the unsustainable impacts of transport, external costs are usually used. The external costs of transport are negative impacts caused by transport activities imposed on actors which are not a direct part of the transport activity. These are generally costs to society in terms of negative environmental, social and economic consequences. Based on current standards, the transportation impacts analysed when evaluating the external costs are the following:

- Congestion
- Safety
- Air pollution
- Noise pollution
- Greenhouse gas emissions
- Infrastructure wear
- Other environmental impacts

5.2 Research question 2 – Sustainable mobility

- *RQ2: What characterises sustainable mobility (passenger and freight) representing an attractive and safe urban environment?*

When discussing the topic of meeting sustainability requirements within an area or country, this generally refers to the accomplishments of some standards based on a series of indicators and the promotion of more sustainable initiatives. These are oriented to change the mobility patterns of the different activities to contribute positively to the society and the environment. However, given that life quality is a relatively subjective aspect, it is not easy to decide what initiatives present the best positive effects. For this reason, it is necessary to consider thresholds and perspectives developed by objective and trustworthy organizations such as the EU Commission of the WHO (World Health Organization).

To evaluate the sustainability of a city, many indicators have been developed considering all the daily activities done in urban areas and the different needs they present to be completed (EU Commission, 2018). These indicators tend to focus on social, environmental and economic factors to then define their sustainability level. These three areas are the three different dimensions that are generally discussed and analysed to reach sustainability on an overall level: society, environment and economy. The three of them need to be weighed equally when assessing their causes and consequences. In addition, these three dimensions need a well-planned governance to control them and decide regulations to meet the objectives. As for the impacts of transportation, some of which have been detailed in the literature review, these are the main consequences according to their respective field:

- Impacts on the society: consequences of harmful pollutants on public health, deaths and injuries from traffic accidents, negative effects of noise, damage on buildings caused by pollution
- Impacts on the environment: emission of pollutants, use of non-renewable natural resources, waste products, loss of wildlife
- Impacts on the economy: inefficiency and waste of resources, decrease of journey reliability caused by congestion, alterations in punctuality resulting in a low-quality service

When considering freight transportation, the companies involved in this matter have historically focussed on minimizing costs and maximizing benefits. Therefore, they never examined the environmental and social scope of their activity (Lindholm, 2012). If freight transportation is expected to meet sustainable standards, some factors need to be taken into account to contribute to creating an attractive and safe environment in urban areas. The following factors are examples of what characterises sustainable transportation as they minimize the impacts towards the previous dimensions (McKinnon *et al.*, 2010):

- Delivery vehicles should impose as few social and environmental impacts as possible
- Actors and stakeholders in transportation must cooperate to make sure that the objectives are met. These includes public planners (city, urban and local) and private companies.
- Urban planners may need to alter or control the movement of goods
- Transport companies must optimize operational efficiency to reduce traffic congestion and their environmental impacts

In addition, urban areas also need to provide a safe environment for its citizens which will help in the sustainability performance of the site. As presented in the literature, transportation generates a series of negative impacts and establishing thresholds is a suitable way of characterizing sustainable mobility. Even though for some impacts research studies to define sustainable limits are scarce, others such as noise, air pollution and greenhouse gases emission have recently been researched extensively and have reached generally accepted limits.

Regarding noise pollution, the effects on citizens are related with cardiovascular diseases, cognitive impairment for children, sleep disturbance and annoyance. They are caused by the stress constant noise provokes in humans (WHO, 2011). For myocardial related problems, it has been studied that noise levels under 50-60dB have no direct effect on the risk of developing these kind of diseases (WHO, 2009). For cognitive impairment in children, appropriate noise level is under 55dB and regarding sleep disturbance, with noise levels under 40dB no major consequences are observed in human beings (WHO, 2011). As for night noise, it is important to comment that inside wellinsulated apartments, human being perceive a reduction of external noise in about 30dB (WHO, 2009).

For air pollution, as it has a direct effect on both the environment and society, international organizations have done complete studies of its consequences and established some guidelines for the most common air pollutants (EU Commission, 2018). According to the AQG (Air Quality Guidelines) elaborated by the World Health Organization (WHO, 2006) the thresholds are the following:

- $PM_{2.5}$: 10µg/m^3 as annual mean and 25µg/m^3 as 24-hour mean
- PM_{10}: 20µg/m^3 as annual mean and 50 µg/m^3 as 24-hour mean
- O_3: 100 µg/m^3 as 8-hour mean
- NO_2: 40 µg/m^3 as annual mean and 200 µg/m^3 as 1-hour mean
- SO_2: 20 µg/m^3 as 24-hour mean and 500 µg/m^3 as 10-minute mean

Compared to noise or air pollutants, defining regional thresholds for greenhouse gas emissions is not generally considered as it the emissions as such do not have direct negative effects on the local or regional environment. However, since the effects of GHG emissions are global and long-term, global targets have been established to avoid the worst consequences of climate change. To do so, global CO_2 emissions must be cut by at least 50% by 2050 in comparison to the current emissions (IAE, 2009). Based on the figures estimated by the United Nations Development Programme (UNDP) that states that limiting the global CO_2 for this century to 1.5 trillion metric tonnes would allow to control global warming (UNDP, 2007). When transforming this global threshold to CO_2 per inhabitant, the result is around 1.700 kg of CO_2eq per person per year.

With all this stated, urban mobility systems have to consider the thresholds defined above minimizing the impacts of transportation to citizens and environment, in order to be defined as a sustainable mobility system.

5.3 Research question 3 – Evaluation of the solutions

- *RQ3a: How unsustainable is urban transport in high-density areas with business-as-usual solutions?*

Traditionally, urban logistics is a private industry and solutions to consolidate the fragmented freight flows in urban areas are rarely used. Furthermore, authorities have been reluctant to impose restrictions on the freight industry in order not to harm the urban economy. These two aspects present severe consequences for society and the environment as congestion, GHG emissions and noise pollution are the most critical impacts when evaluating the external costs of transportation. Not only are BAU practices generally less environmentally friendly than other solutions, but also effect negatively the attractiveness of urban areas. In dense areas, the possibility of exceeding the thresholds for some indicators is much higher, thus, this issue needs to be tackled to provide safe and attractive environments.

- *RQ3b: Innovative solutions, different scenarios: What is the improvement potential of innovative solutions?*

Innovative logistics solutions have significant potential to contribute to sustainable urban mobility. Traffic in sensitive urban areas can be reduced with the introduction of consolidation facilities in dense areas (UCC or other examples presented in the literature review). In addition, the environmental problems of air pollution and climate change can be mitigated by the introduction of innovative vehicle technologies such as electric vehicles offering zero-tailpipe emissions.

However, UCCs and zero-emission vehicles do not have any effect on congestion on the urban access roads, which is by far the most significant problem of urban logistics in terms of external costs. Hence, additional initiatives are needed aiming for consolidating freight flows further upstream the transport chain. One example is using other transportation modes (urban trains or vessels) for freight transportation, which reduces the number of road vehicles needed and consequently reduces road congestion and other impacts such as GHG emissions and air pollution. However, these solutions require an urban logistics infrastructure for consolidating and transhipping between modes, which tend to increase transportation costs and lead time. The development of competitive business models taking the benefits generated into account is crucial for the long-term sustainability of these initiatives.

The effect in the total traffic reduction derived from consolidation and modal shift initiatives is limited, since they do not offer any solution for the biggest traffic generators, which are the service construction sector. In these sectors, the only way to mitigate the external impacts generated is reducing the amount of pollutants and GHG emitted by introducing innovative vehicle technologies.

All in all, the potential of any innovative solution is directly linked to the capacity of reducing the total traffic. If then these solutions also promote the use of energy efficient or even zero-emission vehicles, their contribution to create a more sustainable and attractive environment is even higher.

6 Conclusions

The main purpose of this thesis was to explore the characteristics of passenger and freight mobility services in sustainable dense neighbourhoods and to evaluate and quantify the reduction in transportation impacts according to different mobility solutions. Mobility solutions were presented for both passenger and freight transportation, and a model to estimate the external impacts caused by freight transportation was developed. This model helped to understand the extent of the mobility solutions' unsustainable impacts.

