E.T.S. de Ingeniería Industrial,
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COMPARING METHODOLOGIES TO ASSESS THE ENVIRONMENTAL IMPACT OF FREIGHT TRANSPORTATION CROSSING TWO DIFFERENT ROUTES CONNECTING PAMPLONA WITH IRÚN

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Abstract

Over the last 10-15 years, environmental awareness is growing strongly and with it many changes are being brought about in many aspects of our society. Companies have also become aware of their role in this change. To reduce its environmental impact, one of the key points has been to reduce the impact of its transports. The impact of freight transport is diverse, both because of the range of externalities and the distances over which its adverse effects are experienced.

A large percentage of goods are transported on roads, and consequently road transport is one of the main sources of pollution, within the scope of goods transport. In the case of the EU, most inland transport is carried out by road. This makes road transport the focus of most research to reduce the environmental impact of transport. The present work is developed in this context.

A major challenge in this task will be to carry out a comparative study of the environmental impact of freight transport on two different routes which connect Pamplona with Irún. It should be borne in mind that this problem is subject to a very topical social debate. The routes are:

- Route 1. Pamplona- Irún via the AP-15 motorway.

- Route 2. Pamplona- Irún via the N-121-A road.

To address this problem, several models that approximate the emission of gases must be analyzed and those that best adapt to the conditions that arise will be used to compare the environmental impact of both routes. In this way, it will be possible to determine which of the two routes has the least environmental impact.

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PART 1

1. Introducction

This work is part of the field of transport and logistics, one of the sectors that consumes the most energy. In addition, freight transport by road is the mode of transport that moves the largest volume of freight at the level of inland transport, which implies a very significant energy expenditure within the transport sector. Consequently, the sector has a major impact on society as a whole and on the environment, which is often not positive. This is known as externalities or external costs, and appears when a series of social or economic activities of one group of people has an impact on another group of people, and in addition, the first group of people does not compensate the second for the impact caused. Accidents, noise, congestion, water pollution or emissions are some examples of such external costs.

This paper focuses on one of these externalities: emissions, and more specifically CO_2 emissions. These types of emissions are the main cause of one of the greatest problems facing society today: global warming. Therefore, many of the environmental policies promoted by European governments try to reduce this type of emissions as much as possible. So much so that the most important environmental summits at the global level have established protocols such as those of Kyoto or Paris, which oblige countries to reduce their emissions by 18% with respect to those of 1990. Thus, the need to seek solutions to reduce the impact of CO_2 emissions in road freight transport seems very important.

Another key point of the work is that it is linked to a current conflict: the problem with the N-121-A road. This is one of the roads with the highest number of accidents in the region of Navarra. In addition, a large number of heavy vehicles travel along it from Pamplona in the direction of Irún, which is one of the main axes of Trans-Pyrenean transport and through which a large number of vehicles pass daily. To try to reduce the number of accidents on the N-121-A road, the government of the area is considering redirecting the traffic of trucks travelling from Pamplona to Irún along an alternative route: the AP-15 highway. The problem that arises then is, in view of this possible measure that the local government is considering taking, to see which of the two alternatives has the least environmental impact, from the point of view of CO_2 emissions.

To address this problem, models that approximate emission of gases and fuel consumption will be used to compare the environmental impact of both routes. Microscopic estimation models have been used for this study, which provide more accurate results than macroscopic models. In addition, this type of models is better suited to the data available for the study. In this way, it will be possible to determine which of the two routes has the least environmental impact. The models used are in Demir et al. (2011), and are the following:

- A four-mode elemental fuel consumption model (Bowyer et al. (1985)).
- A running speed fuel consumption model (Bowyer et al. (1985)).
- A comprehensive modal emission model (Barth et al. (2000, 2005); Boriboonsomsin (2008)).

Along with the emission calculation models, a Geographic Information System (GIS) will be used to obtain the geographic data necessary to implement the emission models.

Different scenarios are proposed to simulate the route of a lorry carrying goods from Pamplona to Irun, in order to determine which of the two routes has the least fuel consumption and consequently less environmental impact in terms of CO_2. In this way it will be seen whether the option of diverting lorries on the AP-15 a good measure in environmental terms is.

2. Preious concepts

2.1. General transport concepts

Transportation can be defined as the transfer of persons or goods from one place to another. Transport is an essential activity in our society and in order to carry out the transport, several elements are necessary: infrastructure, mobile, operator, standards and object.

- Infrastructure: is the part where the activity is physically carried out, such as roads for road transport, cables for electric transport or canals for maritime transport. Elements such as traffic lights, control towers or ports are also part of this group.
- Mobile: is the instrument that allows the transfer of persons or objects from one place to another.
- Transport operator: is the person in charge of managing the mobile with which the object or person is to be moved.
- Standards: are the elements that dictate how the transfer is to be carried out, while at the same time regulate the operation.
- Object: is the transported element, which nature can be diverse.

In addition, the discipline of transport is extended to very diverse fields, so it is classified according to different factors.

The first is according to the object: passengers or freight. The transport of freight consists of moving material goods in a mobile made for this purpose and it is associated with the concept of logistics, which consists of placing the important products at the right time and at the desired destination. For passenger transport it is also important to consider aspects such as comfort or travel time. There is also mixed transport, which is dedicated to the joint transport of people and goods, in vehicles equipped for this purpose and with proper separation.

Another way of classifying it is according to its territorial scope. If the itinerary runs through territories of different states, it is known as international transport. If, on the other hand, the journey has its origin and destination in the same state, the transport will be internal. In turn, whether the transport is within the same city or not, it is called urban or interurban transport respectively. Transport can also be distinguished according to whether it is public or private.

If we enter the world of business, transport is part of logistics, which is one of the key departments in any business. The transport of goods, both raw materials, parts or any element necessary for the operation of a plant, as well as the delivery of finished products to their respective destinations, are in most cases the most important component of the overall logistics cost of the company. However, despite representing an important percentage of the total cost of a product, they do not add as much value to the product as other departments, such as production or R&D&I. For this reason, logistics and transport are one of the main objectives when it comes to optimizing costs for the manufacture of a product. In the search for more efficient routes or modes of transport, many of the investigations within the area of logistics are focused, since there are usually margins for improvement.

2.2. Transport history

Transport is a fundamental activity within society, which has been evolving for many years, and in recent times it has been a very innovative sector of great importance for the development of societies.

Humans began to transport their food because of their nomadic life and human capacity to carry large loads. This was thanks to the invention of the wheel 5,500 years ago. The man of that time used the animals to carry the goods he wanted to transport. Although wagons pulled by animals were also used in those paths wide and flat enough. With the passage of time, trade emerged, which was carried out using the stagecoaches of horses that traveled different trade routes. These merchants were already able to travel large routes to bring goods to distant villages. It was not until the middle of the eighteenth century that modern roads began to be built in Spain in the vicinity of the major cities of the time. These were also made following the ancient paths of the Roman roads.

In the middle of the eighteenth century, the construction of modern roads began in Spain near the urban centers, using great part or the lines built by the ancient Roman, causeways. Still at that time the transport was carried out by animals, although there were certain stretches that, because they were in flat areas could have been widened to be traveled by cars as well. At that time, however, transportation was still mainly with animals, although there were certain sections that allowed the use of carriages with which to transport larger volumes of goods. At the end of this century, the use of horse-drawn carriages is widespread, and a more modern infrastructure, such as bridges or tunnels, is needed. In addition, works are carried out in places where the road is in difficult terrains, and retaining walls or embankments are built.

For the case of Spain, with the reign of the monarch Carlos III the construction of roads was increased, building almost 2000 kilometers of road network. One of the main routes was the one connecting Madrid with Cádiz, where one of the most important ports of Spain and Europe was located.

It was not until the nineteenth century that land transport planning began in Spain. Several agreements and programs were established, including:

- First Road Plan of Spain: it consisted of a list of the roads that the State has in charge, in which they are classified, and their length is specified (approximately 35,000 kilometers).
- Second Road Plan of Spain: it was made to replace the previous one in 1864. With it, new roads which passed though poorly communicated towns where built and some roads were replaced by the new railways.
- Road Law of Spain: approved a year later than the second road plan for Spain, in 1877. It approved a list of provincial roads according to their classification (1st, 2nd or 3rd order).

The growing industrial revolution caused the last Road Plan to be abolished in 1911. The volume of goods being moved was too large and a much larger road network was needed. Sometime later, the National Circuit of Special Signs was born in order not to create new roads, but to reform and conserve the existing ones, especially busiest ones (those that united the large populations). The map was divided into three groups (East, Northeast and South) and the sum of kilometers was 7,000.

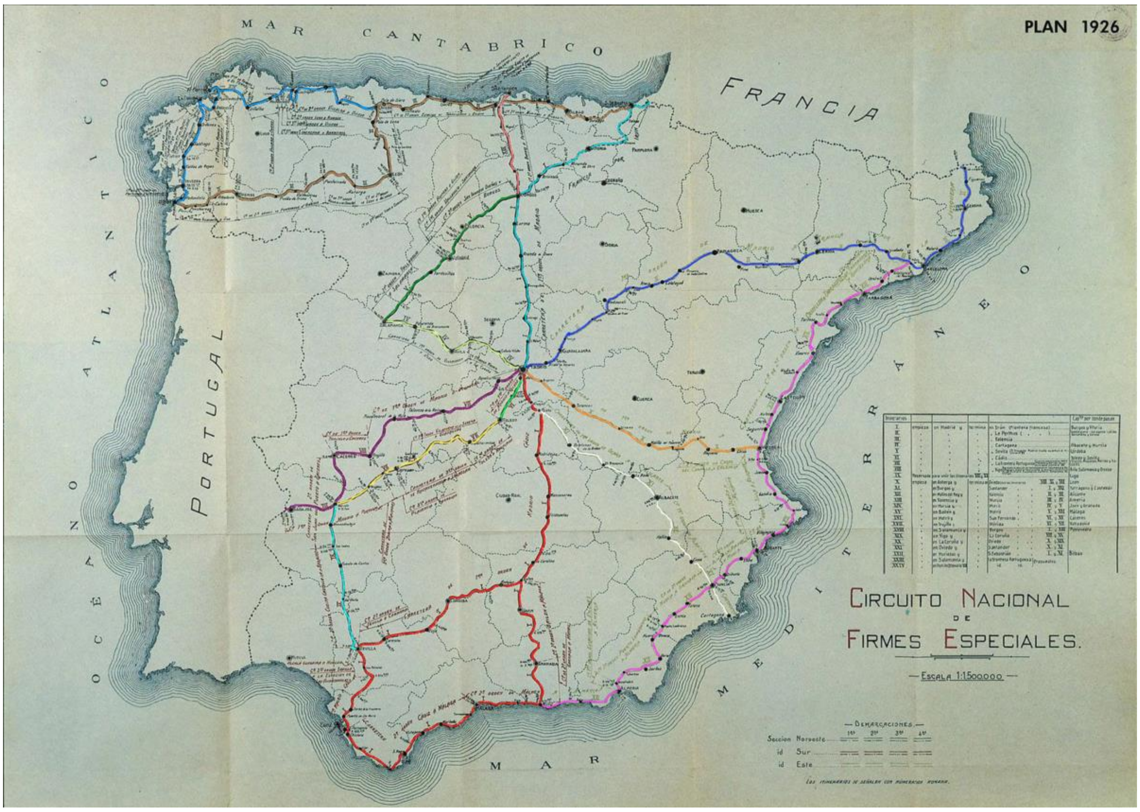


Figure 1: National Circuit o Special Signs

As early as the middle of the twentieth century, roads were equipped with elements that characterize today's road network, such as signs or motorways. These changes were introduced with the Modernization Plan in 1950 and the 1984 Plan. Some more recent plans at Spanish efect are:

- Infrastructure Master Plan (1993-2007).
- Transport Infrastructure Plan (2000-2007).
- Strategic Plan for Road Freight Transport (2002).
- Strategic Plan for Infrastructure and Transport (2005-2020).
- Strategic Plan for Road Freight Transport.

At the local level, the latest road plans concerning this project are:

- The Navarra III Road Master Plan (2010-2018).
- Third General Road Plan of the Basque Country (2017-2028).

2.3. Transport modes

Some of the main modes of transport will be introduced in the next section. Transport modes are combinations of networks, vehicles and operations, with which the physical movement of goods across borders, or the transport of goods, can be done.

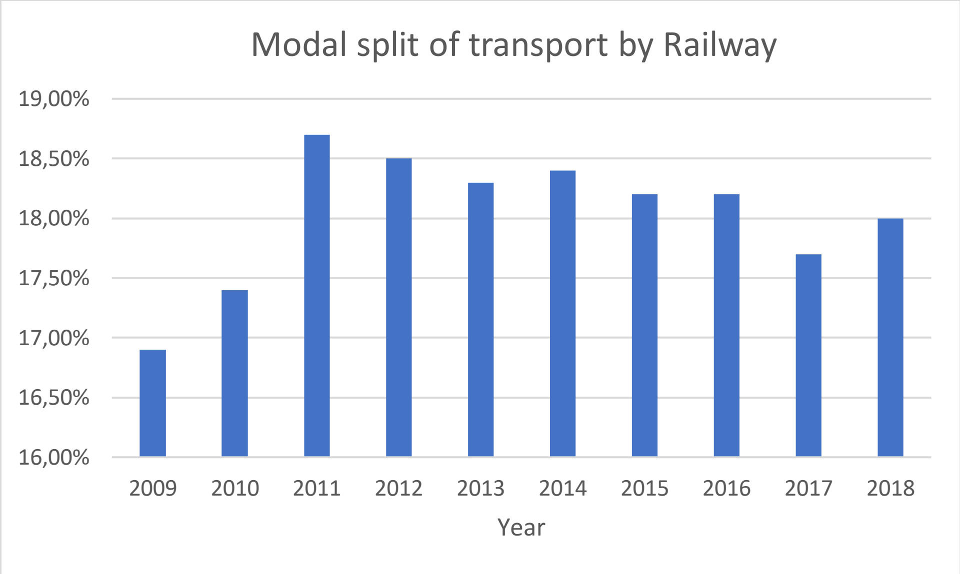
2.3.1. Railway

The railway or rail transport is a system of transport of people and goods guided on a track, usually of iron or steel, although there are also some that use magnetic levitation. This mode of transport has significant advantages such as fuel consumption, reducing environmental impact or mass transport.

The first railroad of the modern era was manufactured in 1768. From this, and with the invention of the steam engine, the railway was one of the fundamental pillars of the industrial revolution and was an essential mode of transport, at least until after World War II, when railroads declined in relative share after (John, 2019).

However, its use has increased in share since 1990 because of fuel prices and other factors. In the actuality, railroads typically move bulk, low-value commodities such as grain, coal, ore, and chemicals for longer distances, which impacts their ton-miles share. Though, in recent years, rail traffic by container, which transports relatively higher value finished goods, has increased. In the case of Spain, the railway has a smaller weight and has functionality problems, compared to other countries of the European Union, where the railway network is much larger. In addition, there are large differences between the regions of Spain, since most of the rail traffic is concentrated in a few autonomous communities, which prevents rail from being an alternative to road transport. However, there are government forecasts that rail use will increase, thanks to improved infrastructure and regulation in the sector.

This mode of transport saves energy and fossil fuels in comparison with other modes, such as road and air transport. On the economic side too, all costs being taken into account, the balance sheet is very positive in favor of rail transport. Today, there is no doubt that when energy is clean and renewable, rail is the means of transport that consumes the least energy and generates the least noise and pollution. Since the beginning of the century, however, Spain has placed much greater emphasis on road transport and, because of this, the percentage of freight transported under this mode of transport has been decreasing over the last decade. Graphic 1 shows this decreasing trend in recent years.