The analysis of the generation of external impacts from transportation in the future urban area of Frihamnen, Gothenburg, contributed positively to the main aims of the thesis for three reasons. Firstly, it quantifies the resulting external costs (€) that freight transportation will impose on the area. Secondly, the study provided valuable information of which impact or impacts are the most significant ones, and also identifies the relative contribution of the different urban freight sectors. Finally, the study helped to understand the benefits of different mobility solutions that can likely be implemented in dense urban environments.

In relation to the 3 research questions stated initially, the following considerations can be made. Regarding research question 1, when defining passenger mobility, it is crucial to investigate the total transport demand and the modal split between each transport mode according to the type of journey. On the other hand, for freight mobility the key factors for the evaluation are the economic characteristics of the urban area and the special characteristics of the commercial businesses. For defining the sustainability performance of freight and passenger mobility, environmental and social impacts need to be considered. With reference to research question 2, many indicators are available to classify the level of sustainability in urban areas. When focussing on mobility (passenger and freight), all are based on the impacts generated on society, the environment and the economy of the region. In addition, for an urban area to present safe and attractive conditions, thresholds linked with health issues need to be analysed. Lastly, research question 3 presents the importance of reducing road traffic with the objective of tackling congestion which is the biggest sustainability challenge in urban transport.

Both the results from the case study and the model developed for the evaluation of the impacts can provide relevant information for city planners when designing new urban areas. Based on the results, they should focus on the promotion of consolidation strategies and the use of efficient vehicles. Furthermore, municipalities need to extend their scope which currently focuses exclusively on the delivery of goods, by developing holistic solutions that also include service trips and the transport of waste. These sectors are crucial for the well-functioning of urban areas, but existing consolidation strategies have very limited effect on them.

The study presented some limitations related to the scope and the calculation of some estimations in the model. Only freight transportation was evaluated, and some assumptions were made for the generation of waste and service trips. Even though the other estimations were thoroughly studied and calculated, the traffic estimated from service trips can be different from reality affecting the validity of the numerical values presented in the report.

As commented throughout the report, some aspects should be studied in the future to provide a better knowledge of freight demand transportation and a better evaluation of certain impacts. Few studies analyse the demand of service trips in urban areas when considering urban freight transportation and therefore few data is available. Moreover, some impacts have not yet been assessed in a similar way to the ones assessed in the study. A clear example is land-use impacts; many studies have been made to understand the positive effects of correct land-use planning, but little has been done to quantify them numerically due to the large number of factors that are involved. These topics provide interesting opportunities for future research for a better design of urban areas.

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8 APPENDIX I

This appendix contains the different unit values given to the different transportation impacts.

Table 20: Marginal Congestion Costs (€ct/vkm)

Vehicle	Region	Road type	Free flow (€ct/vkm)	Near capacity (€ct/vkm)	Over capacity (€ct/vkm)
Car	Metropolitan	Motorway	0.0	26.8	61.5
		Main roads	0.9	141.3	181.3
		Other roads	2.5	159.5	242.6
	Urban	Main roads	0.6	48.7	75.8
		Other roads	2.5	139.4	230.5
	Rural	Motorway	0.0	13.4	30.8
		Main roads	0.4	18.3	60.7
		Other roads	0.2	42.0	139.2
Rigid truck	Metropolitan	Motorway	0.0	50.9	116.9
		Main roads	1.8	268.5	344.4
		Other roads	4.7	303.0	460.9
	Urban	Main roads	1.2	92.5	144.1
		Other roads	4.7	264.9	438.0
	Rural	Motorway	0.0	25.4	58.4
		Main roads	0.8	34.8	115.3
		Other roads	0.4	79.8	264.5
Articulated truck	Metropolitan	Motorway	0.0	77.6	178.4
		Main roads	2.7	409.8	525.6
		Other roads	7.2	462.5	703.5
	Urban	Main roads	1.8	141.1	219.9
		Other roads	7.2	404.4	668.6
	Rural	Motorway	0.0	38.8	89.2
		Main roads	1.2	53.1	176.0
		Other roads	0.6	121.9	403.8
Bus	Metropolitan	Motorway	0.0	66.9	153.8
		Main roads	2.3	353.3	453.1
		Other roads	6.2	398.7	606.4
	Urban	Main roads	1.6	121.7	189.6
		Other roads	6.2	348.6	576.3
	Rural	Motorway	0.0	33.5	76.9
		Main roads	1.0	45.8	151.7
		Other roads	0.5	105.0	348.1

Table 21: Marginal Accident Costs (€/vkm)

	Car			HGV			Motorcycle		
State/Type	Motor-way	Other non-urban road	Urban road	Motor-way	Other non-urban road	Urban road	Motor-way	Other non-urban road	Urban road
Austria	0.5	0.4	0.9	5.8	1.8	3.8	0.4	5.6	12.1
Belgium	0.3	0.3	0.4	3.0	1.5	0.9	1.6	3.0	6.0
Bulgaria	0.1	0.1	0.3	0.5	0.5	1.1	0.0	0.0	0.1
Croatia	0.3	0.2	2.9	0.9	0.6	16.4	0.0	0.2	1.6
Cyprus	0.8	0.1	2.1	2.0	0.3	46.2	0.3	0.1	5.6
Czech Republic	0.1	0.2	0.2	1.1	0.6	1.0	0.0	0.2	0.2
Denmark	0.1	0.1	0.1	1.1	1.0	0.7	0.3	1.2	3.8
Estonia		0.4	0.2		0.5	0.8		0.2	0.2
Finland	0.1	0.1	0.1	0.2	0.5	0.3	0.3	1.1	2.1
France	0.1	0.2	0.2	0.4	0.5	0.7	0.9	2.3	7.8
Germany	0.2	0.4	0.6	2.4	1.3	1.5	0.6	3.3	8.5
Greece	0.2	0.2	0.2	0.9	1.3	1.3	0.1	0.1	0.4
Hungary	0.1	0.3	1.3	0.8	1.2	6.8	0.0	0.1	2.4
Ireland	0.1	0.2	0.1	1.7	1.4	0.6	0.2	0.4	0.3
Italy	0.1	0.2	0.6	2.1	1.0	4.0	0.1	0.2	1.5
Latvia		0.3	0.2		0.4	0.5		0.1	0.3
Lithuania		0.2	0.3		0.3	0.9		0.2	0.2
Luxembourg	0.9		0.1	1.8		0.1	23.8		3.5
Malta			3.6			17.3			0.7
Netherlands	0.0	0.1	0.1	0.3	2.3	1.2	0.2	4.5	11.6
Poland	0.1	0.2	0.5	0.6	0.6	1.9	0.0	0.1	0.4
Portugal	0.1	0.1	0.3	2.1	2.7	9.3	0.1	0.2	0.9
Romania	0.0	0.2	2.1	0.1	0.6	12.0	0.0	0.0	1.5
Slovakia	0.1	0.3	0.5	0.8	0.7	12.2	0.0	0.2	0.5
Slovenia	0.1	0.2	0.2	0.5	0.7	1.7	0.0	0.3	0.1
Spain	0.2	0.1	0.1	1.8	0.9	0.3	1.0	0.8	1.6
Sweden	0.3	0.3	0.3	1.2	1.0	0.9	1.0	3.4	8.1
Great Britain	0.1	0.1	0.2	0.9	0.5	0.3	0.4	1.3	2.1
EU average	**0.1**	**0.2**	**0.3**	**1.2**	**0.8**	**1.1**	**0.2**	**0.5**	**1.9**

Table 22: Marginal air pollution costs for cars, light commercial vehicles and buses (€ct/vkm)

Vehicle	Engine	EURO-Class	Urban	Suburban	Rural	Motorway
			(€ct/vkm)	(€ct/vkm)	(€ct/vkm)	(€ct/vkm)
Car diesel	<1.4l	Euro 2	3.6	1.5	0.8	0.8
		Euro 3	2.5	1.2	0.8	0.9
		Euro 4	1.7	0.9	0.6	0.6
		Euro 5	0.9	0.6	0.4	0.4
		Euro 6	0.7	0.3	0.2	0.2
	1.4-2.0l	Euro 0	9.9	3.1	0.9	0.9
		Euro 1	3.6	1.5	0.8	0.9
		Euro 2	3.2	1.4	0.7	0.8
		Euro 3	2.6	1.3	0.8	0.9
		Euro 4	1.8	0.9	0.6	0.6
		Euro 5	0.9	0.6	0.4	0.4
		Euro 6	0.7	0.3	0.2	0.2
	>2.0l	Euro 0	10.3	3.4	1.2	1.3
		Euro 1	3.7	1.5	0.8	0.9
		Euro 2	3.3	1.4	0.8	0.8
		Euro 3	2.6	1.3	0.8	0.9
		Euro 4	1.8	0.9	0.6	0.6
		Euro 5	0.9	0.6	0.4	0.4
		Euro 6	0.7	0.3	0.2	0.2
Car petrol	<1.4l	Euro 0	3.5	3.2	2.2	2.7
		Euro 1	1.0	0.7	0.3	0.4
		Euro 2	0.7	0.4	0.2	0.2
		Euro 3	0.4	0.2	0.1	0.1
		Euro 4	0.4	0.2	0.1	0.1
		Euro 5	0.4	0.2	0.1	0.1
		Euro 6	0.4	0.2	0.1	0.1
	1.4-2.0l	Euro 0	3.6	3.3	2.8	3.4
		Euro 1	1.1	0.8	0.3	0.4
		Euro 2	0.7	0.4	0.2	0.2
		Euro 3	0.4	0.2	0.1	0.1
		Euro 4	0.4	0.2	0.1	0.1
		Euro 5	0.4	0.1	0.1	0.1
		Euro 6	0.4	0.1	0.1	0.1
	>2.0l	Euro 0	3.8	3.5	2.8	3.5
		Euro 1	1.0	0.7	0.3	0.4
		Euro 2	0.6	0.4	0.2	0.2
		Euro 3	0.4	0.2	0.1	0.1
		Euro 4	0.4	0.2	0.1	0.1
		Euro 5	0.4	0.1	0.1	0.1
		Euro 6	0.4	0.1	0.1	0.1

Vehicle	EURO-Class	Urban	Suburban	Rural	Motorway
		(€ct/vkm)	(€ct/vkm)	(€ct/vkm)	(€ct/vkm)
LCV petrol	Euro 1	1.3	0.9	0.5	0.5
	Euro 2	0.8	0.5	0.2	0.2
	Euro 3	0.7	0.4	0.2	0.1
	Euro 4	0.6	0.3	0.1	0.1
	Euro 5	0.6	0.2	0.1	0.1
	Euro 6	0.6	0.2	0.1	0.1
LCV diesel	Euro 1	5.3	2.4	1.4	1.3
	Euro 2	5.9	2.5	1.4	1.3
	Euro 3	4.6	2.0	1.1	1.1
	Euro 4	3.2	1.5	0.9	0.8
	Euro 5	1.4	0.8	0.6	0.6
	Euro 6	1.1	0.5	0.3	0.3

Vehicle	Category	EURO-Class	Urban	Suburban	Rural	Motorway
			€c/vkm	€c/vkm	€c/vkm	€c/vkm
Urban Buses	Midi <=15 t	EURO 0	30.2	15.5	10.4	9.5
		EURO I	15.9	9.8	7.0	6.0
		EURO II	13.2	9.4	7.1	6.1
		EURO III	11.4	7.9	5.4	4.3
		EURO IV	6.7	5.1	3.7	3.0
		EURO V	5.8	4.2	2.4	1.9
		EURO VI	1.8	0.7	0.3	0.3
	Standard 15 - 18 t	EURO 0	35.6	21.7	15.3	12.9
		EURO I	21.1	13.1	9.2	7.8
		EURO II	17.4	12.5	9.3	7.9
		EURO III	14.7	10.4	7.2	5.8
		EURO IV	8.6	6.7	4.9	3.9
		EURO V	6.9	5.0	2.8	2.2
		EURO VI	1.9	0.8	0.4	0.3
	Articulated >18 t	EURO 0	46.4	28.5	19.8	16.3
		EURO I	27.3	17.2	12.0	9.8
		EURO II	22.1	16.0	11.8	9.8
		EURO III	18.5	13.3	9.3	7.5
		EURO IV	10.8	8.7	6.6	4.6
		EURO V	7.0	4.9	3.0	2.3
		EURO VI	2.0	0.8	0.5	0.4
Coaches	Standard <=18 t	EURO 0	28.8	17.4	11.9	10.4
		EURO I	22.7	13.4	8.9	7.7
		EURO II	18.1	13.1	9.4	8.1
		EURO III	17.0	11.5	7.6	6.4
		EURO IV	9.0	7.0	5.1	4.5
		EURO V	10.0	7.9	4.4	2.7
		EURO VI	2.5	1.3	0.6	0.4
	Articulated >18 t	EURO 0	34.9	21.5	14.7	12.5
		EURO I	26.9	16.3	10.9	9.2
		EURO II	21.4	15.7	11.2	9.5
		EURO III	19.2	13.2	8.8	7.2
		EURO IV	10.3	8.1	5.9	5.0
		EURO V	10.6	8.4	4.6	2.7
		EURO VI	2.4	1.3	0.6	0.4

Table 23: Marginal air pollution costs for heavy goods vehicles (€ct/vkm)

Vehicle	Category	EURO-Class	Urban	Suburban	Rural	Motorway
			€c/vkm	€c/vkm	€c/vkm	€c/vkm
Rigid HGV	<=7,5 t	EURO 0	15.4	7.7	5.6	5.9
		EURO I	8.5	4.8	3.8	4.1
		EURO II	6.9	4.6	3.8	4.1
		EURO III	6.1	3.7	2.9	3.1
		EURO IV	3.8	2.5	2.1	2.1
		EURO V	3.7	2.3	1.2	0.8
		EURO VI	1.7	0.6	0.3	0.2
	7,5 - 12 t	EURO 0	20.5	12.4	9.4	9.3
		EURO I	13.0	7.6	5.7	5.6
		EURO II	10.5	7.2	5.8	5.7
		EURO III	9.1	5.9	4.5	4.3
		EURO IV	5.4	3.9	3.2	3.0
		EURO V	5.2	3.6	1.8	1.2
		EURO VI	1.8	0.7	0.3	0.3
	12 - 14 t	EURO 0	22.5	13.8	10.3	9.8
		EURO I	14.4	8.5	6.2	5.9
		EURO II	11.6	8.1	6.3	6.0
		EURO III	10.1	6.8	5.1	4.6
		EURO IV	6.0	4.4	3.5	3.2
		EURO V	5.5	3.9	2.0	1.3
		EURO VI	1.8	0.7	0.3	0.3
	14 - 20 t	EURO 0	29.0	17.8	12.8	11.6
		EURO I	18.3	10.9	7.7	7.0
		EURO II	14.5	10.4	7.9	7.2
		EURO III	13.0	8.8	6.4	5.5
		EURO IV	7.3	5.5	4.3	3.8
		EURO V	7.4	5.6	3.0	1.7
		EURO VI	2.1	1.0	0.4	0.3
	20 - 26 t	EURO 0	31.8	20.0	14.2	12.2
		EURO I	23.8	14.3	10.0	8.6
		EURO II	18.9	13.6	10.1	8.8
		EURO III	16.3	11.2	8.1	7.1
		EURO IV	9.1	7.1	5.6	4.9
		EURO V	8.3	6.3	3.3	2.0
		EURO VI	2.1	1.0	0.5	0.3
	26 - 28 t	EURO 0	33.4	21.0	15.0	12.8
		EURO I	25.0	15.1	10.5	9.0
		EURO II	19.9	14.2	10.6	9.1
		EURO III	16.9	11.6	8.4	7.2
		EURO IV	9.4	7.3	5.7	5.0
		EURO V	8.4	6.3	3.3	2.1
		EURO VI	2.1	1.0	0.5	0.4
	28 - 32 t	EURO 0	38.2	24.2	17.4	14.9
		EURO I	28.5	17.4	12.3	10.5
		EURO II	22.8	16.4	12.2	10.6
		EURO III	19.1	13.3	9.7	8.3
		EURO IV	10.7	8.5	6.7	5.6
		EURO V	8.5	6.2	3.3	2.3
		EURO VI	2.1	0.9	0.5	0.4
	>32 t	EURO 0	39.2	25.1	17.7	14.8
		EURO I	29.8	18.1	12.5	10.5
		EURO II	23.7	17.0	12.5	10.6
		EURO III	19.9	13.9	10.1	8.4
		EURO IV	10.9	8.7	6.8	5.8
		EURO V	8.5	6.3	3.4	2.3
		EURO VI	2.1	0.9	0.5	0.4