Graphic 1: Modal split of transport by Railway (Data from Eurostat, 2020)

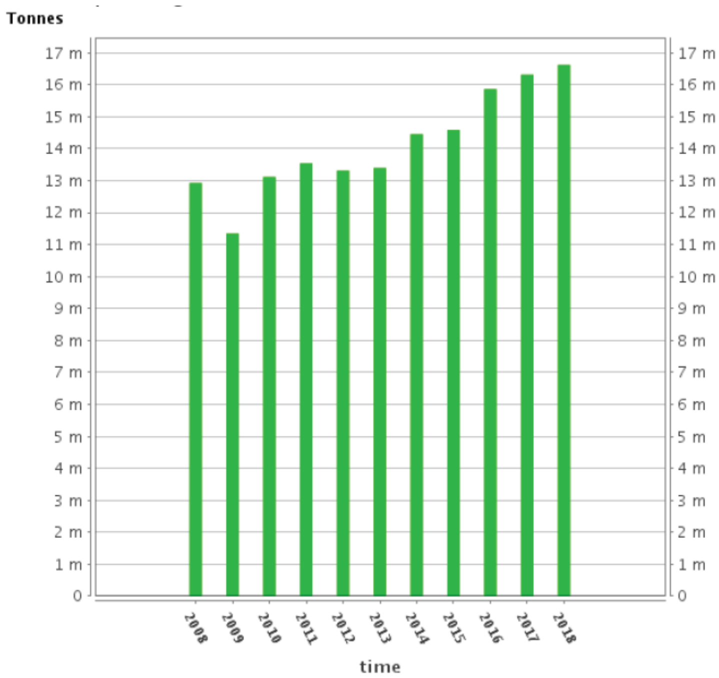
2.3.2. Air

Air transportation is the service of moving passengers or cargo from one place to another using an aircraft. The primary purpose of the aircraft was military, and subsequently aircraft for passenger transport were developed. Later, aircraft and air containers were adapted for the transport of freights and has been the most rapidly developed form of modern transport.

Its technology has come a long way in recent decades and is considered one of the safest means of transport in the world. When it develops in the air, it enjoys the advantage of its continuity, which extends over land and sea. The characteristic that best defines this mode of transport is that you do not need a track on the surface throughout your journey, only at the beginning and at the end. It also differs from other modes of transport in that it has no physical barriers and its most important advantage lies in its speed. However, it is limited by the need for costly infrastructures and a higher economic cost than the rest of the means of transport. The construction of air transport infrastructure is much more costly than for other modes of transport. Also, they are highly polluting, as they require the burning of fossil fuels to propel them, spreading waste gases throughout the atmosphere as they move. On the other hand, although it is one of the safest modes of transport, air accidents are a fatal risk, for passengers, pilots and crew.

They are classified according to the technology that supports them and their total cargo capacity, the latter being the great limitation in all types of flights. A plane can put a certain amount of weight into the air, no matter what its contents. Capacities can vary from the 20 tons a small plane can carry to the 70 tons a larger plane can carry.

Air freight transport is largely dedicated to the transfer of postal mail and packages. In Spain, which follows UE 28 trend, exclusive cargo aircraft operate, but most of the cargo is transported in the hold of passenger aircraft. Since 2008, the transportation of goods by air has been increasing in Spain, from 539,803 tonnes in 2008 to 806,518 tonnes in 2018. Same trend has the European Union, which can be seen in Graphic 2.



Graphic 2: Air transport of goods in the UE 28 (Data from Eurostat, 2020)

2.3.3. Water

Maritime transport is defined as the transfer of passengers or cargo by sea from one geographical point to another by ship. Shipping, is the most widely used mode for international trade. It is the one that supports the greatest movement of goods, both in container, dry or liquid bulk. Maritime transport is by its very nature international, although there is navigation along the coasts of a country or also in the interior of the country through channels or rivers.

Two-thirds of the planet earth is covered by water and man has always sought ways to travel on it. Mankind discovered shipping and the transport of goods more than 5,500 years ago, and for two centuries now, it has undergone a dizzying development. Today, all countries have port stations where increasing ships dock through a network that connects with the rest of the world. In addition, the use of containers has also contributed to this case.

The main characteristics of the water freight transport are:

- Large capacity: large vessels can carry large bulk or container masses. Larger oil tankers can carry up to 500,000 deadweight tonnes, while container tankers carry up to 220,000 deadweight tonnes.
- International level: this is the best way to transport large volumes of cargo between two very remote points, thanks to the development of motorways of the sea and short sea shipping, which facilitates interconnection with other means of transport.
- Flexibility: it is possible to use ships from small sizes to the greatest possible capacity to transport in any other mode of transport.
- Versatility: ships of different sizes have been built and adapted to all types of loads. In addition to the traditional cargo ships, there are container ships, methane carriers, for rolling cargo, for refrigerated cargo or for solid bulk

Although maritime freight transport is booming, passenger transport has lost much importance, not least because of the development of commercial aviation. Spain has 46 ports of general interest, managed by 28 Port Authorities. The importance of ports as links in logistics and transport chains is reflected in the fact that they account for about 60 per cent of exports and 85 per cent of imports, representing 53% of Spanish foreign trade with the European Union and 96% with third countries. In addition, the activity of the state port system contributes about 20% of the GDP of the transport sector, representing 1.1% of the Spanish GDP. It also generates direct employment of over 35,000 jobs and about 110,000 indirectly (Ministry of Transport, Mobility and Urban Agency, 2020).

2.4. Economic data of transport in Spain

Road freight transport has a high economic weight in transport and in the whole Spanish's economy. The weight of transport in Spain in relation to GDP was stable between 2008 and 2015, remaining between 2.9% and 3% (Transgesa, 2018). Furthermore, there is a high synchronization between the growth of freight transport and the growth of gross domestic product (GDP), which makes freight transport a good advanced indicator of economic growth in Spain. Another interesting fact about the transport sector is that it accounts for about 8.5% of the added value (Álvaro Escribano, 2020).

In terms of average employment between 1995 and 2016, there were 1.303.312 employed, representing 7,6 % of the total employed. Of the various transport sectors, 56 % are in transport and storage, followed by commerce (25 %) and industry (19 %). In terms of transport modes, passenger transport is dominated by the car, while the importance of freight transport is shared between two modes of transport: road and maritime transport.

3. Road transport

3.1. General road transport concepts

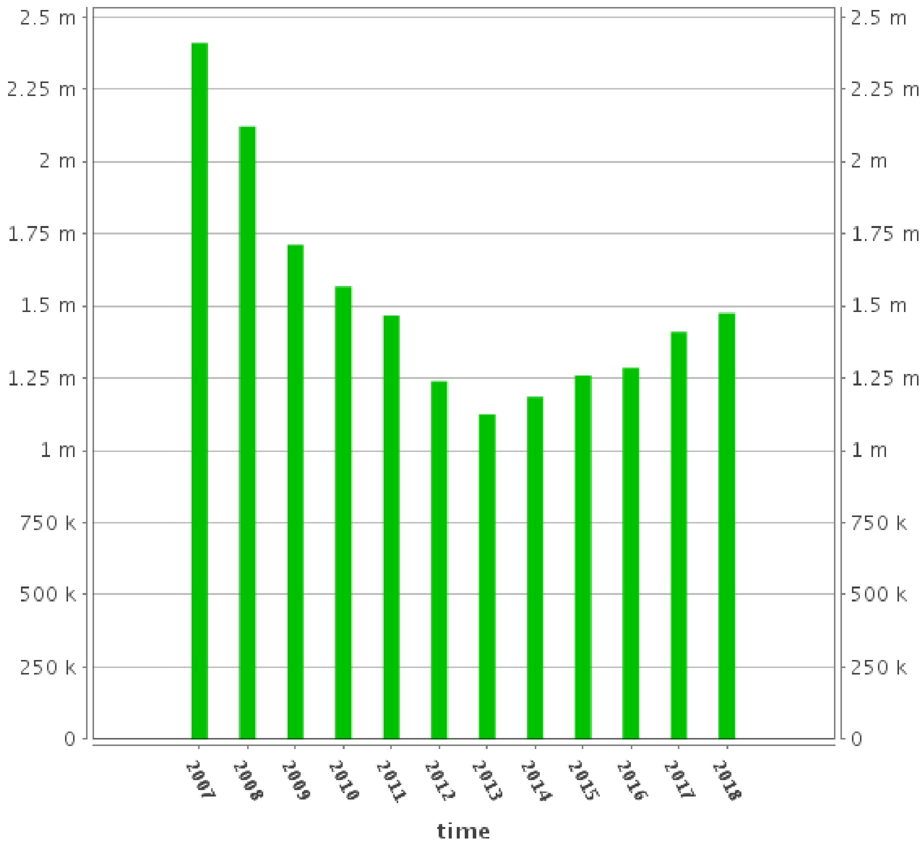
Road transport, defined as the movement of persons or roads through roads, is the most used mode of transport these days. Therefore, because of its great volume of use, it is also one of the most damaging modes of transport, as it will be seen later. In terms of freight transport, motor carriers have increased their relative share of the total tonne-mile market after 1980.

A determining aspect in the fact that almost 95% of freight transport in Spain is carried out by road, compared to just 2% in rail transport (Spanish Centre for Logistics, 2018), is the progressive evolution of the roads. Thanks to the first roads and paths traced since the Middle Ages, passing through the national roads drawn during the eighteenth and nineteenth centuries, the Special Purpose Plan of the nineteenth century and then the Network of Asphalted Itineraries, up to the plans of Freeways and Infrastructures, a complete connection has been achieved both nationally in Spain, as in other countries of Europe and the rest of the world. Spain has almost 200,000 kilometers of roads that allow the connection between almost any point in the country.

The development of lorries is also a very important factor in the history of road transport. From the first chariots pulled by horses and the transport of cargo in animals, was switched to steam vehicles. Today, trucks have great flexibility, it is a fast vehicle, it can do door-to-door service, it can change route if necessary, it guarantees safety and adaptability, it is localized and, for all that, it is more economical.

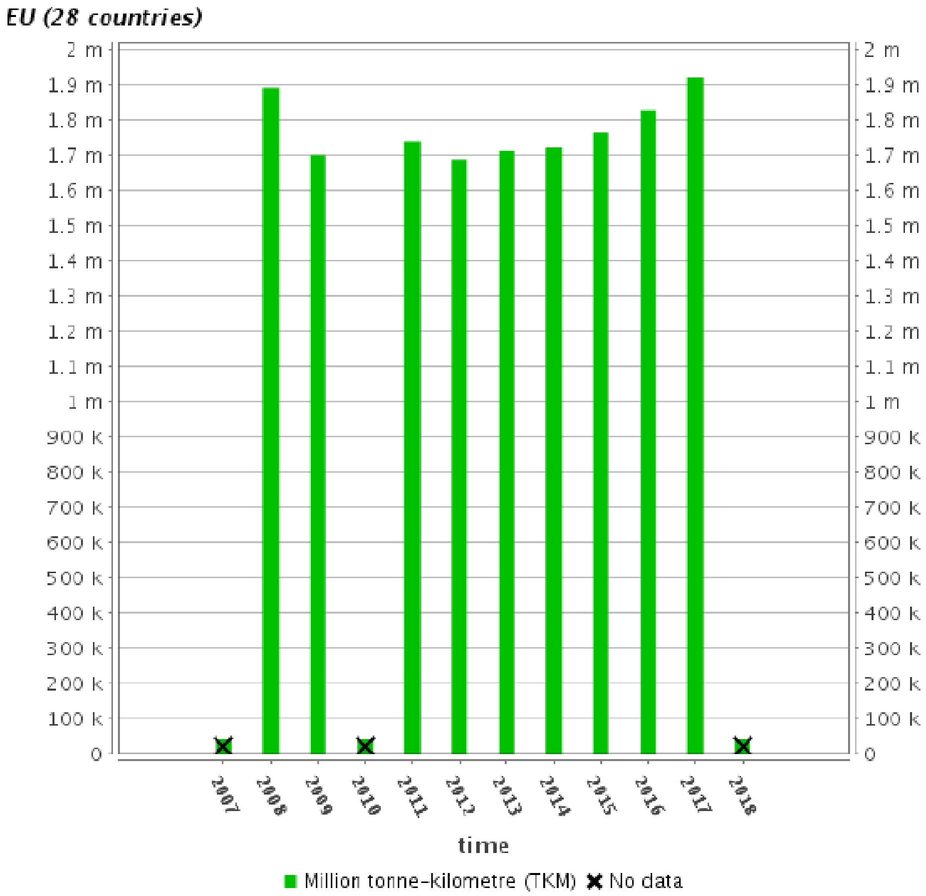
Road freight transport has traditionally been a transport mode used by many companies to carry out their business transactions, mainly due to savings in both time and cost, especially if we are talking about the intercity level. The freight intercity modal split is dominated by trucks, with about 45 percent of the tonne-miles in 2011. Also, when we talk about city transport, road is the most effective mode of transport, because of its flexibility and adaptability.

This intense use of road transport, especially in cities, leads to high pollution levels and bad air quality, which is an actual problem for big cities in which population density is high. This means that most research is focused on optimizing urban routes, rather than on interurban routes. However, as far as CO_2 emissions are concerned, they mostly occur on inter-urban routes, as will be seen later.



Graphic 3: Goods transported by road in Spain, units in tonne-kilometre (Data from Eurostats, 2018)

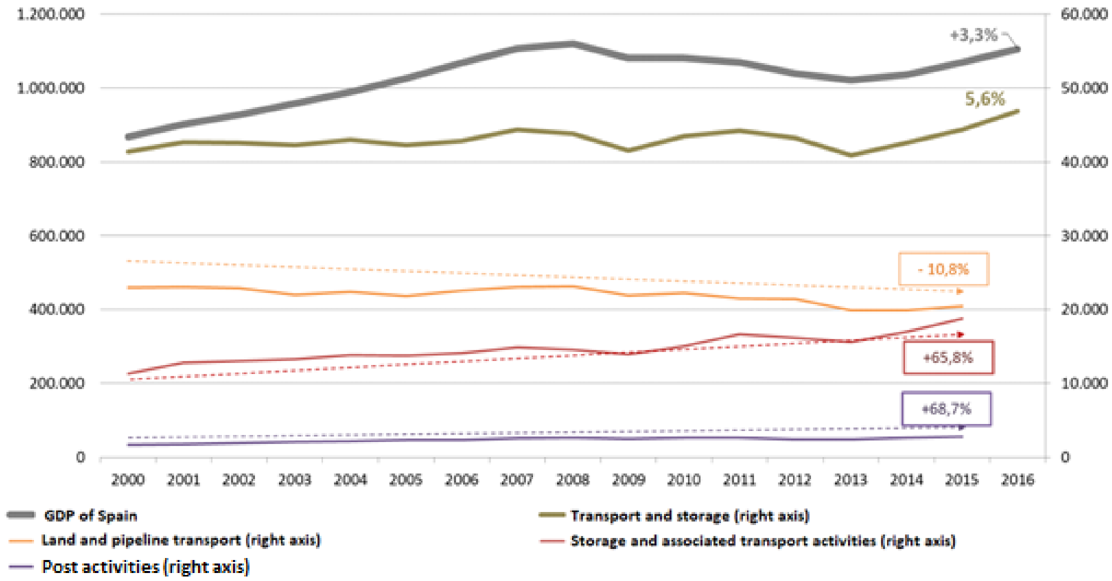
Graphic 3 shows how over the past 5 years road transport sector has a growing trend, after having declined sharply since 2008, due to the economic crisis. These results confirm the trend towards the recovery in activity shown by the sector, which advances towards its sixth consecutive year of growth and which closed 2018 with a rise of 4.6% (El Vigía, 2019). For the EU-28, there has also been a two-year decline since 2008, but there has been an upward trend in recent years. Graphic 4, which shows the carriage of goods by road by means of goods road medium and heavy-duty transport vehicles registered in the EU 28, shows this upward trend.



Graphic 4: Freight road transport in the UE (Data from Eurostat, 2018)

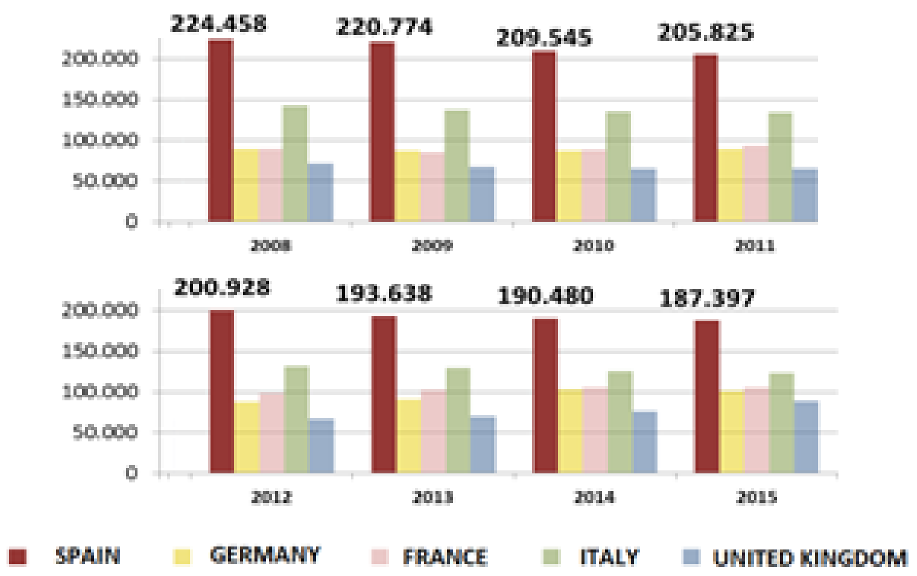
3.2. Sector importance in Spain

Road freight transport is a major factor in the Spanish economy. It also has strategic value as a reference point for transport change in general and as an instrument for dealing with the globalization of the economy. If we add up the entire "Transport and Storage" sector, the result is 5.6% of the Gross Added Value of Spain in 2016 and has been growing up in the lasts years, as can be seen from Graphic 5. In addition, within the "Transport and Storage" subsectors, the "Land and Pipeline Transport" subsector has the largest GVA, followed by the "Postal Mail and Ancillary Activities" subsector. (INE, 2018).