Vehicle	Category	EURO-Class	Urban	Suburban	Rural	Motorway
			€c/vkm	€c/vkm	€c/vkm	€c/vkm
Articulated HGV	14 - 20 t	EURO 0	28.5	17.6	12.5	11.0
		EURO I	17.9	10.7	7.5	6.6
		EURO II	14.4	10.3	7.7	6.8
		EURO III	12.6	8.6	6.1	5.3
		EURO IV	7.2	5.5	4.2	3.7
		EURO V	6.8	5.1	2.7	1.6
		EURO VI	2.0	0.9	0.4	0.3
	20 - 28 t	EURO 0	32.2	20.4	14.4	12.0
		EURO I	24.4	14.8	10.2	8.6
		EURO II	19.4	13.8	10.1	8.6
		EURO III	16.4	11.4	8.1	6.7
		EURO IV	9.2	7.2	5.5	4.6
		EURO V	7.8	5.8	3.0	2.0
		EURO VI	2.0	0.9	0.4	0.4
	28 - 34 t	EURO 0	34.7	22.2	15.5	12.8
		EURO I	26.2	16.0	10.9	9.0
		EURO II	20.8	14.9	10.7	9.0
		EURO III	17.4	12.2	8.6	7.0
		EURO IV	9.8	7.8	5.8	4.8
		EURO V	7.6	5.5	3.0	2.0
		EURO VI	2.0	0.9	0.5	0.4
	34 - 40 t	EURO 0	40.9	26.3	18.1	14.8
		EURO I	31.1	18.9	12.7	10.4
		EURO II	24.7	17.7	12.7	10.4
		EURO III	20.5	14.4	10.2	8.3
		EURO IV	11.2	9.0	6.9	5.6
		EURO V	8.5	6.2	3.4	2.3
		EURO VI	2.1	0.9	0.5	0.4
	40 - 50 t	EURO 0	46.5	30.2	21.0	17.1
		EURO I	35.4	21.7	14.7	11.7
		EURO II	28.0	20.1	14.5	11.8
		EURO III	23.0	16.4	11.6	9.3
		EURO IV	12.5	10.3	7.9	6.3
		EURO V	8.5	6.1	3.5	2.5
		EURO VI	2.1	0.9	0.5	0.5
	50 - 60 t	EURO 0	56.6	37.2	25.9	20.2
		EURO I	43.1	26.6	17.9	14.0
		EURO II	33.9	24.5	17.5	14.1
		EURO III	27.4	19.7	14.1	10.9
		EURO IV	15.1	12.6	9.5	7.5
		EURO V	9.4	6.7	4.1	3.0
		EURO VI	2.2	1.0	0.6	0.6

Table 24: Marginal noise costs (€/1000vkm)

Mode	Time of day	Traffic type	Urban	Suburban	Rural
Car	Day	Dense	8.8	0.5	0.1
		Thin	21.4	1.4	0.2
	Night	Dense	16.1	0.9	0.1
		Thin	38.9	2.5	0.4
Motorcycle	Day	Dense	17.7	1.1	0.1
		Thin	42.7	2.7	0.4
	Night	Dense	32.1	1.9	0.2
		Thin	77.9	5.1	0.6
Bus	Day	Dense	44.0	2.4	0.4
		Thin	107.0	6.8	0.8
	Night	Dense	80.3	4.5	0.7
		Thin	194.7	12.7	1.5
LCV	Day	Dense	44.0	2.4	0.4
		Thin	107.0	6.8	0.8
	Night	Dense	80.3	4.5	0.7
		Thin	194.7	12.7	1.5
HGV	Day	Dense	81.0	4.5	0.7
		Thin	196.6	12.7	1.5
	Night	Dense	147.8	8.3	1.3
		Thin	358.2	23.1	2.6
Passenger train	Day	Dense	273.4	12.1	15.0
		Thin	540.2	23.8	29.7
	Night		901.6	39.8	49.6
Freight train	Day	Dense	484.8	23.9	29.9
		Thin	1,169.6	46.3	57.8
	Night		1,977.6	78.3	97.7

Table 25: Marginal climate GHG emission costs for road transport vehicles (€ct/vkm)

Vehicle	Size	EURO-Class	Urban (€ct/vkm)	Rural (€ct/vkm)	Motorways (€ct/vkm)	Average (€ct/vkm)
Passenger Car - Petrol	<1,4L	EURO-0	2.8	1.7	1.8	2.0
		EURO-1	2.6	1.5	1.7	1.8
		EURO-2	2.5	1.4	1.5	1.7
		EURO-3	2.4	1.4	1.5	1.7
		EURO-4	2.4	1.4	1.5	1.7
		EURO-5	2.4	1.4	1.5	1.7
	1,4-2L	EURO-0	3.4	2.0	2.1	2.3
		EURO-1	3.1	1.8	1.9	2.1
		EURO-2	3.0	1.7	1.7	2.0
		EURO-3	2.9	1.7	1.7	2.0
		EURO-4	2.9	1.7	1.7	2.0
		EURO-5	2.9	1.7	1.7	2.0
	>2L	EURO-1	3.9	2.3	2.3	2.8
		EURO-2	3.9	2.3	2.3	2.7
		EURO-3	3.5	1.9	1.8	2.4
		EURO-4	3.5	1.9	1.8	2.4
		EURO-5	3.5	1.9	1.8	2.4
Passenger Car - Diesel	<1,4L	EURO-2	1.7	1.1	1.2	1.3
		EURO-3	1.6	1.1	1.2	1.3
		EURO-4	1.6	1.1	1.2	1.3
		EURO-5	1.6	1.1	1.2	1.3
	1,4-2L	EURO-0	2.4	1.7	1.9	1.9
		EURO-1	2.2	1.5	1.8	1.7
		EURO-2	2.2	1.5	1.6	1.7
		EURO-3	2.1	1.4	1.5	1.6
		EURO-4	2.1	1.4	1.5	1.6
		EURO-5	2.1	1.4	1.5	1.6
	>2L	EURO-0	3.3	2.3	2.7	2.6
		EURO-1	3.0	2.1	2.4	2.4
		EURO-2	3.0	2.0	2.3	2.3
		EURO-3	2.9	1.9	2.1	2.2
		EURO-4	2.9	1.9	2.1	2.2
		EURO-5	2.9	1.9	2.1	2.2
Light commercial vehicles	Petrol	EURO-0	4.0	2.5	2.8	2.7
		EURO-1	3.6	2.3	2.5	2.5
		EURO-2	3.7	2.2	2.4	2.5
		EURO-3	3.7	2.2	2.4	2.5
		EURO-4	3.4	2.1	2.3	2.3
		EURO-5	3.4	2.1	2.3	2.3
	Diesel	EURO-0	2.9	2.0	2.9	2.4
		EURO-1	2.8	1.8	2.6	2.2
		EURO-2	2.8	1.8	2.6	2.2
		EURO-3	2.8	1.8	2.5	2.1
		EURO-4	2.8	1.7	2.4	2.1
		EURO-5	2.8	1.7	2.4	2.1

Vehicle	Type	EURO-Class	Urban (€ct/vkm)	Rural (€ct/vkm)	Motorways (€ct/vkm)	Average (€ct/vkm)
Buses		EURO-I	7.7	5.8	5.3	6.3
		EURO-II	7.6	5.6	5.1	6.1
		EURO-III	7.6	5.6	5.1	6.1
		EURO-IV	7.4	5.1	4.6	5.8
		EURO-V	7.4	5.1	4.6	5.8
HGVs	<7.5t	EURO-0	3.8	3.2	3.4	3.4
		EURO-I	3.1	2.7	3.0	2.9
		EURO-II	2.9	2.5	2.8	2.7
		EURO-III	2.9	2.6	2.8	2.7
		EURO-IV	2.7	2.3	2.5	2.5
		EURO-V	2.7	2.3	2.5	2.5
	7.5-16t	EURO-0	6.5	5.4	5.1	5.6
		EURO-I	5.7	4.7	4.5	5.0
		EURO-II	5.5	4.4	4.2	4.7
		EURO-III	5.7	4.3	4.2	4.8
		EURO-IV	5.3	3.9	3.7	4.4
		EURO-V	5.3	3.9	3.7	4.4
	16-32t	EURO-0	10.6	8.3	7.3	8.5
		EURO-I	9.7	7.7	6.8	8.0
		EURO-II	9.4	7.4	6.4	7.8
		EURO-III	9.7	7.2	6.2	7.6
		EURO-IV	8.9	6.5	5.5	7.0
		EURO-V	8.9	6.5	5.5	7.0
	>32t	EURO-0	13.2	10.4	9.0	10.4
		EURO-I	12.1	9.6	8.2	9.5
		EURO-II	11.9	9.3	7.9	9.3
		EURO-III	12.1	9.0	7.5	9.1
		EURO-IV	11.2	8.1	6.7	8.3
		EURO-V	11.2	8.0	6.7	8.3

Table 26: Marginal infrastructure costs for road transport vehicles (€ct/vkm)

Vehicle category	All roads	Motorways	Other trunk roads	Other roads
Motorcycles and mopeds	0.2	0.1	0.1	0.3
Cars	0.5	0.2	0.3	0.8
Buses	2.0	0.8	1.4	2.7
LDV < 3.5 t	0.7	0.3	0.5	1.2
HGV 3.5 - 7.5 t, 2 axles	0.1	0.0	0.0	0.4
HGV 7.5 - 12 t, 2 axles	1.5	0.6	1.0	8.2
HGV 12 - 18 t, 2 axles	3.9	1.6	2.7	21.5
HGV 18 - 26 t, 3 axles	5.2	2.2	3.6	28.9
HGV 26 - 32 t, 4 axles	6.6	2.8	4.6	36.7
HGV 26 - 32 t, 5 axles	3.6	1.5	2.5	20.1
HGV 32 - 40 t, 5 axles	8.0	3.3	5.6	44.6
HGV 32 - 40 t, 6 axles	4.8	2.0	3.3	26.7
HGV 40 - 50 t, 8 axles	5.0	2.1	3.5	28.1
HGV 40 - 50 t, 9 axles	3.8	1.6	2.7	21.5
HGV 50 - 60 t, 8 axles	10.6	4.4	7.4	59.3
HGV 50 - 60 t, 9 axles	7.6	3.2	5.3	42.3
HGV 40 t, 8 axles	3.5	1.5	2.4	19.4
HGV 40 t, 9 axles	2.8	1.2	2.0	15.6
HGV 44 t, 5 axles	18.8	7.9	13.1	105.0
HGV 44 t, 6 axles	10.3	4.3	7.2	57.7

9 APPENDIX II

This appendix contains the total costs of external impacts for the network and the area and the evolution during working hours (7:00 – 18:00) of the parking space demand are presented for each scenario. All results presented show the external costs in each scenario for an average working day.