Graphic 5: Economic importance of road transport in Spain, units in million € (Graphic extracted from "El observatorio hispano-francés del transporte en los pirineos", 2018)

Another interesting fact is the number of companies related to the "Transport and Storage" sector. In the case of Spain, this number is significantly higher than in other European Union countries such as Germany, France, Italy or the United Kingdom, as the Graphic 6 shows.



Graphic 6: Number of companies related to the "Transport and Storage" sector (Graphic extracted from "El observatorio hispano-francés del transporte en los pirineos", 2018)

The traditional approach for associated activities is to reduce costs in order to increase profitability. In the case of transport, reduce the direct costs: cost of fuel, wages of drivers, etc. Environmental awareness is growing in society, governments, markets and other private entities. These organizations have become aware of the impact of its activities, such as transport, on society. This impact has the term 'externalities' (Demir et al., 2015).

3.3. The concept of external costs

Externalities or external costs arise when the social or economic activities of one group of people have an impact on another group of people. In addition, the first group does not compensate the second for the impact caused. (European Commission, 2019).

Transport externalities are differentiated between social costs and private costs. Social costs are all those costs that society faces due to the supply and use of transport infrastructure. Direct costs are the costs incurred directly by the transport user. The market does not encourage transport users to try to reduce social costs and therefore it has never been a primary objective for transport users to reduce them.

Externalities are not normally taken into account in transport user's decisions; however, internalization attempts to correct this anomaly by raising prices for transport services, in proportion to the cost to society and the environment. Internalization can be done by regulating transport activities (e.g. control measures) or by giving incentives to transport users (e.g. charges, emission trading, taxes, etc.). It is therefore very important for internalization to impose a value on the external costs of transport.

It is possible to attribute a monetary value to externalities in different ways. One of them, called the 'damage function', assesses the damage that transport activities cause to the environment; on the other hand, it can also be done by estimating the cost of avoiding these damages. The impact of these externalities is great. In 2008, the total external costs of transport in EU-28 amount to more than 5–6% of the total GDP (Van Essen et al., 2011).

According to Levinson et al. (1998), Spellerberg (1998) and Santos et al. (2010) the most significant negative external costs in relation to transport are:

- → Emissions (air pollution and greenhouse gases)
- → Noise
- → Water pollution
- → Congestion
- → Accidents

In addition, the use of land for the construction of infrastructure is also becoming a source of concern, due to the visual effect it produces and its intrusion into ecosystems.

This section examines these various externalities and quantify its monetary value. Climate change is now considered to be the most serious environmental problems; therefore, the main focus will be on greenhouse gas (GHG) emissions from freight transport.

3.3.1. Accidents

There is not an agreed definition for the external accident costs. The European Commission define them as '*the social costs of traffic accidents that are not covered by risk-oriented insurance premiums*'. If the costs of an accident are not covered by the insurers, then they are considered as externalities.

Within the costs of accidents, there are 5 different types of costs:

- Human costs. This is a proxy for estimating the pain and suffering caused by traffic accidents in monetary value.
- Medical costs. This is the cost of the whole process for treating accident victims (hospitals, rehabilitation centers, general practitioners, nursing homes, etc.).
- Administrative costs. These are the costs of services at the accident site as well as the costs of legal proceedings.
- Production losses. These are the costs of the net value of the production losses caused by the accident.
- Material damages. This consists of the monetary value of damages to vehicles, infrastructure, freight and personal property resulting from accidents.

Taking all these costs into account, it is possible to know the impact of accidents, in monetary value. According to studies by the European Commission, the total cost of accidents for 2016 in the EU28 was 281 billion euros, of which 43 billion euros were caused by freight transport (European Commission, 2019).

3.3.2. Noise

Noise emissions can be defined as unwanted sounds which cause inconvenience, damage and distress in people (Goines and Hagler, 2007). Traffic noise is a growing environmental problem, supported by increasing urbanisation and increasing cargo volumes. The increase in transport generates a higher level of noise and the creation of large cities makes the number of people affected greater. As a result, the external costs of noise are increasing.

The main causes of noise within the transport activity are road, rail and aviation. Other means of transport such as inland waterways and maritime transport generate relatively low levels in sparsely populated areas and therefore their impact is considered negligible.

Frequent and prolonged exposure to transport-generated noise causes several pathologies which have been studied. Goines et al. (2007) show scientific evidence for problems caused by noise emissions. Some of these problems are:

- Ischaemic heart disease
- Stroke
- Dementia
- Hypertension
- Annoyance

As with accidents, it is possible to quantify the impact of noise emissions on society. These health problems have been measured and analyzed, and it can be established a value for the cost of the impact of noise in society. The cost generated by noise pollution in the EU-28 for 2016 was 17 billion, of which 14.5 came from road transport (European Commission, 2019).

3.3.3. Congestion

Traffic congestion, defined as 'traffic moving at well below the legal maximum speed' (Bern Grush et al., 2018), is common on many roads around the world, especially those near large cities. It happens when the number of vehicles which travel on the road increases or the roadway capacity decreases due to various reasons (e.g. reparation jobs, accidents, etc.). It is the cause of disturbances such as extra travel times for the drivers and freights, increased of the fuel consumptions and greenhouse gas emissions or higher vehicular crash rates (Qing Tang and Xianbiao Hu, 2019).

Traffic congestion in the United States in 2007 caused an additional 4.2 billion hours of travel and an extra 3.8 billion liters of fuel consumption (Schrank and Lomax, 2009). In Japan, about 8 billion hours per year are lost due to traffic congestion, and this amount corresponds to about 40% of the travel time (Ministry of Land, Infrastructure, Transportation and Tourism, 2015). Measuring the impact of traffic congestion is based on the value of lost time and excess fuel burn. The cost generated by traffic congestion in the EU28 for 2016 is 200.6 billion euros from passenger transport and 70.1 billion euros from freight transport (European Commission, 2019).

3.3.4. Emissions

The importance of measuring environmental impact is recognized globally, but due to its difficulty, no consensus has been reached on how it should be measured. On the one hand, it can be considered all those emissions from the time energy is produced to the time it is consumed by the means of transport, known as the Well-to-Wheel emissions. On the other hand, Well-to-Tank emissions is an average of all the emissions released into the atmosphere from the production, processing and delivery of fuel. Finally, the narrowest form of measuring emissions is to consider only those coming out of the vehicle exhaust pipe, known as Tank-to-Wheel. The latter will be the considered way for the realization of this work.

Vehicles emit pollution mainly because of the incomplete combustion process in their engines. If it were possible to achieve perfect combustion of hydrogen and carbon contained in both diesel and petrol, the result would be water and CO_2. However, combustion is not complete, and tailpipes emits pollutants such as hydrocarbons, carbon monoxide and nitrogen oxides (Holmen and Niemeier, 2003). Thus, this section will distinguish between pollutants and greenhouse gases (GHG).

The emissions can be divided into local, regional and global according to their scope. Local pollutants remain close to the source of the emission. Regional effects can occur far away from the source of the emission and affect wider geographical areas, sometimes spanning several adjoining countries. GHG emissions, on the other hand, affect the global atmosphere. The same pollutants, such as Sulphur dioxide or nitrogen dioxide, can have an adverse effect on the environment over differing distance ranges.

	SO_2	**NOx**	**CO**	**CH_4**	**CO_2**	**N_2O**
Global	X	X	X	X	X	X
Regional	X	X				
Local		X	X			

Table 1: Emissions classified by scope (Adapted from McKinnon et al. (2015))

a) Air pollution

Air pollution costs are one of the most analyzed externalities external cost categories. Since the 90s researchers from all over the world have worked on this topic and particularly at European level efforts are increasing in recent years to investigate air pollution.

The emission of pollutants causes several problems, but without any doubt, the most notable is the damage to people's health. It also causes other problems that are relevant, such as building and material damages, crop losses and biodiversity loss. The inhalation of air pollutants such as particles (PM10, PM2.5) and nitrogen oxides (NOx)can have chronic or severe effects on human health and affects various systems and organs. It leads to a higher risk of respiratory and heart disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks. Its exposure in both short and long periods is linked to premature mortality and lower life expectancy (Kampa and Castanas , 2008).

Acid air pollutants such as SOx or NOx, which cause acid rain, or ozone as a secondary pollutant, affects the quality of the soil and the growth of crops leading to agricultural losses. In addition, a high concentration of these substances in crops decreases their yield (Wei et al., 2014). As for the loss of the materials that cause, they mainly damage the facades of buildings by corrosion processes or by deposition of particles. As well, air pollutants can lead to damage in ecosystems, by acidifying soil, precipitation and water. In general, it can lead to decrease flora and fauna.

Table 2 shows the latest available data on emissions of the most important air pollutants. It presents the emissions (in tonnes) of the most determinative sectors.

	Total emissions	**Energy production and distribution**	**Energy use in industry**	**Road transport**	**Commercial, institutional and households**	**Industrial processes and product use**	**Agriculture**
Ammonia	69,095	442	391	1,278	572	162	64,615
Particles (< 5μm)	15,613	1,008	1,110	2,596	8,144	1,751	310
Particles (< 10μm)	27,942	1,319	1,303	3,647	8,535	7,995	3,928
Sulphur oxides	12,809	1,323	9,247	136	1,365	568	1
Nitrogen oxides	144,712	11,153	27,913	70,764	20,051	472	10,876

Table 2: Emissions of the most important air pollutants in tonnes (Data from European Environment Agency)

In order to better appreciate the impact of the road transport sector, Table 3 shows the individual percentage of each sector on the total emissions of each pollutant.

	Energy production and distribution	**Energy use in industry**	**Road transport**	**Commercial, institutional and households**	**Industrial processes and product use**	**Agriculture**
Ammonia	1%	1%	2%	1%	0%	94%
Particles (< 5μm)	6%	7%	17%	52%	11%	2%
Particles (< 10μm)	5%	5%	13%	31%	29%	14%

Sulphur oxides	10%	72%	1%	11%	4%	0%
Nitrogen oxides	8%	19%	49%	14%	0%	8%

Table 3: Emissions per sector (Data from European Environment Agency)

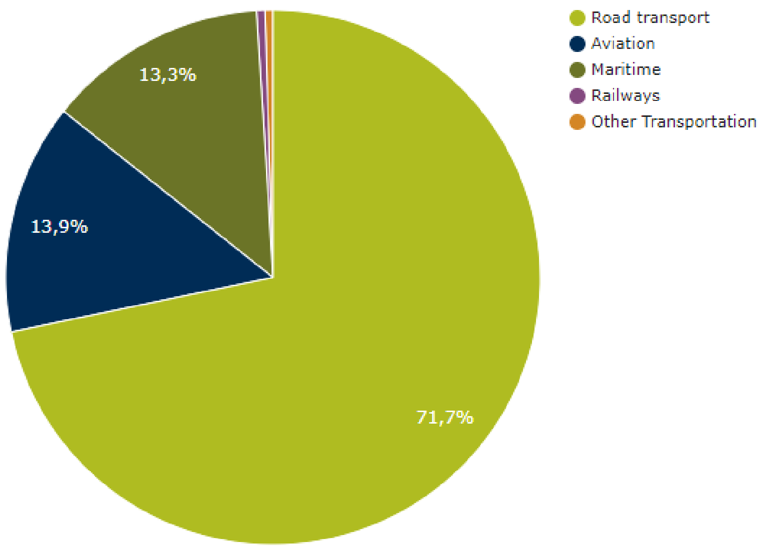
Data shows that road transport is the main emitter of nitrogen oxides (49%) and contributes substantially to particulate emissions (17% of fine particles and 13% of thick particles). However, the road transport sector does not contribute much to the emission of Sulphur oxides and ammonia.

The external costs of transport caused by air pollution estimated for 2016 were 32 billion euros, of which 29 billion euros were caused by road freight transport (European Commission, 2019).

b) Greenhouse gases

Transport emits many gases such as CO_2, N_2O and CH_4, all of which are greenhouse gases that contribute to global warming and climate change. According to the latest IPCC reports, if no measures are taken to curb greenhouse gas emissions, temperatures are expected to rise significantly by the end of the century. Furthermore, the sector is growing more rapidly than most others and its emissions are projected to double by 2050 (Creutzig et al., 2015).

In Europe, EU-28 countries have increased their GHG emissions in the transport sector since 2014. Between 2016 and 2017 emissions increased by 2.2%. In 2017, transport (including aviation and shipping) was responsible for 27 % of total greenhouse gas emissions in the EU-28. and road transport was responsible for almost 72 % of total greenhouse gas emissions from transport (including international aviation and international shipping). Of these emissions, 44% were from passenger cars, 9% from light commercial vehicles and 19 % came from heavy-duty vehicles. The second biggest emitting mode of transport was aviation, with a 13.9%, whereas maritime transport caused 13.3% of total greenhouse gas emissions. Other modes of transport such as railways caused much smaller emissions, as Graphic 7 shows (European Environment Agency, 2017).



Graphic 7: Share of transport greenhouse gas emissions (Graphic extracted from European Environment Agency, 2017)

As already mentioned, climate change is not only linked to CO_2 but also to other gases. Each gas contributes a different degree of greenhouse effect. For example, water vapor has a much greater capacity to retain heat in the atmosphere than CO_2, so it is necessary to consider the influence of each gas. Because of this, the concept of Global Warming Potential (GWP) is created. GWP is a relative measure that compares the amount of heat that can trap a given mass of gas with the heat that retains the same mass of CO_2 over the same period. Thus, the GWP value for CO_2 is 1. Some GWP values for different gases are shown in Table 4.

Gas	GWP
CO_2	1
Methane (CH_4)	28-36
Nitrous Oxide (N_2O)	265-298
Hydrofluorocarbons (HFCs)	140-11,700
Perfluorocarbons (PFCs)	6,500-9,200
Sulphur hexafluoride (SF_6)	23,900

Table 4: GWP for different gases (Data from Defra 2013)

It can be seen as CO_2 value is not as high as for other GHG, however is one of the most important GHG in global warming because of its high volume of emissions. The movement of freight caused approximately 10 % of energy-related CO_2 emissions worldwide and CO_2 accounts for around 96 % of all direct GHG emissions from road transport, thus the focus should be on the CO_2 element (UK Air Quality Archive, 2008).

The calculation of the external cost of greenhouse gases is complex. The consequence of the emission of greenhouse gases is the acceleration of global warming, which is the cause of natural phenomena such as melting at the poles, among others. These disasters are complicated to quantify in monetary terms. One way to estimate these externalities is based on the temperature increase allowed by the Paris agreement, which sets a maximum increase of 1,5-2ºC. A higher temperature rise poses too great a risk for future generations. The economic impact of European transport due to GHG emissions in 2016 was estimated in 23.43 billion euros, almost all because of road transport, 22.79 billion euros (European Committee, 2019).

3.4. Evaluation of external costs

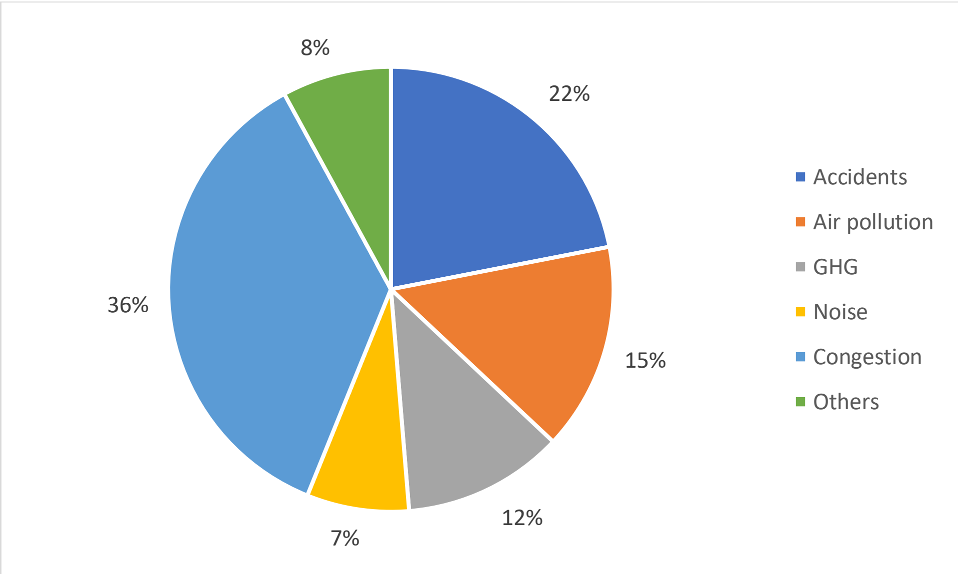
The above sections have analyzed the different types of externalities of transport and soma data about cost has been given. In this section the different externalities will be compared according to the economic impact they produce with road transport. The data provided by the European Committee for 2016 in the EU-28 have been used for this purpose.

	Road	Train	Vessel
Accidents	42,8	0,3	0,1
Air pollution	29,4	0,7	1,9
GHG	22,8	0,2	0,4
Noise	14,5	2,5	0,0
Congestion	62,3	0,0	0,0
Others	15,5	1,6	0,5

Table 5: Costs in billion euros of different modes of transport (Data from European Committee, 2020)

Data show that the impact caused by road transport is much greater (97,5% of total, excluding maritime and aviation) than the impact caused by rail or vessel transport, which seems logical, since the volume of cargo transported by reel is much higher. In order to be able to compare the efficiency of the different means of transport, the cost per Tonne-kilometre travelled is available (€-cent per tkm). The costs for rail transport are 1.3 €-cent per tkm in average. The costs for inland waterways are slightly higher (€-cent 1.9 per tkm) than for rail. Costs for road freight transport are 4.2 €-cent per tkm in heavy goods vehicles (HGVs) (3.2 times higher than for rail freight transport) and €-cent 3.4 per tkm regardless of congestion, which is 2.6 times higher than for rail. Within the road transport, the greatest external impact is generated by congestions, which account for 36% of the total cost. Then, emissions are the second most significant cost with 27%, of which 15% come from pollution and 12% from GHG. Accidents with 22% also have a considerable cost and finally noise with a slightly lower impact, 8%.

The total cost generated by transport in the UE28 for 2016 is of 17,1 billion euros, of which 14,5 billion are from the road transport and 2,5 billion are from the railway. Thus, almost 85% of the environmental impact is caused by road transport, nearly 15% railway and the impact caused by aviation is minor. (European Committee, 2020)



Graphic 8: Modal Split of External costs impact (Data from European Committee, 2016)

For Spain in particular, the cost of transport is 65.1 billion euros, or 5.2% of GDP. Of these 64.3 billion euros are caused by road transport, which has a cost per kilometer and tonne of 2.6 € for HGVs and 19.2 € for light commercial vehicles (LCVs).

3.5. Environmental policies

The Paris Agreement (2015) is currently in force and sets out a series of objectives that the developed countries, which are signatories to the agreement, must meet by certain dates. However, this agreement is the continuation of a series of pacts that some countries have been making for more than 30 years. It was in 1972, following a series of social movements, when the United Nations Conference on the Human Environment was held in Stockholm (Sweden). There, the member countries of the United Nations decided to create the United Nations Environment Programme (UNEP), concerned about environmental degradation. The talk about global warming and climate change began in the 1980s. In response to this concern, in 1988, the World Meteorological Organization (WMO) and the UNEP decided to create the IPCC, with the objective that it would compile all the scientific evidence existing to date on climate change and provide recommendations to countries.

The IPCC produced its first report in 1990 and that was when the United Nations General Assembly decided to prepare a United Nations Framework Convention on Climate Change (UNFCCC). In 1992, the Earth Summit on Environment and Development was held in Rio de Janeiro, Brazil. During this summit, two conventions were adopted that now govern environmental policies at the global level: The Convention on Biological Diversity (CBD) and the UNFCCC. The latter entered into force in 1994 and is supported by 196 parties. In order to make this convention operational, in 1997, the Kyoto Protocol was born. This instrument set out obligations for developed countries, aiming to reduce carbon emissions by between 5% and 8% between 2008 and 2012, compared to 1990 emissions. The Kyoto Protocol was the seed that developed the first legislation for a low carbon economy (Christiana Figueres, 2015). The Paris Agreement, adopted in December 2015, replaces the Kyoto Protocol from 2020 and reflects the urgency for countries to address the problem. This instrument brings together the measures agreed by countries to prevent the planet's temperature from rising above 2°C and ideally remaining below 1.5°C.

For its part, the European Union has established several objectives concerning transport, set out in the 2011 White Paper for Transport. Its purpose is to reduce greenhouse gas emissions from transport by 2050 to a level that is 60 % below that of 1990. This includes the intermediate goal for 2030 of reducing greenhouse gas emissions from transport by 20 % compared with 2008 levels, which is equivalent to an +8 % increase compared with 1990 levels. These targets for transport are monitored annually and are in line with the economy-wide targets of a 20% reduction in total greenhouse gas emissions by 2020 from 1990 levels and a 40 % reduction by 2030. Other regulations are monitored through the Transport and Environment Reporting Mechanism (TERM), which supports the achievement of these CO_2 targets. Figure 2 shows the CO_2 emissions in the transport sector, together with the targets set by the EU.

As far as the implementation of concrete policies is concerned, already in 2005, the EU launched a plan to try to reduce CO_2 emissions in all 28 member states. To this end, it established the general principle that the polluter pays. However, as it is not always possible to determine who is the cause of a given pollution, emissions trading was established. The aim is to create an economic incentive for factories to collectively reduce emissions of polluting gases into the atmosphere

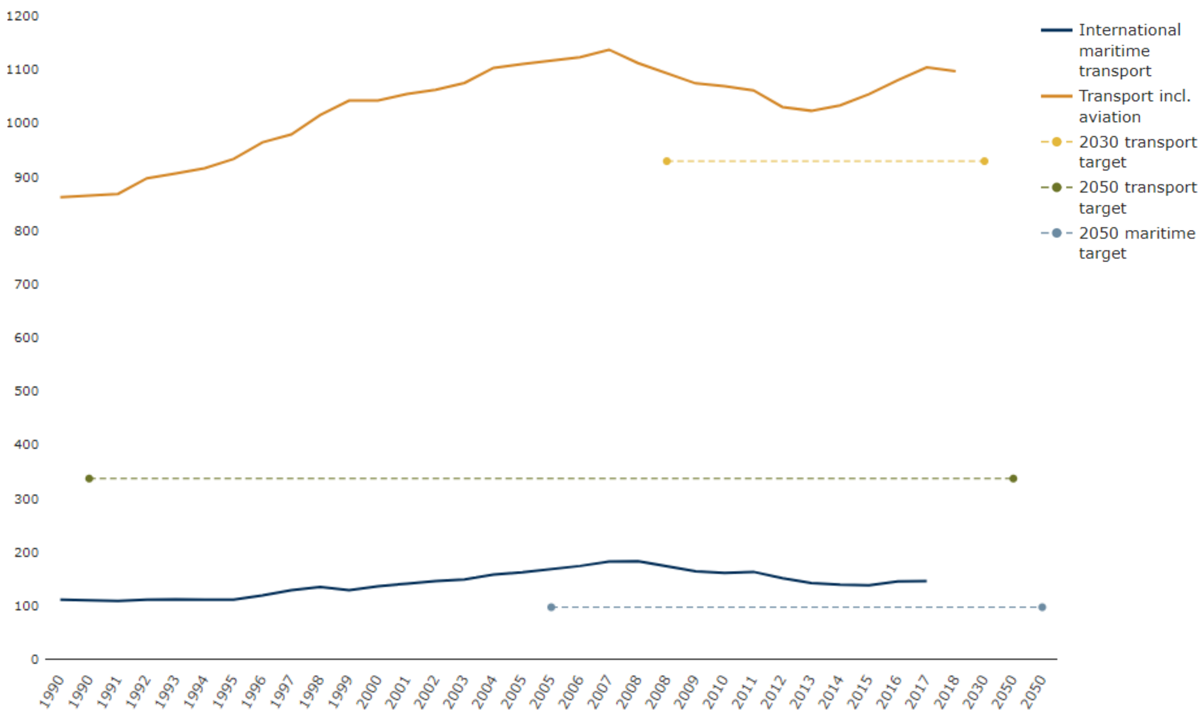


Figure 2: GHG emissions (million tonnes CO_2 equivalent) from transport and GHG emissions targets (Extracted from European Enviroment Agency)

4. Situation of road transport in Navarre

The Autonomous Community of Navarre is in the north of Spain, at the western end of the Pyrenees, and it maintains 163 kilometers of border with France. Its total area is 10,421 km^2 and it is bordered in Eastern by Aragon, Huesca and Zaragoza, in the South by La Rioja, and in the Northwest by the Basque Autonomous Community, Álava and Guipúzcoa.

4.1. Roads classification

Throughout this section, the present situation of Navarra's roads will be explained using the information available on the website of the Public Works Department of the Government of Navarre. The Road Network of Navarre, at the beginning of 2010, consists of 3821,73 Km divided in high capacity roads and ordinary roads. Moreover, within these two groups there are different roads, which are shown in the following Table 6.

TIPE OF ROAD	LENGHT [Km]
Highway	118,25
Freeway	223,74
Roads of high performance	50,77
Roads split up	25,60

General interest roads	232,34
Interest roads of the Foral Community	1021,04
Local roads	2149,99
TOTAL	3821,73

Table 6: Roads classification in Navarre

Freeways and highways are roads specially constructed, projected and signed for the exclusive use of automobiles vehicles and have the following characteristics:

- They have several lanes in each way of way and are separated of each other by a gap which is not set aside for circulation purposes.
- They are not crossed at the same level by any other road, cyclist cross, railway or any other infrastructure.
- The adjacent properties have no direct access to them.
- They are enclosed in both sides.
- They have an infrastructure for its access.
- Freeways do not have tolls, while highways do have.

Roads of high performance are the ones which have the following characteristics:

- They have one lane in each way and there can be distancing elements between the two ways.
- They have a significant percentage of the roads where there are two lanes in one of the two ways to facilitate the overtaking.
- The intersections with other roads are preferable through connection at a different level.
- There is not longitudinal enclosing excepting specific sections.

Roads split up are generally urban roads which have the following characteristics.

- The have different lanes in each way, separated between each other by a central urban reservation, by a gap which is not set aside for circulation purposes or by longitudinal physical elements, except some section.
- Its intersections are preferable at the same level, as a roundabout.
- There is not longitudinal enclosing excepting specific sections.
- They can have urban elements aside.
- They can e crossed by paths.

General interest roads are the ones which form the interregional network and support a significant volume of the traffic. The Interest roads of the Foral Community are the roads that without being general interest roads structure the connection inside the region of Navarre. Finally, the local roads allow the connection between more important roads and give access to populational nucleus. These three types of roads are known as conventional roads and have the following characteristics:

- They have one lane in each way.
- The intersection with other ways is preferable at the same level.
- The adjacent properties have direct access to the roads, limited to the design of the road.
- Without longitudinal enclosing.

4.2. Environmental constraints

Despite of being a small region, in Navarre there are coexisting three important geomorphological unities: the Pirenaic massif in the north, the Cantabric mountain range in the northwest and the Ebro valley in the south. This three give rise to a territory with great topographic and climatic contrast and to a great diversity of natural environments between north and south.

In Navarre there are several protected natural areas:

- 3 natural parks (64,933 Ha): 'Señorío de Bértiz', 'Urbasa-Andía' and 'Bardenas Reales'.
- 3 integral reserves (487 Ha): 'Lizardoia', 'Urkedi' y 'Azparreta'.
- 38 nature reserves (9,178 Ha), such as 'Larra'.
- 28 natural enclaves (931 Ha)
- 2 natural recreational areas (459 Ha): 'Bosque de Orgi' and 'Embalse de Leurtza'.
- 14 areas for the protection of wildlife (2,815 ha), such as 'Arabarko' or 'Arrigorri'.

There are also two Wetlands of International Importance: Laguna de Pitillas and Laguna de las Cañas (Viana). In addition, the Government has proposed 42 Sites of Community Interest for integration into the Natura 2000 network, set up by the European Union for the conservation of biological diversity.

There are two Natural Parks of special interest for this study: 'Señorío de Bértiz' and 'Urbasa y Andía'. Both are very close to the roads that connect Pamplona with Irún. The natural park Señorío de Bertiz has a Surface of 2,040 Ha and it is placed in the north of Naverre, next to the Bidasoa river. This park constitutes a singular place because its landscape, being one of the few valleys of its nature. It presents a great altitudinal gradient and its vegetation and fauna are representative of the valleys from the Atlantic influence, although there are not endemic species. Urbasa and Andía are two mountain ranges with a wide range of geological, biological, ecological, and socio-cultural values. They are placed in West Navarre and it is an area where the Atlantic ecosystem, from the north, and the Mediterranean, from the south, join. This creates an ecosystem with very diverse fauna and flora. The park also constitutes a big sub terrain aquifer, its drain flows to the surface through river sources such as Urederra's.

The pollution can damage this ecosystem, which in some cases they are noticeable vulnerable. For example, in case of water pollution, the areas of highest permeability with the greatest risk of aquifer contamination are mainly in the Sierra de Aralar, where there are also numerous points of geological interest, especially on its north side. Most of the territory is considered a wooded area, belonging mostly to public utility mounts. Furthermore, there are numerous grids with distribution areas of vulnerable and sensitive flora. About the fauna, there are two spaces classified as IBAS, one of them also belonging to the Natura Network as SPAs; in addition, up to seven UTM grids appear with species of endangered vertebrates. In the northwest there are grids with mink presence. With respect to the ecological connectivity, this region is constituted as the entrance of the Cantabrian corridor towards the Pyrenees. There are also important river corridors.

In this Northwest region, the main environmental values are those related to the natural environment, especially the flora and fauna, not only because of the biotopes present and their associated fauna, but also because they constitute important areas of green connectivity. In addition, the landscape in this area is constituted as an element of risk, as it has a unique quality and fragility. Also noteworthy are the river environments of the small rivers that flow into these valleys. In this way the concentration of risk in these prominent areas is considered particularly serious when assessing performances in this region.

A study carried on by the Goberment of Navarre, concludes that the highest environmental risk considered as 'sever' which correspond to the N-121 A, in sections Sunbilla - Etxalar, Etxalar - Bera, Bera - Endarlatsa and Endarlatsa Bridge. All of them present a high risk of affecting the hydrogeology, areas of high floristic quality, crossing mountains wooded public areas and areas of river environments, being close to a rivers and affecting the narrow valleys of the riverbeds in the area, so the risk of affecting connectivity is also high ecological associated with river environments. In addition, the high risk of affecting a landscape unit is highlighted of great quality and fragility (Sierras y Montes Vascos and the Navarran Pyrenees).

All these environments are protected by the Foral Law of Natural Spaces of Navarre, establishes a legal framework for Navarre, with the aim of protecting, preserving, and improving parts of its territory endowed with natural values worthy of protection. It should also be noted that in the region of the Basque Country there are two other Natural Parks: Aralar and Aiako Harri, which like the other two natural parks mentioned above have great environmental value.