9.1 Scenario 0 -BAU

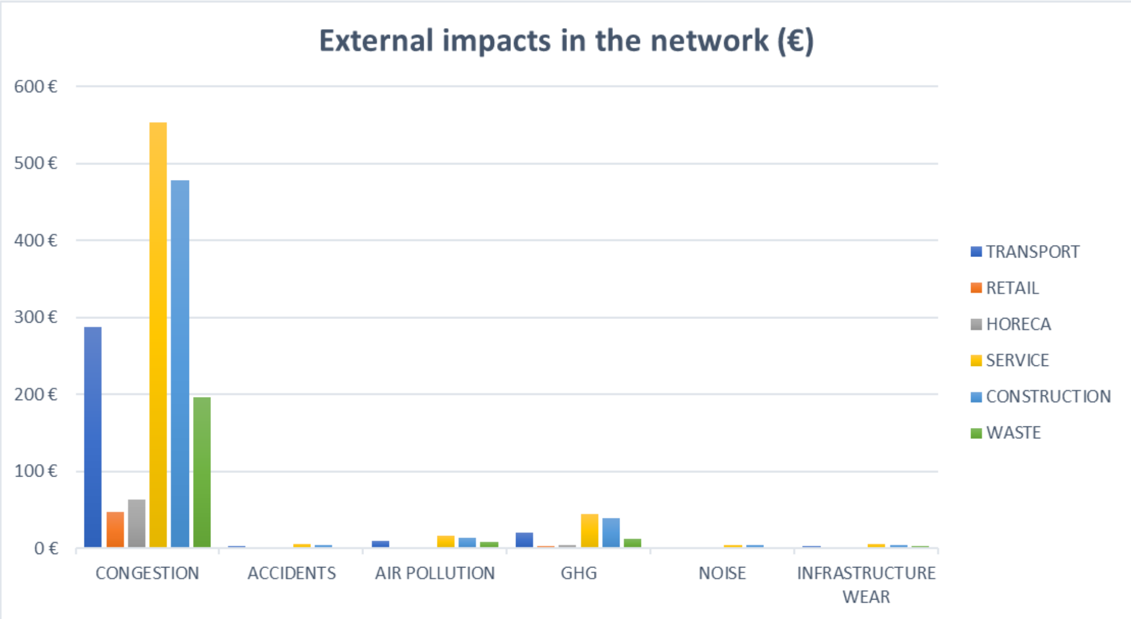

Figure 24: Total external impacts in the network for the BAU scenario

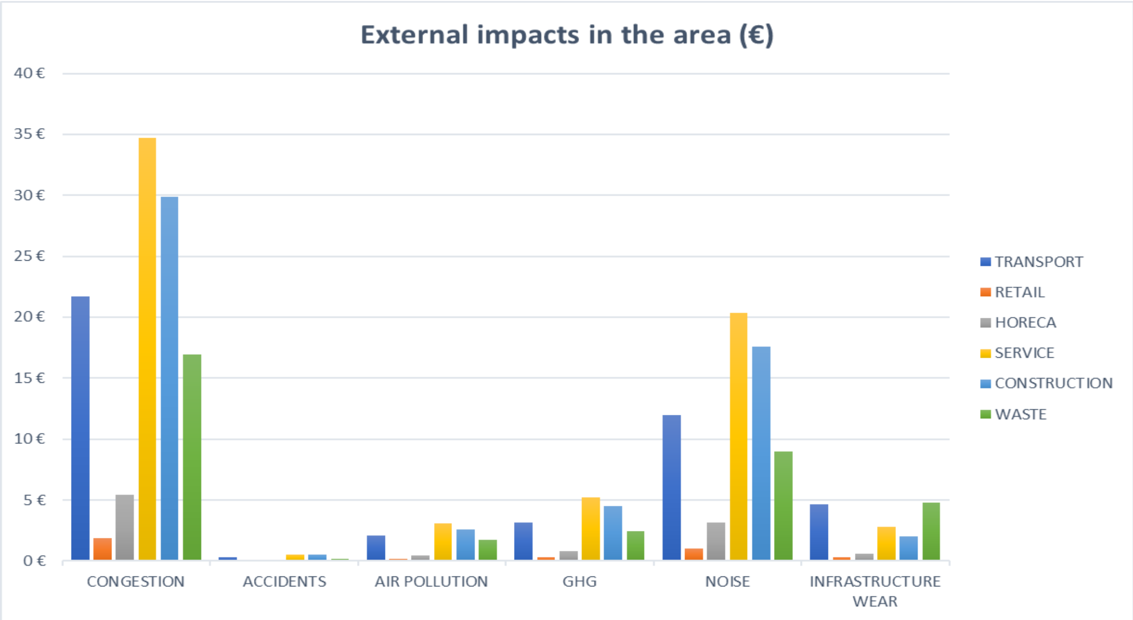

Figure 25: Total external impacts in the area for the BAU scenario

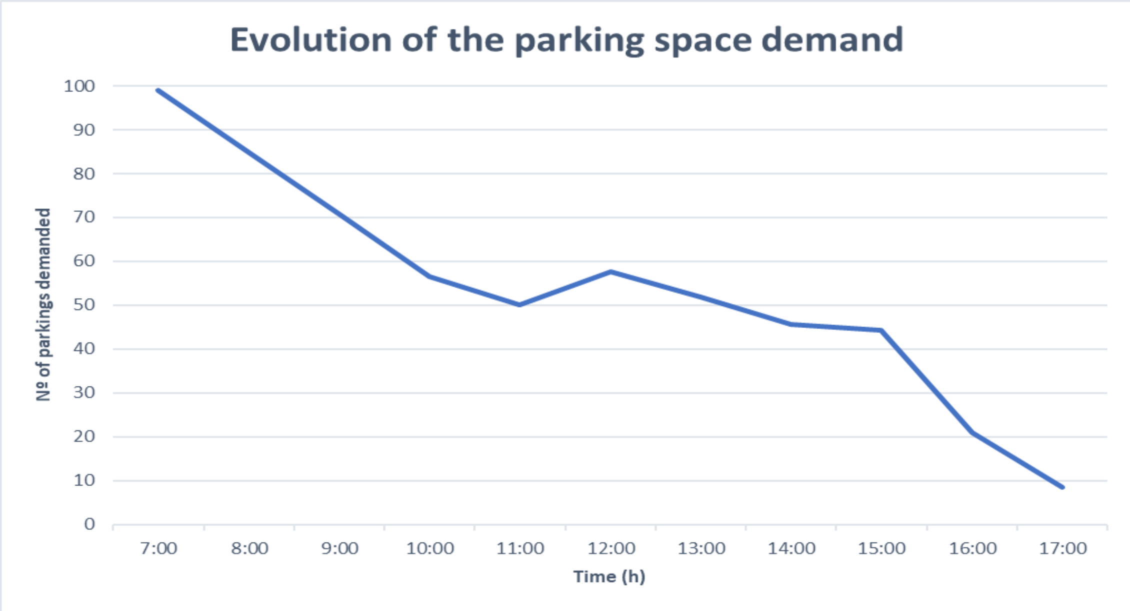

Figure 26: Evolution of the parking space demand for the BAU scenario

9.2 Scenario 1 – Full-service apartment

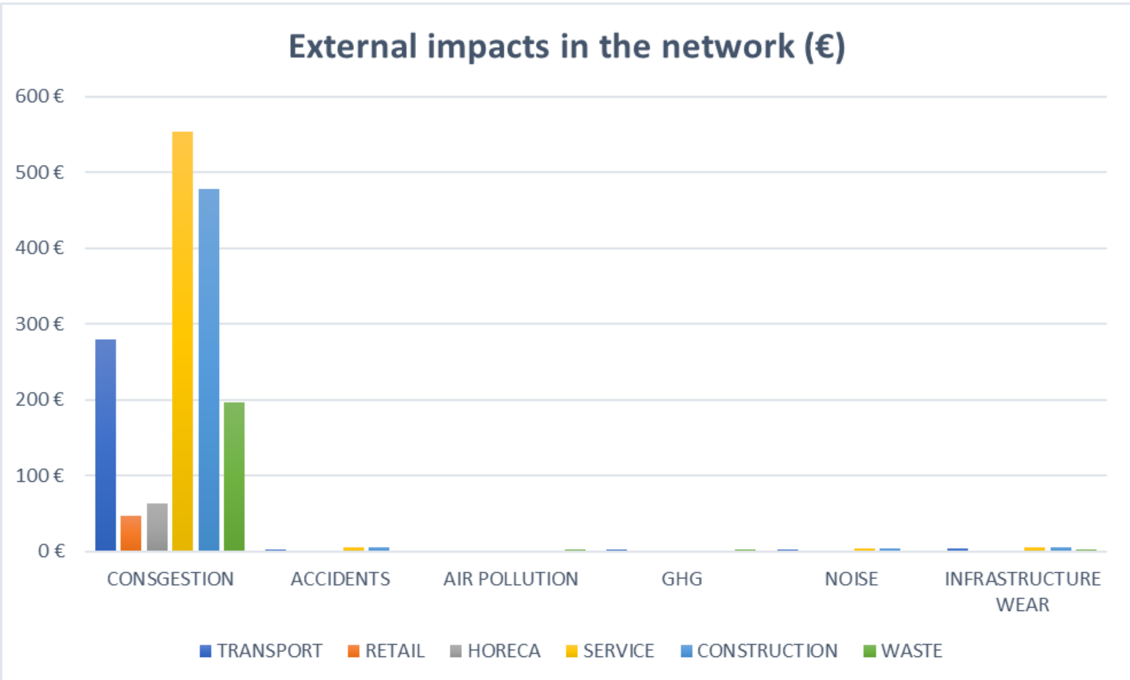

Figure 27: Total external impacts in the network for scenario 1