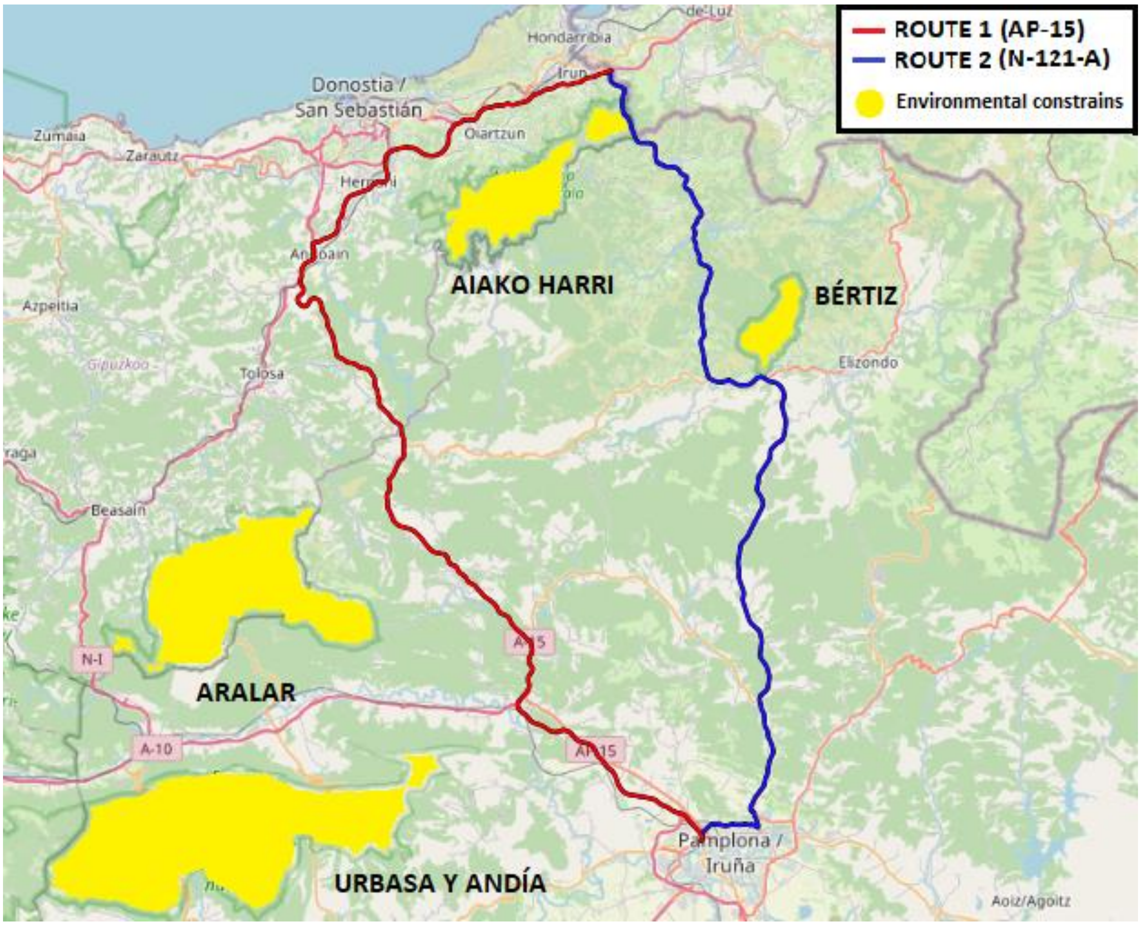


Figure 3: Location of the two routes and the nearby natural parks.

PART 2

5. Description of the problem

As has already been explained, the need to give importance to the environmental problem, in addition to the mere economic cost, is already a reality and the policies being implemented by the European Union are beginning to seriously affect businesses. With them, environmental responsibility becomes an important factor to take into account for the businesses of the sector.

A major challenge in this paper will be to carry out a comparative study of the environmental impact of freight transport, based on the fuel consumption of heavy trucks on two different routes which connect Pamplona with Irún. The alternatives considered in this work are analyzed in the following section. The situation surrounding the two routes will also be described. Firstly, Trans-Pyrenees transport, since both routes end at one of the most transit points for freight trucks, Irún. On the other hand, mention will be made of a current conflict affecting one of the affected alternatives.

5.1. Trans-Pyrenees transport

The Pyrenees are a mountain range of about 425 km located to the north of the Iberian Peninsula, which occupies the countries of Spain, Andorra and France. Its limits are, to the east, the Mediterranean Sea and to the west, the Cantabrian Sea.

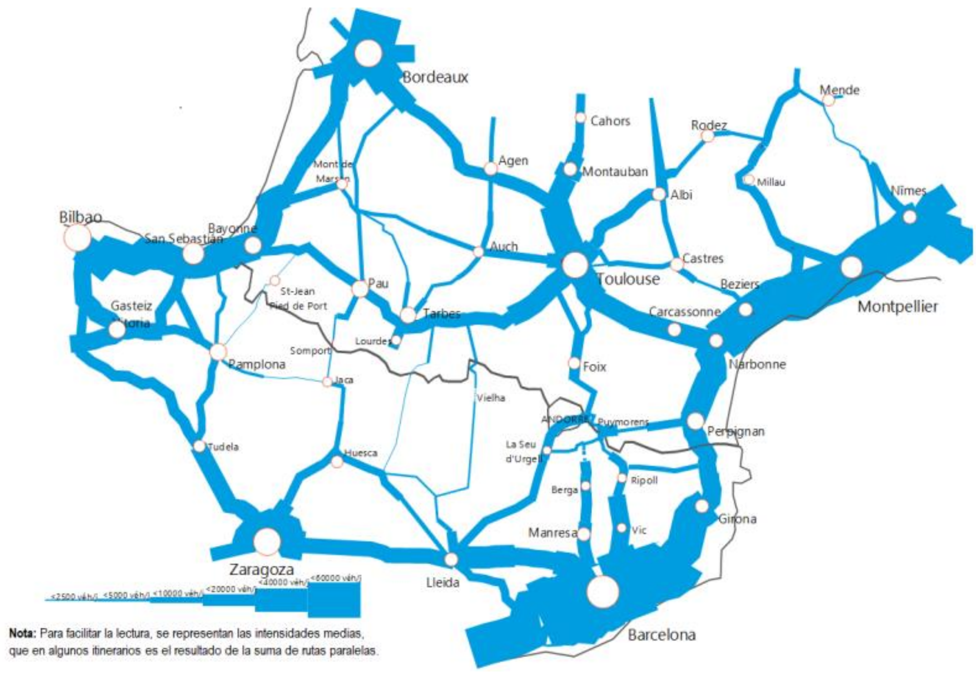


Figure 4: Average Daily Intensity (Extracted from 'Ministerio de Fomento', 2020)

This mountain range is a physical barrier between Iberian Peninsula and Europe, which complicates land trade. The area has received financial support and subsidies for example in the Common Agricultural Policy or in initiatives such as LEADER and INTERREG. The aim is to ensure that the area has comparable economic development to other zones. The Trans-Pyrenean routes are the gateway to a large number of products that arrive in Europe from the Iberian Peninsula, and many of them from other parts of the world or from other continents such as America or Africa

The connection between Spain and France is by roads of different categories, but the main routes that cross this border are 2 and the sum of the goods crossing these two routes is 95% of the total. The passage that accumulates the largest annual IMD is the AP-7 La Jonguera highway, where 32,280 vehicles passed by the Spanish side a day. Whereas 24,040 vehicles cross the AP-8 highway by Irún, according to data from the Ministry of Public Works. The latter, Irún, is the final point of the two routes to be studied in this project, which are traveled daily by freight trucks towards the border with France.

In the case of heavy goods vehicles, until 2008 heavy goods vehicles traffic was more important in the AP-7 than in the AP-8. From 2009 to 2011, the Atlantic route surpassed the Mediterranean route, but since 2012 heavy vehicle traffic on the AP-7 is again higher than that of the AP-8.

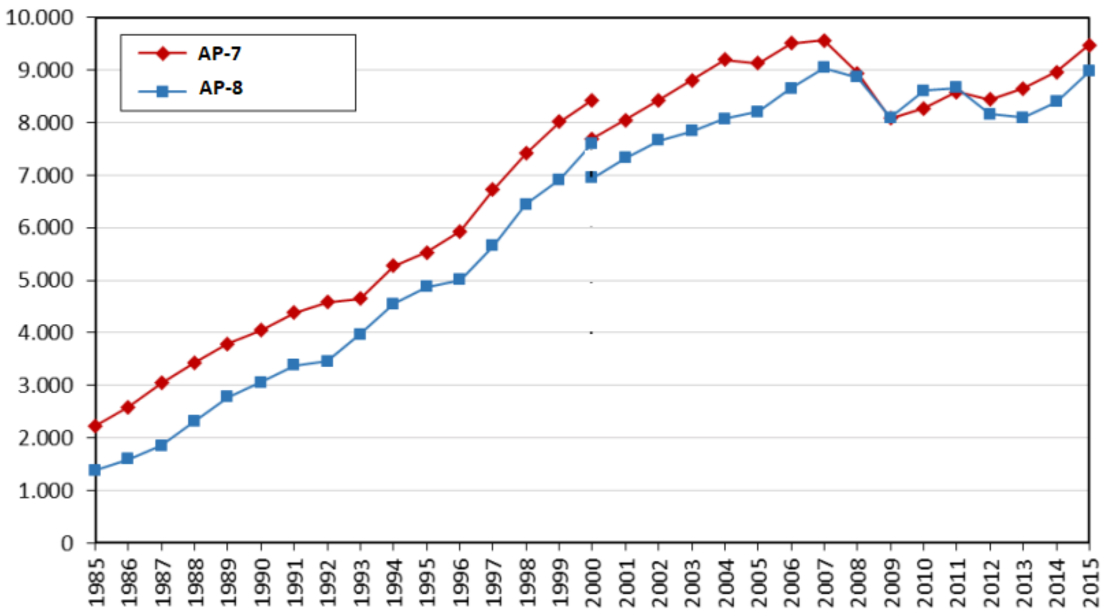


Figure 5: Heavy trucks per day in AP-7 and AP-8 (Extracted from 'El observatorio hispano-frances del transporte en los pirineos')

5.2. Alternatives

The two routes proposed in this project are the two main Trans-Pyrenees routes of the Autonomous Community of Navarre, whose strategic location as well as the good state of its roads, has made Navarra one of the most used border crossing points in the transport sector today. In addition, Navarra is not just a crossing point, there are a number of industries in Pamplona, which have to use these routes to export their products to Europe by road. The location of this the two routes is shown in Figure 6.

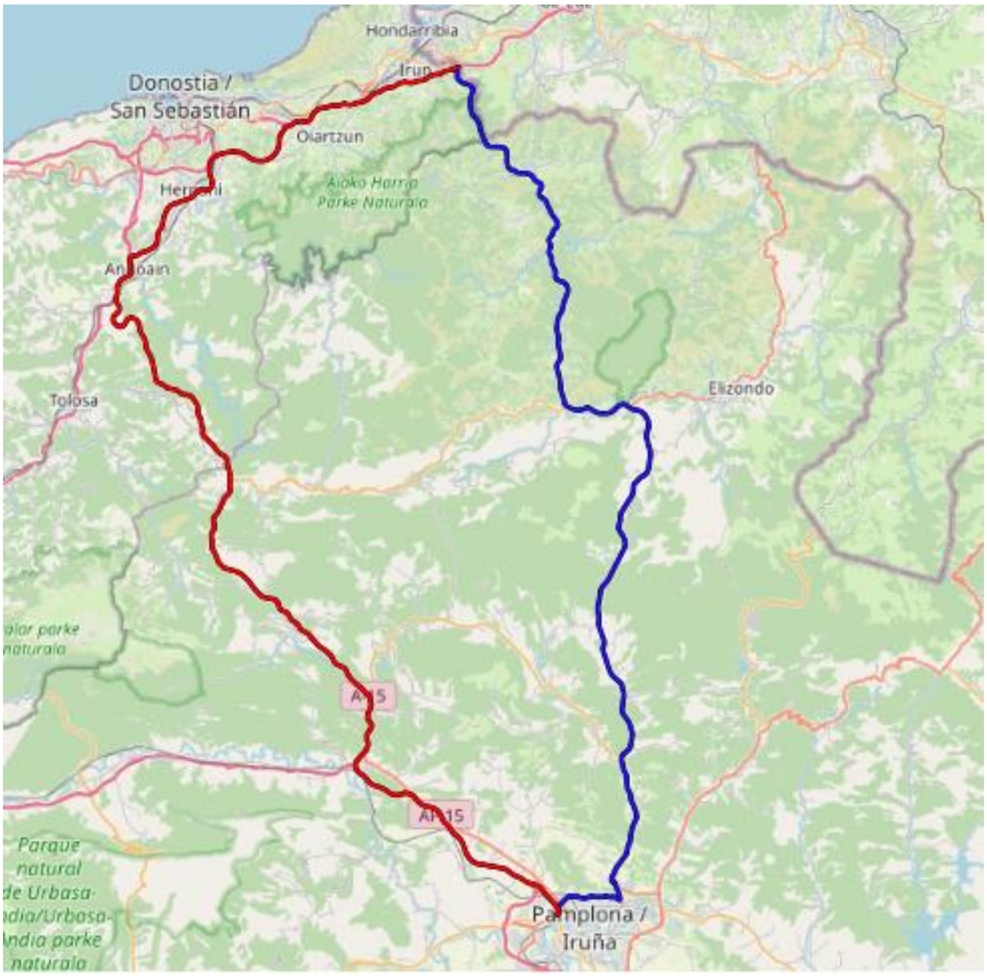


Figure 6: Location of the two alternatives (Route 1: AP-15, in red; Route 2: N-121-A, in blue)

Both routes connect Pamplona with Irún, but for the results to be as representative as possible, the same starting and ending point will be established on both routes. As a starting point, the beginning of the PA-34 road has been selected as it is a point close to the Landaben industrial estate, from where trucks will regularly depart towards the French border (Figure 7). The AP-8 border with France has been chosen as the final point, as this is the point at which trucks must pass on their way to Europe (Figure 8).

Figure 7: Map location of initial point

Figure 8: Map location of final point

5.2.1. Route 1. Pamplona- Irún via AP-15 motorway

This route has a total length of 94.3 km, its average speed is 88 km/h and runs mainly on the A-15, AP-15, AP-1 and A-P8 motorways. As this route is mainly on the motorway, the state of the road is good and there are two lanes for almost the entire drive. However, due to its configuration as a mountain motorway, snow, rain and fog make driving conditions complicated, hence there is a greater number of accidents than in a regular motorway.

The route begins on the AP-15 motorway for 15 km, until it reaches the A-15 motorway. The Leitzaran Motorway (A-15) is one of the main roads on the route. This is one of the strategic axes of Navarra's roads, that of "Pamplona - San Sebastián - France". This motorway has its origin in the motorway AP-15 at Irurtzun and it travels 28 kilometers thought Navarre. After another 16 kilometres through Gipuzkoa, it connects in Astarriaga with the A-I motorway to Irún. It is 44 kilometers long in total and was built between 1989 and 1995. During its construction there was a debate as the motorway runs at a high altitude, which means slow traffic, with higher fuel consumption, and more dangerous for trucks. The route ends on a stretch that runs along the AP-1/AP-8 for 20 km, until it reaches the border with France, naturally delimited by Bidasoa river.

Table 7 shows the Average Daily Traffic (ADT) of vehicles measured in 3 measuring stations A-15 motorway.

Pkm	ADT	Light	Heavy	% Heavy
118.02	15702	13001	2701	17.19
131.75	14627	11962	2665	18.21
138.86	15028	12442	2586	17.21

Table 7: AP-15 data (Data from Public Work Department, 2018)

A point to consider by the companies that send their trucks to the border with France, is that there are two payment sections on this route: the AP-15 and the AP-8. This is one of the main reasons why today many companies are looking for alternative routes to avoid these payment tranches.

5.2.2. Route 2. Pamplona- Irún via N-121-A road

This route has a total length of 76.0 km, its average speed is 77 km/h and runs mainly on the N-121-A road. It is the main communication axis in the north of the Navarra region, as well as an alternative to toll roads for journeys between Madrid and Western Europe. Its construction is old, but it has recently been renewed for conversion into a fast track.

Table 8 shows the ADT of vehicles measured in 6 measuring stations of N-121-A road.

Pkm	ADT	Light	Heavy	% Heavy
10.44	10461	8479	1982	18.92
12.93	10690	8311	2379	22.26
27.99	7242	4770	2471	34.13
41.72	7793	5696	2097	26.91
50.00	7710	5511	2199	28.51
65.33	10924	8158	2766	25.32

Table 8: N-121 A data (Data from Public Work Department, 2018)

On average about 10,000 vehicles travel daily on the N-121-A, 25-30% of them heavy, some 2,400 trucks. This traffic density, together with the rugged terrain complicates traffic on this road. According to an accident study from 2009 to 2014, the track recorded a total of 786 accidents, 53% due to collisions.

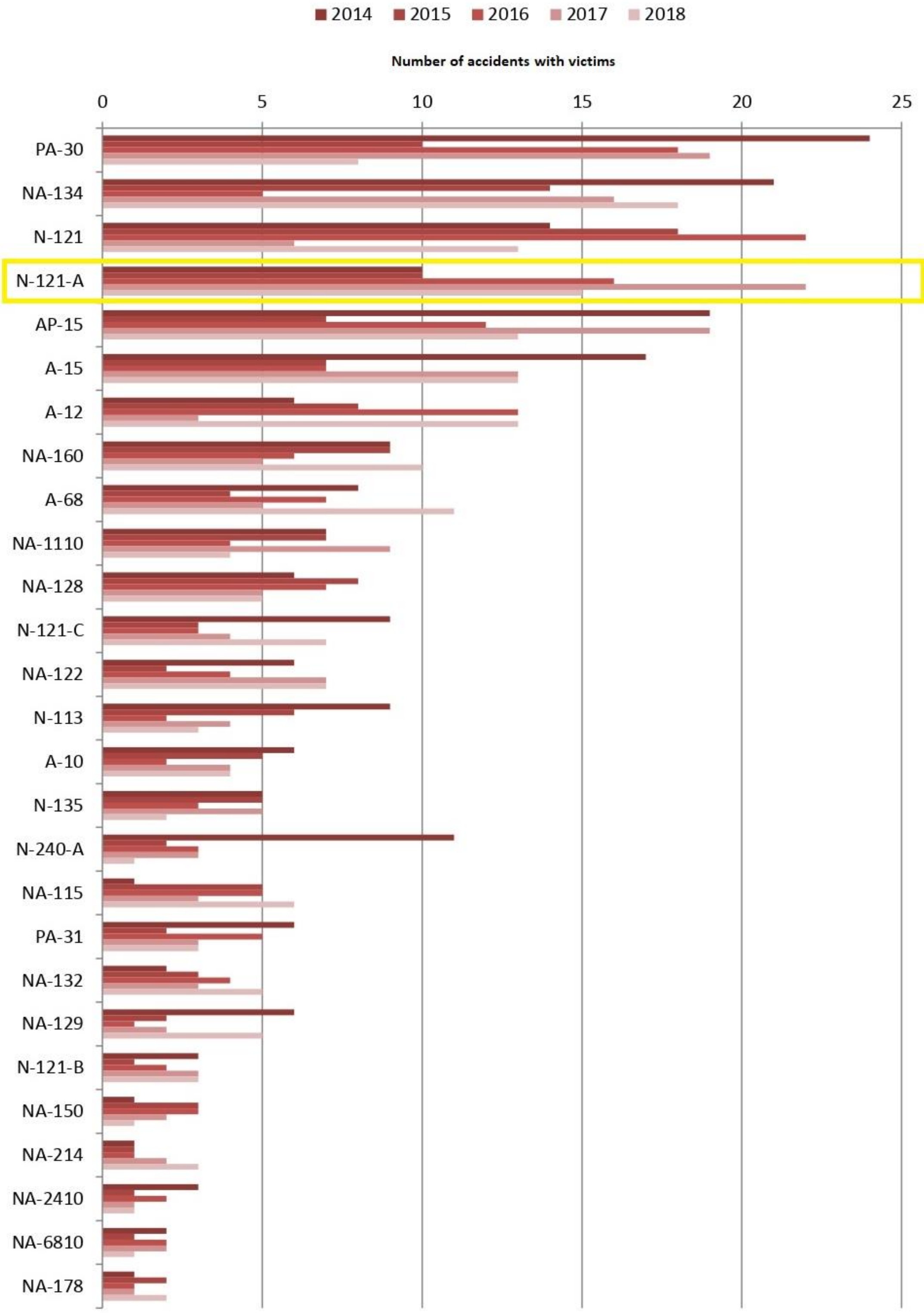
5.3. Current conflict and discussion

The N-121-A is the road in Navarre with the most accidents. On average there are 130 accidents per year, according to a report by the Traffic and Road Safety Department of the Foral Police. This report shows data of accidents occurred in N-121-A road between the years 2010-2019 (Table 9), which show an increasing trend, with an increase of 12.4% in the last year 2019.

Year	Number of accidents
2010	123
2011	135
2012	114
2013	139
2014	122
2015	109
2016	128
2017	140
2018	137
2019	154

Table 9: Number of accidents per year in N-121 A (Data from Traffic and Road Safety Department of the Foral Police, 2020)

With respect to accidents involving victims, the N-121-A road is one where most accidents with victims occur, as Graphic 9 shows.



Graphic 9:Number of accidents with victims in Navarre (Graphic extracted from 'Resumen tráfico y accidentes 2009-2018')

This very high number of accidents has led local councils in the area to request the diversion of heavy vehicles. These local councils intend to convince the Government of Navarre that it is necessary to remove heavy trucks from the road and divert them by other alternative routes, mainly the Leitzaran motorway (A-15). However, associations such as Anet and Tradisna, linked to the transport sector, have repeatedly argued against diverting heavy trucks, arguing that they are not responsible for the high level of accidents on the road.

For its part, the government of Navarre has authorized a project for the reform of the road, which will be carried out in the almost 63 km of the road. The aim of this reform is to improve road safety and operation on this road.

6. Road transport emission models

This section will describe the different emission calculation models to be used, but firstly some general concepts of emission models will be introduced.

In this project the paper by E. Demir et al. *A comparative analysis of several vehicle emission models for road (2011)*, which compare several models, and assess their respective strengths and weaknesses, has been used to consult such of these models.

6.1. General concepts of emission models

It is possible to estimate emissions or fuel consumption using a variety of analytical emission models, which differ to each other in the parameters they consider or in the type of route made.

Calculations of road transport emissions as part of pollution and environmental impact studies, have been made in some European countries since the 1970s. The methods used have been improved and developed since then, mainly depending on the amount, type and quality of data available.

There have been implemented several types of models and below is a classification of them according to various aspects:

- Car or truck models. Depending mainly on the calibration parameters used in the functions, models can predict car or truck emission.
- Fuel consumption or emission model. There are models which provide an estimation for the fuel consumption, petrol or diesel, of a certain vehicle in mL or g. But there are also other models that estimate the mass of a certain emitted compound, such as the amount of CO_2 or NOx emitted, among others.
- Macroscopic or microscopic. Macroscopic models use average parameters and data to estimate fuel consumption, while microscopic models use instantaneous

values for fuel consumption and emission rates. All microscopic models are based on instantaneous vehicle kinematic modal variables, such as speed and acceleration, or on more aggregated modal variables, such as time spent in each traffic mode, cruise and acceleration. This implies that microscopic models are generally more accurate than macroscopic models.

- Urban or highway. This classification is more ambiguous, but for example Ardekani et al. (1996) divide models into urban when the vehicle speed is less than 55 km/h and highway when vehicle speed is at least 55 km/h. Most of the research is made for reducing urban transport emissions, and therefore many of the emission models are approaching this type of routes.

In this work, truck models estimating average fuel consumption will be used. Some of models used in this work are focused on urban transport, despite the two alternatives are not entirely urban routes. Since they run through two different cities, they would be properly named inter-urban routes. However, these routes have several velocity changes and most of the way do not run thought highway or freeway. Furthermore, they are both less than 100 km long, what makes totally possible that these routes could be running through a big city.

6.2. Model 1: A four-mode elemental fuel consumption model

This model is described by Bowyer et al. (1985) in a refinement of Akçelik (1982). It is a model of fuel consumption, which consists of a set of functions to estimate fuel consumption for each of four models of driving: idle, cruise, acceleration, and deceleration. This model is useful for fuel consumption estimations on short roads sections. The calculation procedures and accuracy of fuel consumption depends on the available route data. The minimum parameters required to applicate the model is total section distance, cruise speed, stopped time and average slope. Some more parameters, such as initial and final speeds in each acceleration and deceleration periods, can be used to make better estimations.

It is common for many traffic modes to predict the number of stops, from which to know the acceleration and deceleration ranges. It is therefore important to define what a stop is. A stop is counted whenever the speed falls below a certain speed, dependent on the cruise speed. In this case the limit speed is established in 20km/h. Consequently, each time the speed falls below 20 km/h, a deceleration section and an acceleration section shall be considered.

In the routes that will be studied in this work, in neither of the two the speed will fall below 20km/h, being interurban routes. This implies that no stop will be considered and therefore there will be no acceleration and deceleration modes, only cruise modes. Cruise mode is defined as travel from the end of an acceleration which originated from a 'stop', to the start of the next deceleration which finishes at a 'stop'. The following function is used to estimate fuel consumption by a vehicle during cruise mode:

$$F_c = max\left\{\frac{f_i}{v_c} + A + B \cdot v_c^2 + k_{E1} \cdot \beta_1 \cdot M \cdot E_{k+} + k_{E2} \cdot \beta_2 \cdot M \cdot E_{k+}^2 + 0.0981 \cdot k_g \cdot \beta_1 \cdot M \cdot \omega ; \frac{f_i}{v_c} ; \frac{f_i}{v_c}\right\} \cdot x_c \qquad [1]$$

where:

$$k_{E1} = \begin{cases} \max\left\{\frac{12.5}{v_c}, 0.000013 \cdot v_c, 0.63\right\} & if \quad 0 > \omega \\ 1 - 0.3 \cdot E_{k+} & if \quad 0 < \omega \end{cases} \qquad [2]$$

$$k_g = \begin{cases} 1 - 2.1 \cdot E_{k+} & 0 > G \\ 1 - 0.3 \cdot E_{k+} & 0 < G \end{cases} \qquad [3]$$

$$E_{k+} = \max\{0.258 - 0.0018 \cdot v_c, 0.10\} \qquad [4]$$

The following table shows the parameters that appear in the functions given above and some default values given in the original paper, where the model has been extracted.

Parameter	Description	Unit	Default value
f_i	Idle fuel rate	mL/h	1600
A	Function parameter	mL/h	0.03
B	Function parameter	mL·h²/km³	0.00750
k_{E1}			-
k_{E2}	Calibration parameters	-	3.17
k_g			-
E_{k+}	Sum of positive kinetic energy changes per unit mass per unit distance during cruise	J/kg·m	-
β_1	Fuel consumption per unit of energy	mL·s²/kJ·m	0.090
β_2	Fuel consumption per unit of energy · acceleration	-	0.045
M	Vehicle mass	Kg	-
ω	Slope	%	-
x_c	Distance	km	-

v_c	Cruising speed	km/h	-

Table 10: Model 1 parameters

6.3. Model 2: A running speed fuel consumption model

This fuel consumption model, introduced by Bowyer et al. (1985), is an aggregated form of Model 1 and it estimates separately when the vehicle is stopped and running. It is a more aggregated model than the model described before since the acceleration, deceleration and cruise phases are lumped together.

The function for estimating fuel consumption when the vehicle is moving has the same form as function [1] described in Model 1 except that:

- Excludes the effects of stopped time
- The coefficients for the energy and slope terms are different due to different conditions for calibration.

The function is:

$$F_s = \max\left\{\alpha \cdot t_i + \left(\frac{f_i}{v_c} + A + B \cdot v_c^2 + k_{E1} \cdot \beta_1 \cdot M \cdot E_{k+} + k_{E2} \cdot \beta_2 \cdot M \cdot E_{k+}^2 + 0.0981 \cdot k_g \cdot \beta_1 \cdot M \cdot \omega\right) \cdot x_c \,;\, \alpha \cdot t_s\right\} \quad [5]$$

Where

$$E_{k+} = \max\{0.258 - 0.0018 \cdot v_c, 0.10\} \quad [6]$$

$$k_{E1} = \max\left\{0.675 - \frac{1.22}{v_c}, 0.5\right\} \quad [7]$$

$$k_{E2} = 2.78 + 0.0178 \cdot v_c \quad [8]$$

$$k_g = \begin{cases} 0.9 & 0 > G \\ 1 - 1.33 \cdot E_{k+} & 0 < G \end{cases} \quad [9]$$

The following table shows the parameters that appear in the functions given above and some default values given in the original paper, where the model has been extracted.

Parameter	Description	Unit	Default value
α	Fuel consumption per unit time per idling	mL/s	0.444
t_i	Stopped (idling) time	s	-
t_s	Time to travel along the total section distance	s	-

f_i	Idle fuel rate	mL/h	1600
A	Drag fuel consumption component due to rolling resistance	mL/km	30
B	Drag fuel consumption component mainly due to aerodynamic resistance	mL·m/s²	
k_{E1}, k_{E2}, k_g	Calibration parameters	-	-
E_{k+}	Sum of positive kinetic energy changes per unit mass per unit distance during cruise	J/kg·m	-
β_1	Efficiency parameter relating fuel consumption to energy provided by the engine	mL/kJ	0.090
β_2	Efficiency parameter relating fuel consumption to the product of inertial anergy and positive acceleration	mL·s2/kJ·m	0.045
M	Vehicle mass	Kg	-
ω	Slope	%	-
x_s	Distance	km	-
v_c	Average cruising speed	km/h	-

Table 11: Model 2 parameters

In the description of the model a comment is made on the way in which slope influence. It says that slope term will only accurately reflect the fuel consumption due to slope over short sections where the average slope is a true measure of the changes in grade. This is because positive slopes contribute fully to fuel consumption but, due to breaking, negative slopes sometimes do not contribute fully. Thus, over a long trip, the effect on fuel consumption of positive and negative slopes may not cancel each other out and this can result in underestimation of fuel consumption. In the article it is mentioned that the underestimation in fuel consumption can be up to 4%.

6.4. Model 3: A comprehensive modal emission model

This emissions model for heavy-good vehicles was developed in Barth et al. (2000, 2005) and Barth and Boriboonsomsin (2008), following the model of Ross (1994). In this emissions model, second-by-second tailpipe emissions are modeled as the product of three components: fuel rate (FR), engine-out emission indices ($g_{emission}/g_{fuel}$), and any emission after-treatment pass fraction:

$$tailpipe\ emissions = FR \cdot \left(\frac{g_{emission}}{g_{fuel}}\right) \cdot after\ treatment\ pass\ fraction \qquad [10]$$

FR is the fuel use rate in grams/s, engine-out emission index is grams of engine-out emissions per gram of fuel consumed and the after-treatment pass fraction is defined as the ratio of tailpipe to engine-out emissions. For this work the parameter to be obtained is FR, since from FR the fuel consumption will be calculated in order to be able to compare it with the other models described.

FR is a function of power demand and engine speed. Engine speed is determined based on vehicle velocity, gear shift schedule and power demand. The function is the following:

$$FR = \frac{\phi\left(k \cdot N \cdot V + \frac{P}{\eta}\right)}{44} \qquad [11]$$

Where,

Parameter	Description	Unit	Default value
ϕ	Fuel to air mass ratio	-	1/14.5
k	Engine friction factor	-	0.2
N	Engine speed	rpm	-
V	Engine speed displacement	L	2-8
P	Engine power requirement	kW	-
η	Efficiency for diesel engines	-	0.3

Table 12: Model 3 parameters, function [11]

The function for the engine speed is:

$$N = S \cdot \frac{R(L)}{R(L_g)} \cdot V \qquad [12]$$

Where,

Parameter	Description	Unit	Default value
S	Engine-speed/vehicle-speed ratio in top gear L_g	-	
R(L)	Gear ratio in gear L=1,...,L_g	-	-
v	Vehicle speed	m/s	-

Table 13: Model 3 parameters, function [12]

And the function for the engine power requirement is:

$$P = \frac{P_{tract}}{\eta_{tf}} + P_{acc} \qquad [13]$$

Parameter	Description	Unit	Default value
P_{tract}	Power demand function for a vehicle	kW	-
η_{tf}	Drive train efficiency	-	0.4
P_{acc}	Potency of accessories	kW	0

Table 14: Model 3 parameters, function [13]

The function for the power demand function, due to acceleration, grade, wind, and rolling friction is:

$$P_{tract} = (M \cdot a + M \cdot g \cdot \sin\theta + 0.5 \cdot C_d \cdot \rho \cdot A \cdot v^2 + M \cdot g \cdot C_r \cdot \cos\theta) \cdot \frac{v}{1000} \quad [14]$$

Where,

Parameter	Description	Unit	Default value
M	Weight	Kg	-
a	Acceleration	m/s^2	-
g	Gravitational constant	m/s^2	9.81
θ	Grade	rad	-
C_d	Coefficient of aerodynamic drag	-	0.7
ρ	Air density	Kg/m^3	1.2041
A	Frontal surface	m^2	2.1 - 5.6
C_r	Coefficient of rolling resistance	-	0.01
v	Vehicle speed	m/s	-

Table 15: Model 3 parameters, function [14]

7. Methodology

This section will describe the methodology used in the work, as well as the justification of the data used and their processing, together with the considerations taken. The main program that will be used for this work is Excel, with which the models described in the previous section will be implemented, but also the other computer tools will be used to carry out the work.

7.1. Data

For the correct application of the aforementioned models, a series of parameters are necessary. Each of the models has a series of different requirements, but in all of them it is necessary to know two fundamental facts: speed and slopes.