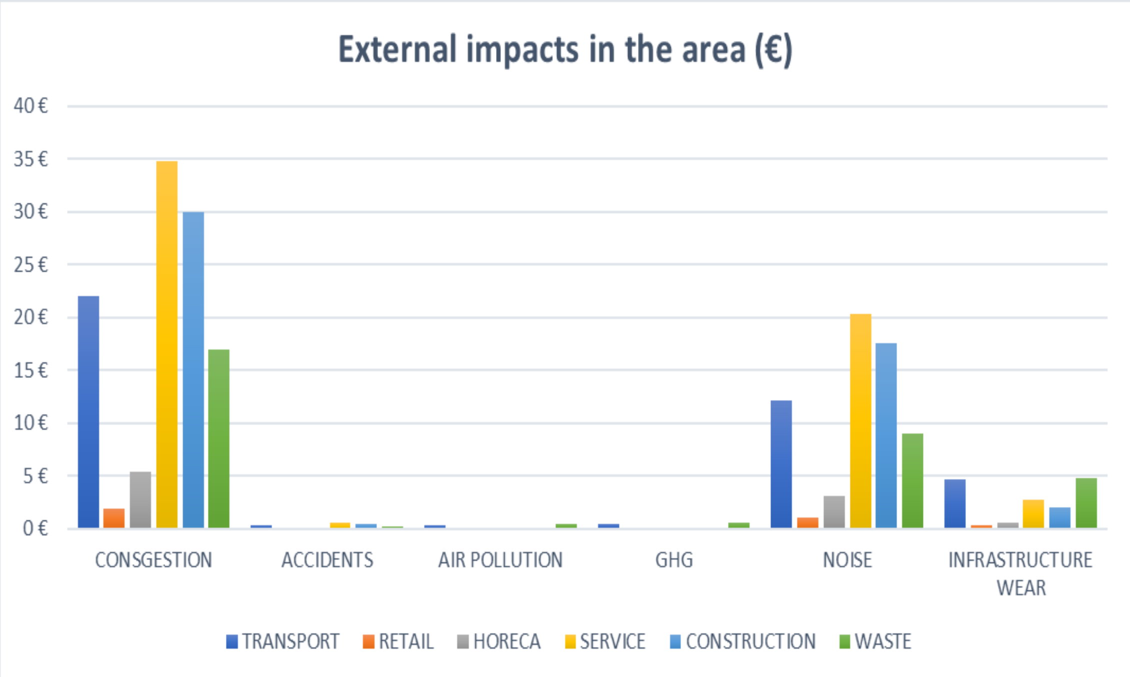

Figure 28: Total external impacts in the area for scenario 1

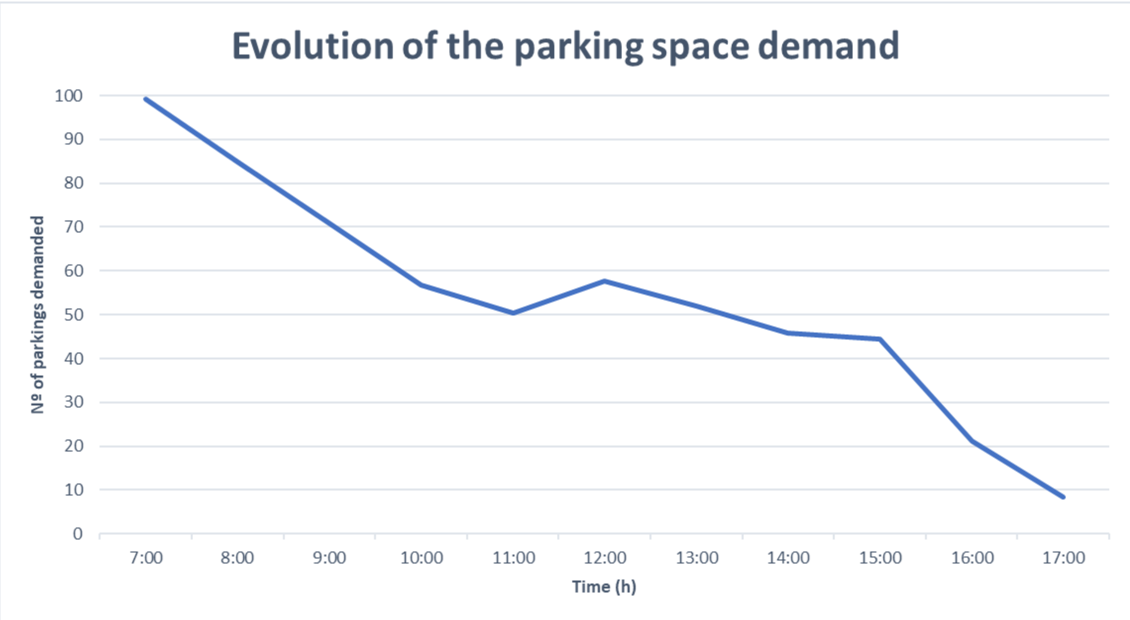

Figure 29: Evolution of the parking space demand for scenario 1

9.3 Scenario 2 – Urban Consolidation Centre

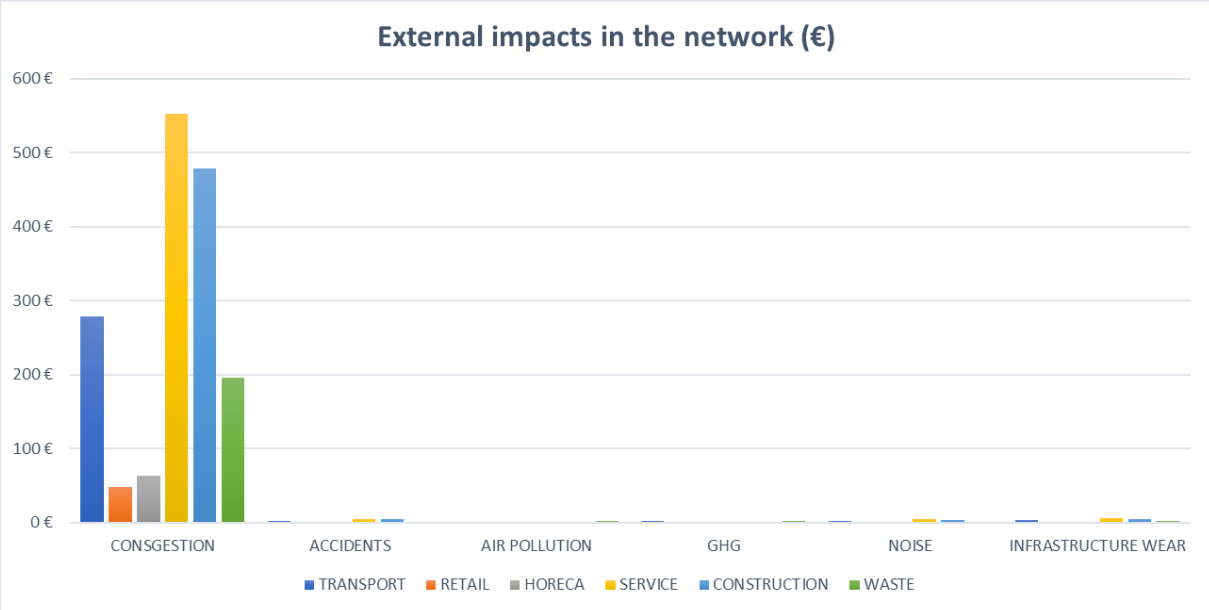

Figure 30: Total external impacts in the network for scenario 2

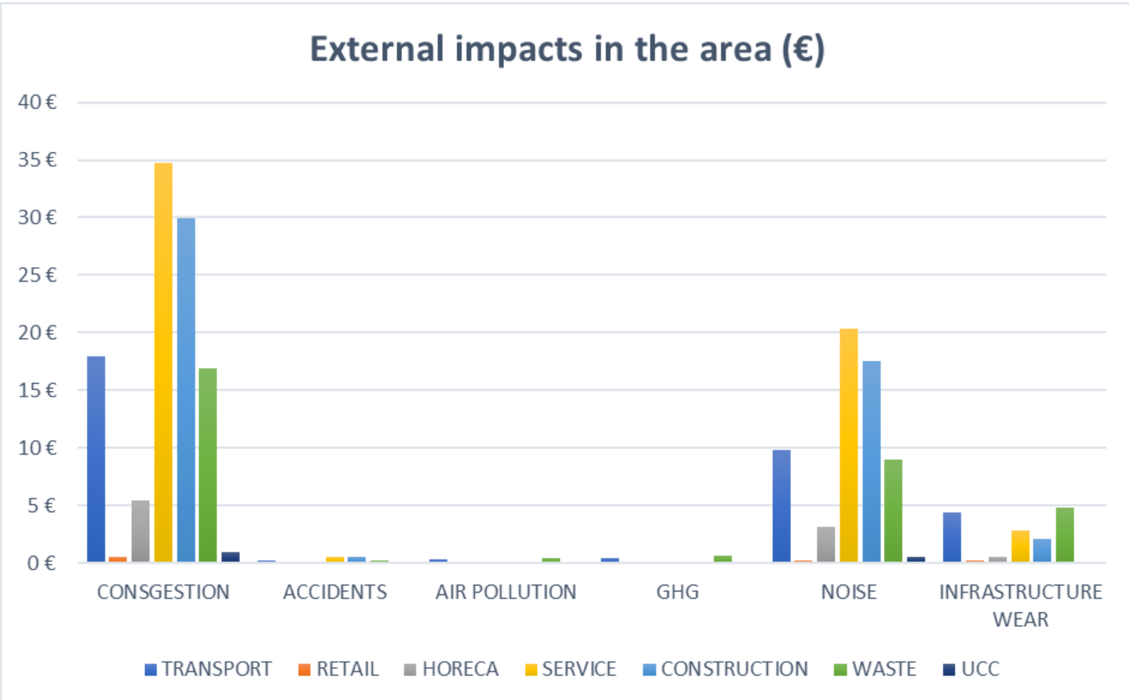

Figure 31: Total external impacts in the area for scenario 2