7.1.1. Speeds

Many factors influence the fuel increase of a vehicle, one of the most important is the speed. The ratio of fuel consumption to speed is exponential from certain values that depend on the type of vehicle. What happens is that from a certain speed, about 100 km/h, consumption increases much faster than speed. Therefore, it would be logical to think that the higher the average speed of a track, the more consumption it will require.

For heavy trucks, vehicles concerning this paper, the speed is limited to 90km/h in motorways and 80km/h in high performance roads and consequently they should not enter the exponential curve zone. In addition to this, at moderate speeds (not exceeding 90 km/h in these vehicles) something important for efficient driving is to try to select the gear to enable the engine to operate at the bottom of the maximum torque interval. This being so, the case in which we find ourselves, it foresees a lower fuel consumption at higher speeds (always below those allowed for these vehicles).

In order to determine the speed per leg on each of the routes, it has been assumed that the trucks will always go at the maximum permitted speed. It is therefore necessary to know the speed limits that are set along the two routes.

In Spain, the maximum permitted speed limit for heavy-duty vehicles of more than 3,5 tonnes is set according to the following criteria:

- 90 km/h, motorways and highways.
- 80 km/h, conventional roads marked as car tracks and on other conventional roads, provided with a 1.50 metres or more paved shoulder, or with more than one lane for any of the traffic directions.
- 70 km/h, rest of the roads out of urban.
- 50 km/h, urban roads.

The road map of the Michelin Guide has been used to determine the type of track on each section. In addition, with the route configuration tool on the official website of the Michelin Guide, it is possible to visualize the signposts appearing along the routes. This tool has been used, together with Google's Street View extension, to locate the sections where an exceptional speed reduction appears on the track, either by a dangerous curve, crossing roads, a roundabout, etc.

Following this methodology, a series of sections have been obtained for each of the two routes, which are shown in table x and table x. For route 1, the number of sections is small, as it runs almost entirely by motorway or motorway. For route 2, which is a road, the number of sections is greater.

Section	Start (km)	End (km)	Speed (km/h)
1	0.00	3.40	80
2	3.40	53.70	90
3	53.70	64.00	80
4	64.00	94.00	90

Table 16: Speed sections, Route 1

Section	Start (km)	End (km)	Speed (km/h)
1	0.00	0.30	40
2	0.30	0.70	80
3	0.70	0.72	60
4	0.72	1.10	40
5	1.10	2.21	60
6	2.21	2.50	40
7	2.50	2.90	80
8	2.90	2.92	40
9	2.92	3.62	80
10	3.62	3.82	40
11	3.82	4.43	80
12	4.43	4.63	40
13	4.63	5.23	80
14	5.23	5.43	40
15	5.43	6.54	80
16	6.54	6.84	40
17	6.84	7.45	80
18	7.45	7.95	70
19	7.95	8.82	80
20	8.82	9.36	70
21	9.36	9.76	80
22	9.76	10.20	70
23	10.20	11.40	80
24	11.40	12.00	50
25	12.00	12.50	70
26	12.50	13.00	80
27	13.00	13.40	70
28	13.40	14.00	80

29	14.00	14.40	70
30	14.40	17.10	80
31	17.10	17.70	70
32	17.70	18.50	80
33	18.50	19.00	70
34	19.00	26.00	80
35	26.00	27.00	50
36	27.00	35.80	80
37	35.80	38.40	70
38	38.40	50.20	80
39	50.20	50.80	70
40	50.80	52.10	80
41	52.10	52.40	70
42	52.40	65.00	80
43	65.00	66.00	70
44	66.00	76.00	80
45	76.00	76.50	40

Table 17: Speed sections, Route 2

To enter the speed data in the Excel table the Excel VisualBasic Programmer was used to create two functions, one for the speeds of Route 1 and one for the speeds of Route 2. The function returns the speed of the route according to the kilometer to be entered as an argument. The function code for Route 1 speeds is shown in the Annex.

For the speed function on Route 2 the same scheme has been followed, but with a greater number of sections. It is also shown in the Annex.

7.1.2. Slopes

The second determining factor in the vehicle's fuel consumption will be the slope of the track it runs on. When a heavy-duty vehicle is set to climb a slope, it is impossible for it to maintain a gear ratio and engine speed that allows efficient driving. The important thing in these cases is that the engine power is enough to keep the vehicle ascending. For this purpose, shorter gears are used to transmit a higher torque to the wheels, even if the speed is lower.

On the other hand, during the downhill slopes, the low speeds to be maintained for safety are also not good for vehicle consumption. The best thing for these vehicles is to drive with slopes close to zero.

A geographic information system (GIS) has been used to obtain the elevation profile of the routes. First, a vector layer containing each route is required. This can easily be done using Google Earth. Introducing the starting point and the end point, the application automatically proposes the two alternatives to study in this work and it is possible to save them independently in a vector file (.kmz). The other file needed to obtain the elevation profile is a map elevation mesh. The Opentopography database has been used to obtain it, which facilitates community access to high-resolution, Earth science-oriented, topography data. However, in some areas no data was available and in order to obtain topographic information for these areas, the spatial database of both communities through which the routes run has been accessed.

Once the layers are available, it is possible to enter them in the GIS. A free-use program called QGIS has been used for this work. QGIS is a framework for data collection, management and analysis. It integrates many types of data and it allows to analyze spatial location and organize layers of information into visualizations, using 3D maps and scenes. QGIS technology has been applied for environmental studies such as Park et al. (2019) or Meyer and Riecher (2019).

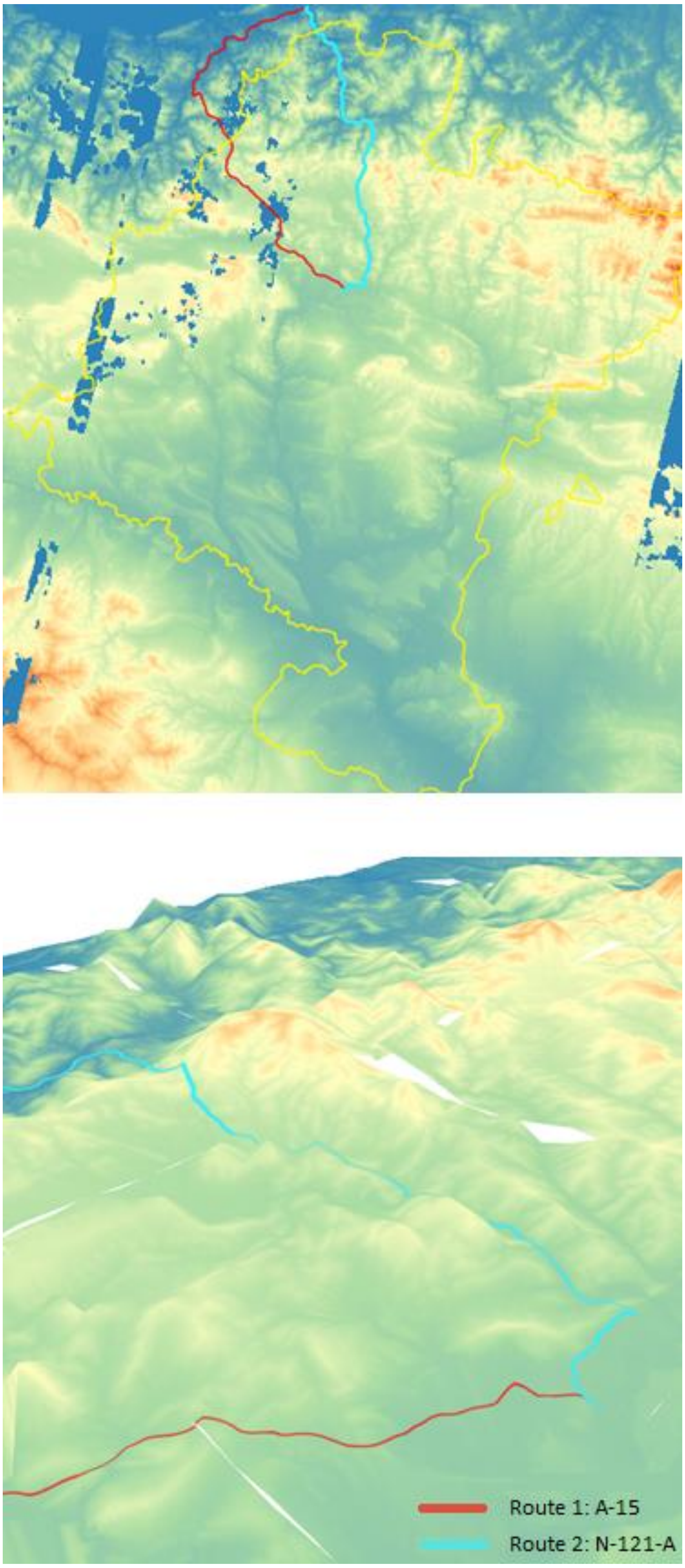
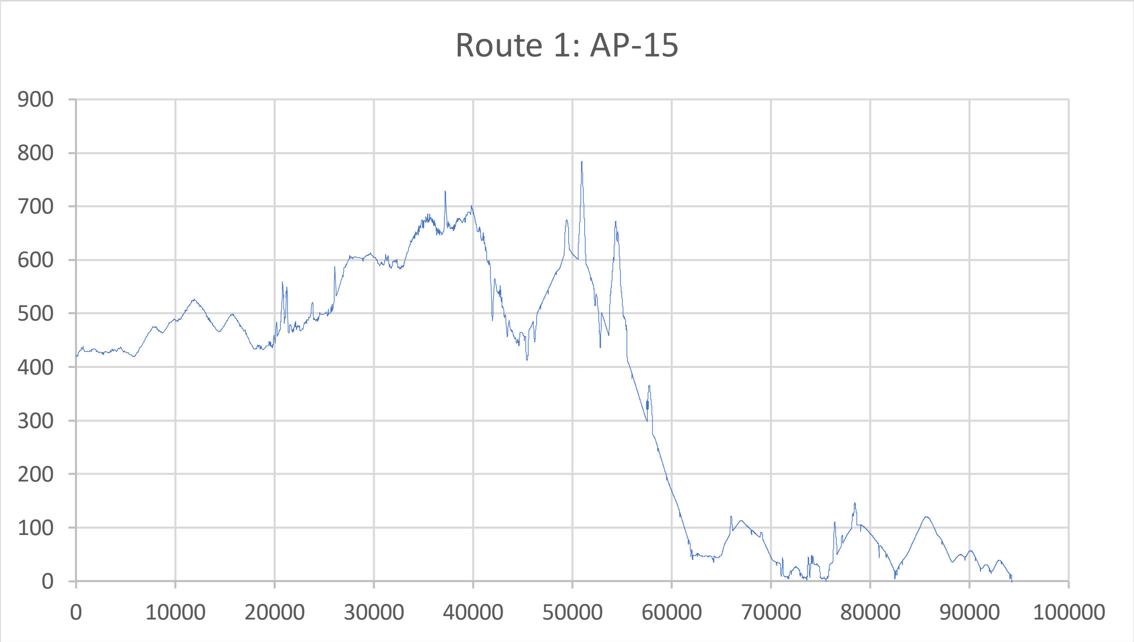
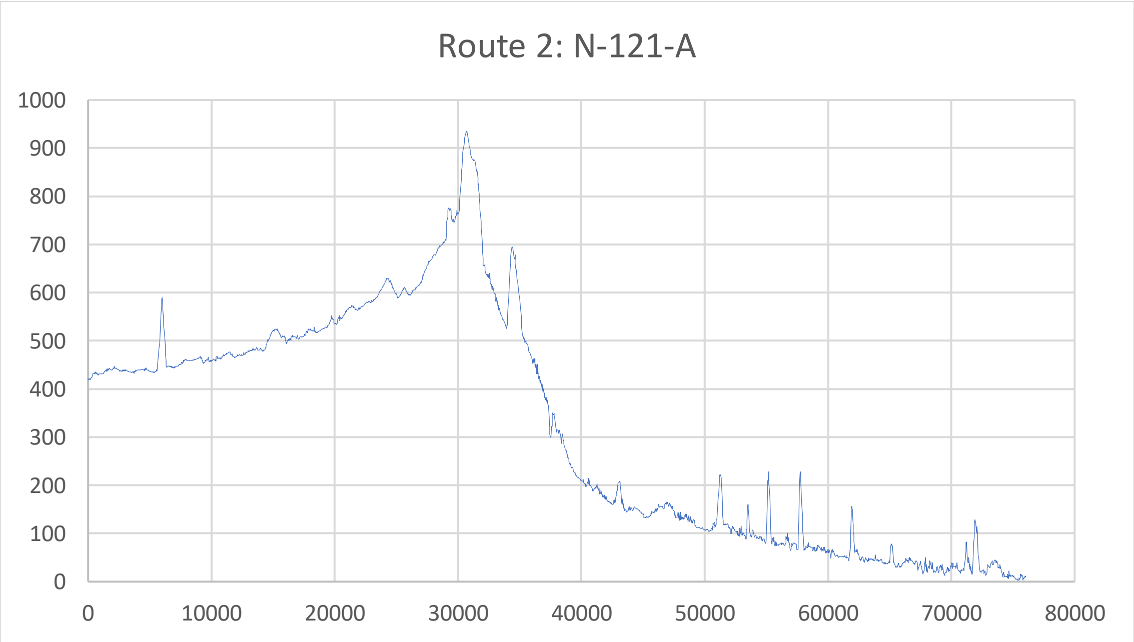


Figure 9: GIS routes view

Within QGIS is available the tool *Terrain Profile* to obtain the elevation profile of a route. On the one hand, it is possible to plot the elevation profiles in a graphic (Graphic 10 and Graphic 11).



Graphic 10: Elevation profile, Route 1



Graphic 11: Elevation profile, Route 2

On the other hand, it is possible to export a file with all points of the route. Each point has two values, the x-coordinate representing the distance travelled from the starting point of the route and the z-coordinate representing the absolute height of the point. Using these files and starting from the elevation profile extracted from the layer provided by Opentopography, the data provided by the other two layers have been entered into the sections where no data were available.

Most of the layer provided by Opentopography has been used as it was more accurate than the other two layers. Using the layers available in the geodatabases of the autonomous communities, the elevation profile obtained was too discontinuous. In addition, by using the same base layer for the two routes, there is a greater similarity between the data of the two routes. Otherwise, Route 2 would mainly make use of the data layer for the Community of Navarre, while Route 1 would have data from the layer of the Basque Country, which could alter the results.

7.2. Procedure

As mentioned above, the program used to implement the emission models has been Excel. In it, functions of each of the models along with the parameters necessary to obtain the estimate of fuel consumption have been introduced. The followed procedure will be explained below.

All models share a series of parameters that are always fixed along the two routes. These parameters are shown in Table 18. The value of some of these parameters is defined by the model itself and has already been mentioned in Section 6, while other parameters will be defined by the characteristics of the vehicle, which will be described later in section 7.4.

Parameter	Description	Default value
$\boldsymbol{A}$	Function parameter	0.03
$\boldsymbol{B}$	Function parameter	0.00750
$\boldsymbol{\alpha}$	Fuel consumption per unit time per idling	0.444
$\boldsymbol{\beta_1}$	Fuel consumption per unit of energy	0.090
$\boldsymbol{\beta_2}$	Fuel consumption per unit of energy · acceleration	0.045
$\boldsymbol{M}$	Vehicle mass	-
$\boldsymbol{\phi}$	Fuel to air mass ratio	1/14.5
$\mathbf{k}$	Engine friction factor	0.2
$\boldsymbol{\eta}$	Efficiency for diesel engines	0.3
$\boldsymbol{\eta_{tf}}$	Drive train efficiency	0.8-0.85
$\boldsymbol{g}$	Gravitational constant	9.81

C_d	Coefficient of aerodynamic drag	0.7
ρ	Air density	1.2041
A	Frontal surface	2.1-5.6
C_r	Coefficient of rolling resistance	0.01
k_{E2}	Calibration parameters	3.17

Table 18: Fixed parameters

However, the value of the rest of the parameters which appear in the model expressions varies along the routes, either as a function of the speed of the vehicle or as a function of the road slope. Therefore, in order to be able to estimate fuel consumption, routes must be discretized in sections whose track speed or road slope is constant. In this way the fuel consumption of the route is calculated as the sum of the fuel consumption in each of the sections created.

It has been decided to create as many sections as points have been exported from the GIS, so that the length of each section is the distance from the point in question to the beginning of the route, minus the distance from the previous point to the start of the route. An example is shown below in Figure 10.