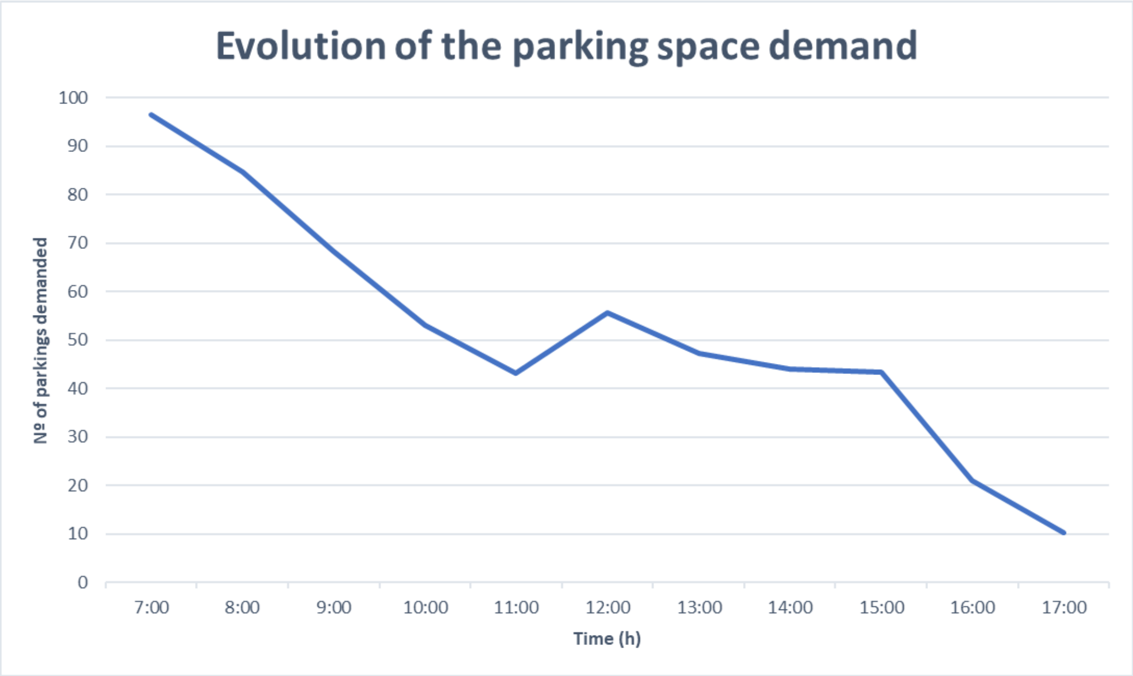

Figure 32: Evolution of the parking demand for scenario 2

9.4 Scenario 3 – Urban Waterways

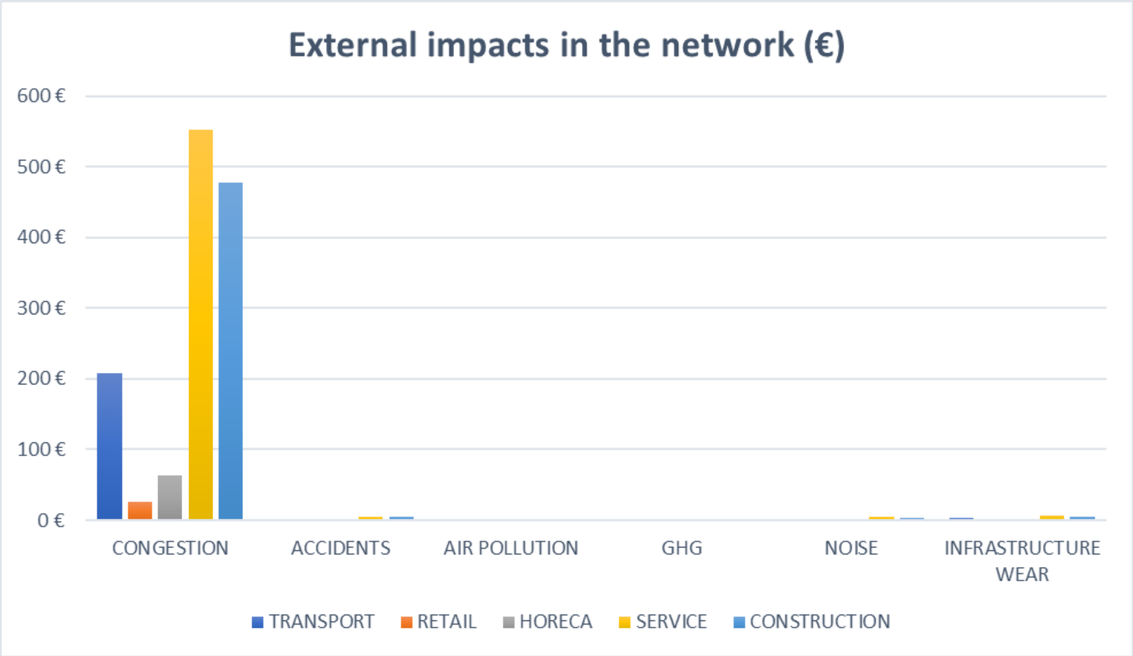

Figure 33: Total external impacts in the network for scenario 3

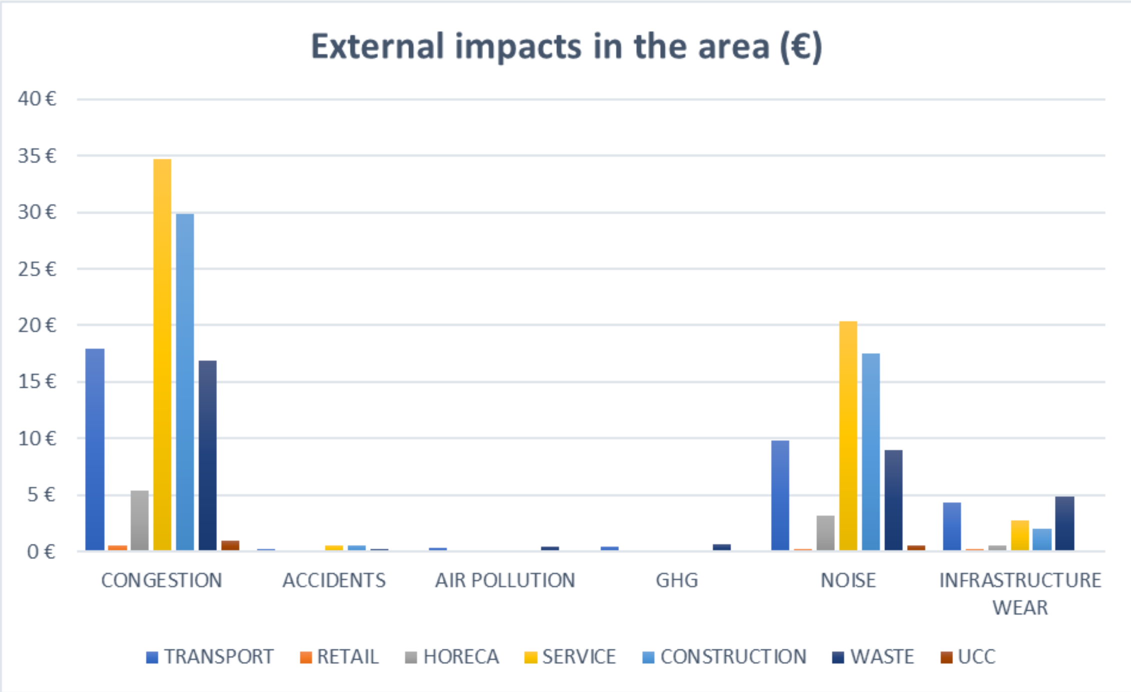

Figure 34: Total external impacts in the area for scenario 3

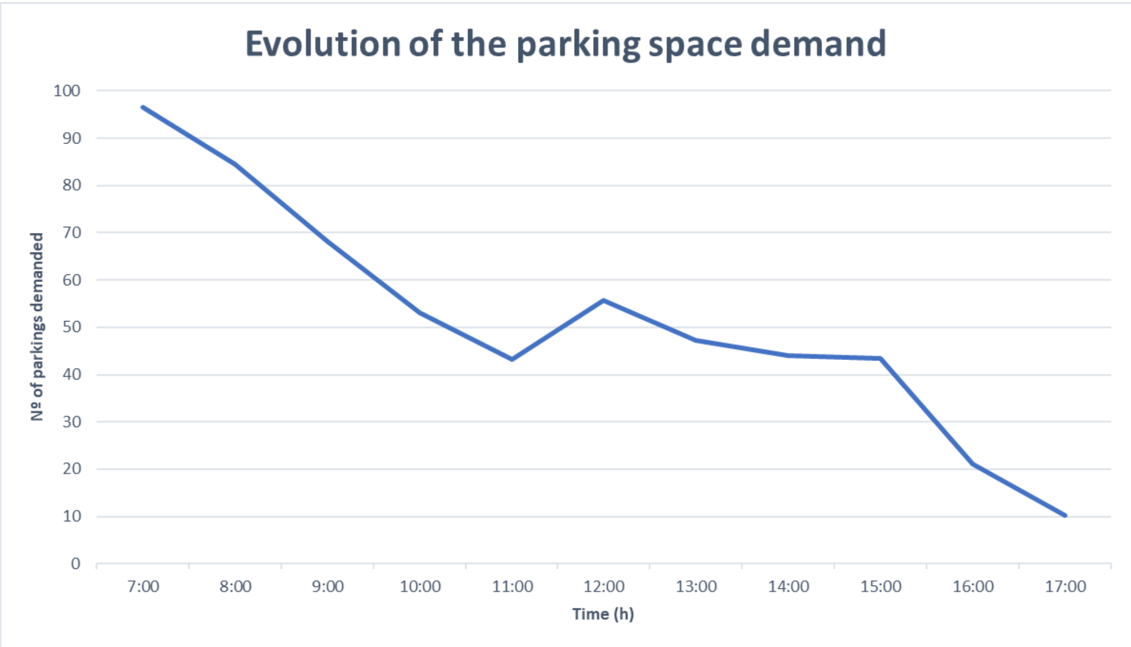

Figure 35: Evolution of the parking spaces demanded for scenario 3