Secction	X	Height	Tunnel/Bridge	Slope (%)	Speed (km	Lenght (km
1115	21443,728	572	FALSO	0,00000%	80	0,0440853
1116	21463,728	571	FALSO	0,00000%	80	0,0200008

Figure 10: Excel table configuration, 1

For each section, the slope has been calculated and whether the section is part of a tunnel or a bridge has been identified. The corresponding speed has also been determined for each section. In this way, 10189 sections have been obtained for Route 1 and 3418 sections for Route 2, in which the slope and speed is constant. The large difference between the number of sections of the routes is since the definition of one topographic layer is greater than that of the other, and therefore the number of points exported from QGIS is also greater.

The next step was to introduce the mathematical functions for estimating the fuel consumption of each model. For this it is necessary to calculate the value of the parameters that vary along the route. For each of the models, the non-constant parameters along the path are shown in Table 19.

Model 1	Model 2	Model 3
v_c	v_c	v_c
E_{k+}	E_{k+}	N

$\boldsymbol{k_{E1}}$	k_{E1}	P
$\boldsymbol{k_g}$	k_{E2}	P_{tract}
-	k_g	a

Table 19: Non constant parameters by model

Finally, the result of the Excel table is shown in the Figure 11. Each of the rows in the table corresponds to a section of the route, while the columns correspond to the non-constant parameters, as well as to the consumption of the stretch according to each of the models. The final consumption for each route estimated by each of the models is the sum of the resulting consumption in the discretized sections.

Secction	X	Height	Tunnel/Bridge	Slope (%)	Speed (km	Lenght (k	Model 1	Ek+ 1	Ke1 1	Kg 1
27	483,762	433	FALSO	2,00000%	80	0,026910211	0,010190602	0,114	0,9658	0,9658
28	506,703	433	FALSO	2,00000%	80	0,022941086	0,008687538	0,114	0,9658	0,9658

Model 2	Ek+ 2	Ke1 2	Ke2 2	Kg 2	ts	Model 3	Ptract	P	Engine sp	FR	a
0,010324961	0,15	0,65975	4,204	0,9	0,000336378	0,009914773	357,025518	420,0300212	1900	6,959404499	0
0,00880208	0,15	0,65975	4,204	0,9	0,000286764	0,008452392	357,025518	420,0300212	1900	6,959404499	0

Figure 11: Excel table configuration, 2

7.3. Simulations

As can be seen from the description of the different models, fuel consumption and the emission of polluting gases depend on a long list of factors. Therefore, different scenarios have been created in which some of these parameters are modified, to be able to analyze later their influence on consumption and emissions.

The most influential factor in the result is the mass of the vehicle, and therefore the load it carries. In this work they go to study heavy duty trucks, those that have the most weight. The gross vehicle weight rating (GVWR) is the maximum allowable mass of the truck when loaded, including the weight of the vehicle itself plus fuel, passengers, cargo, and trailer weight. Currently, trucks with a gross vehicle weight rating (GVWR) of up to 40 tonnes are allowed to circulate, but an extension of this limit to 44 tonnes is being assessed.

The different simulated scenarios have been set according to the state of loading of the truck. The load limit of a truck can be set either by the maximum weight it can legally carry or by the maximum volume it can carry (in the event that the goods are bulkier). In this study it has been established that the truck is fully loaded when the weight of the goods reaches the legal limit. This legal limit comes in the data sheet of the vehicle and for the chosen model is 24,000 kg. Together with the weight of the cab (9,190 kg) and considering that the semitrailer has a weight of 1000 kg, the total weight with 100% load is 34,190 kg.

Varying the percentage of the truck load 4 different scenarios have been proposed and in addition another scenario has been included, which simulates a truck whose GVWR is 44 tons, to analyze the possible improvements that this increase in the limit of the GVWR would bring. This last scenario is named as STruck.

To analyze the influence of speed and slope on each of the routes, simulations have been repeated by changing the data of speeds and slopes. On the one hand, the simulations have been repeated maintaining a constant speed of 70-110 km/h. This speed range has been set to check if there is an optimal speed for which the consumption is lower. According to Volvo Trucks recommends that for regional routes the most efficient cruising speed is between 80 and 85 km/h, so this affirmation will also be tested by these simulations.

On the other hand, the simulations have been repeated maintaining a constant slope of 0%, since it is the optimal slope of traffic for this type of vehicles. Thus, 15 scenarios have been proposed, which are shown inTable 20.

Case		% of load	Freight Weight (kg)	Total Weight (kg)
Regular speed Regular slope	1	25%	6,000	16,190
	2	50%	12,000	22,190
	3	75%	18,000	28,190
	4	100%	24,000	34,190
	5	STruck	33,810	44,000
Regular speed 0 % slope	6	25%	6,000	16,190
	7	50%	12,000	22,190
	8	75%	18,000	28,190
	9	100%	24,000	34,190
	10	STruck	33,810	44,000
Constant speed Regular slope	11	25%	6,000	16,190
	12	50%	12,000	22,190
	13	75%	18,000	28,190
	14	100%	24,000	34,190
	15	STruck	33,810	44,000

Table 20: Simulated scenarios

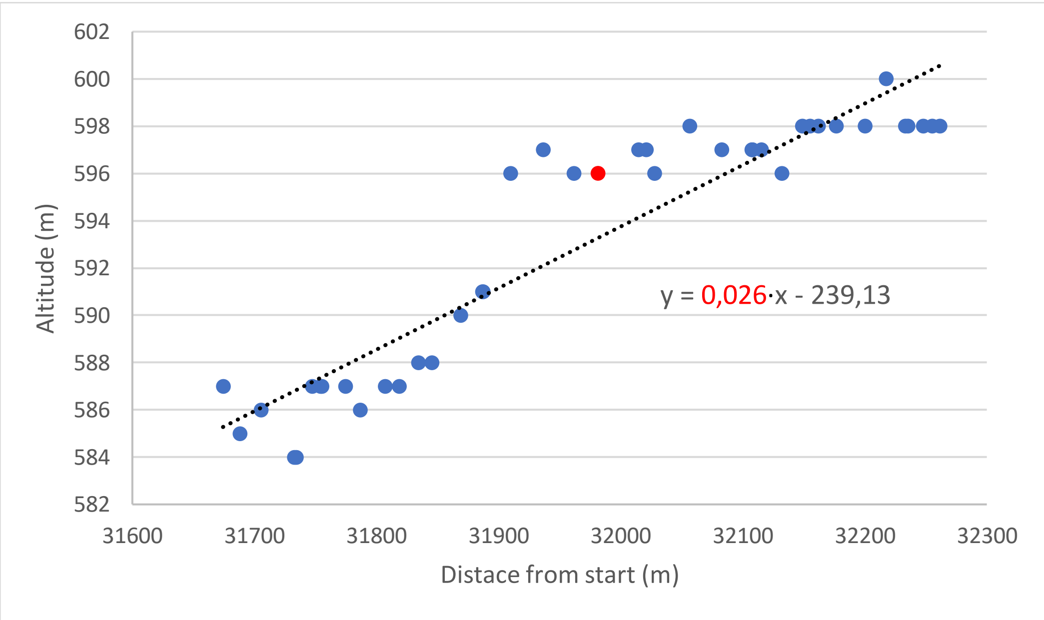
7.4. Assumptions

In order to carry out the comparison of emissions on each of the two routes, several considerations have had to be made. All of them will be cited and commented on this section.

7.4.1. Slopes

To calculate the slope of the different sections into which each route will be divided and to apply the fuel consumption models, it is necessary to make some assumptions or considerations.

Firstly, it is not possible to calculate the slope point by point. Data exported directly from the GIS provide us with topographic information of the terrain, not of the road. This makes the elevation profile obtained too steep to be considered directly from the road. With the purpose of finding a more accurate estimation, the slope at each point has been calculated considering at the same time the previous 20 points and the following 20 points.



Graphic 12: Slope calculation

In this case the slope has been calculated at kilometer 31.981 (red point) of route 1, whose height is 596 m. For this purpose, the 20 points before and after the point of km 31.981 have been used. These are all the points between km 31.674 and km 32.261, 587 m in total. With all of them the average slope is 0.026 or 2.6%. This procedure is easily applicable to all points exported from the GIS, around 4000, using the excel formula "SLOPE()" and introducing the desired points as an argument.

Another problem presented by the data extracted from the GIS is that they are not valid when the road runs through a tunnel or a bridge, since the data it shows are from the surface of the ground. For these cases it has been assumed that the slope is constant along the tunnel/bridge and its value is calculated considering the initial and final height, which is a close approximation to reality.

In order to carry out this task, all the sections with a bridge/tunnel have been located and the initial and final kilometer has been noted (Table 21 and Table 22).

Route 1		
Bridge/Tunnel	**Initial point**	**Final point**
1	19,500	22,000
2	23,500	24,500
3	37,000	38,000
4	41,800	42,500
5	43,000	45,000
6	45,200	47,000
7	49,000	52,000
8	52,300	53,300
9	53,800	56,000
10	57,500	58,500
11	66,200	66,800
12	71,000	72,000
13	73500	75,500
14	76,500	77,200
15	78,500	79,500

Table 21: Bridges and tunnels, Route 1

Route 2		
Bridge/Tunnel	**Initial point**	**Final point**
1	5280	6,440
2	28,000	32,400
3	34,000	35,500
4	37,200	38,300
5	42,500	43,800
6	50,500	52,000
7	53,600	54,400
8	55,000	56,000
9	57,900	58,600
10	62,200	63,000
11	65,000	63,000

12	71,000	73,100

Table 22: Bridges and tunnels, Route 2

Each of these sections has been entered in Excel as with the speeds and a column has been created showing the true value if the corresponding section is part of a tunnel and the false value if it is not part of a tunnel. Then, an expression has been implemented in Excel to be able to calculate the slope along the tunnel. The final expression for the slope column is as follows:

```
IF([@[Tunnel/Bridge]]=TRUE;  'The section is a tunnel

   IF(D19=FALSE;  'The previous section is not a tunnel, hence in this
section starts the tunnel

      INDEX(C20:C$10500;MATCH(FALSE;D20:D$3418;0))-
      [@Height])/(INDEX(B20:B$3418;MATCH(FALSE;D20:D$3418;0)
      )-[@X]);  'Function for the tunnel's slope

      E19);  'The previous section is a tunnel, hence the slope is equal

  ROUND(SLOPE(C1:C41;B1:B41);2))  'The section is not a tunnel, hence
  it is calculated as explained before
```

7.4.2. Acceleration

For model 3 it is necessary to know the acceleration in each section in order to estimate the fuel consumption. However, acceleration is a complex factor to identify and varies according to many other parameters, some known as the slope or the load of the vehicle, but others more complicated to consider, such as the driver's driving style.

Thus, an Excel formula has been implemented to take into account the acceleration factor. Negative accelerations have been found not to be influential in estimating consumption as this power is absorbed by mechanical brakes or motor brakes. For the estimation of positive accelerations, the ranges where there is an increase in speed compared to the previous ranges have been identified and the acceleration calculated assuming that the speed is reached after having accelerated for 1.5 km. The resultant formula is:

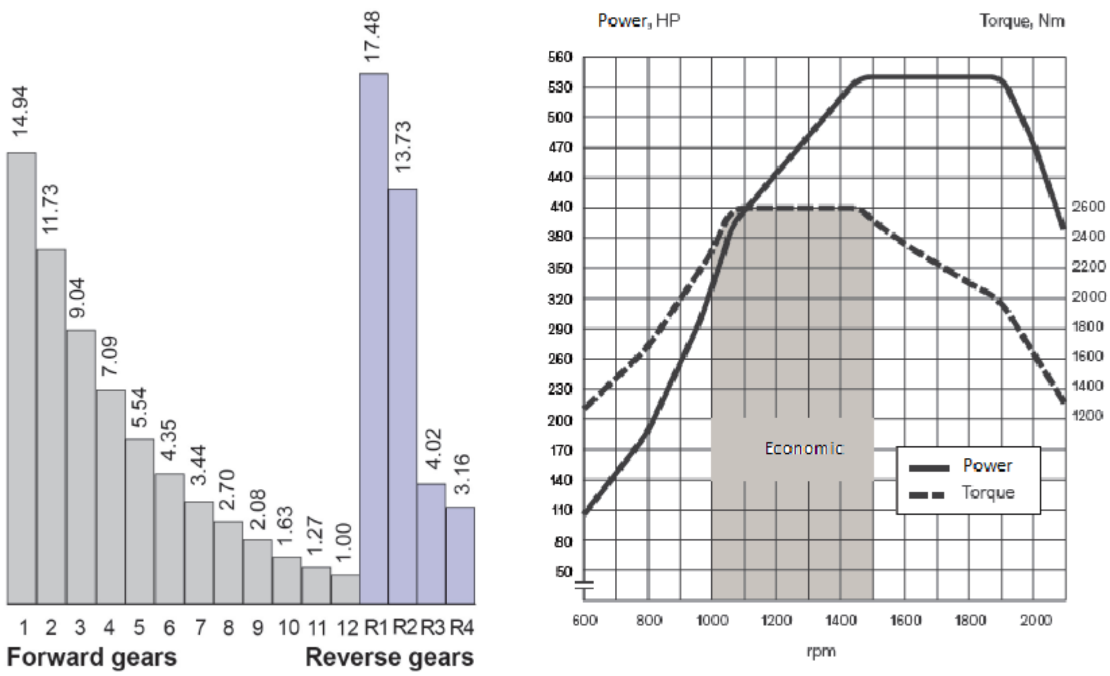
```
=IF.ERROR(IF(IFNA(MATCH(F22;F4:F21;0);0)=1;0;IF(((F22-
F4)/3,6/60)<0;0;((F22/3,6)^2-(F4/3,6)^2)/2000));0)
```

This expression assesses whether there is any change in speed in the previous sections using the formula MATCH and, in that case, the corresponding acceleration is calculated, using the fundamental equations of uniformly accelerated rectilinear motion.

7.4.3. Engine speed

One of the necessary parameters for Model 3 implementation is engine speed. To calculate its value according to the expressions indicated by the model, it is necessary to know the gear in which the truck is running at every time, as it follows the expression [12]. The selection of the gear at which the truck is moving depends on many factors and among them is the driver's driving mode. This makes it impractical to determine the gear in which the truck will be driving at any given point. Therefore, an alternative procedure to estimate the rpm at which the engine is running has been followed.

The procedure followed to determine the engine speed starts from three parameters that are known for each of the sections in which each route is divided. The first of these is the speed at which the truck travels; the second is the torque that has to reach the wheels to overcome the resistance opposed by acceleration, grade, wind, and rolling friction and the third will be the power required in each section. Also, it has been necessary to know some technical specifications of the truck, such as the development of the gearbox (Graphic 13), the reduction of the differential, the tire dimensions and the torque and power curves. These data are shown in detail in Annex 1.



Graphic 13: Gear development, torque and power curves

First, the truck speed at each of the gears has been calculated for the engine working range, from 1000 to 1900 rpm. The equation used is as follows:

$$v\left[\frac{km}{h}\right] = N \cdot \frac{2\pi}{60} \cdot r \cdot \frac{1}{i_n \cdot 3.09} \cdot 3.6 \qquad [15]$$

N is the engine speed in rpm, r is the tire radius, i_n is the gear ratio in gear n, 3.09 is the reduction in the differential and 3.6 is a factor to get km/h. Applying the formula we obtain the matrix shown in Annex 1, that indicates the speed in km/h for each gear, by stages of 50 rpm.

Then, the torque that reaches the wheels from the engine has then been calculated for each gear in the engine working range, using the torque-rpm curve. The equation is as follows:

$$T[N.m] = T_m \cdot i_n \cdot 3.09 \cdot \eta_{tf} \qquad [16]$$

T_m is the engine torque, i_n is the gear ratio in gear n, 3.09 is the reduction in the differential and η_{tf} is the drive train efficiency. Thus, the table shown in Annex 1 is obtained. For each section the minimum torque required at the wheels has been calculated from the power and speed of the vehicle, using the following expression:

$$T_w[N.m] = \frac{P_{tract}}{\omega} = \frac{P_{tract}}{\frac{v}{3.6 \cdot r}} \qquad [17]$$

Where P_{tract} is the tractive power in W, v is the truck speed in km/h and r is the wheel radius in meters.

Last parameter used is the power at the wheel, that is calculated using the following formula:

$$P_w[W] = \frac{P_e(N)}{\eta_{tf}} \qquad [18]$$

Where P_e , in Watts, is the engine power at a certain engine speed.

Once these parameters are known, it is possible to estimate the selected gear and therefore the engine speed by comparing the calculated parameters with the required in each section. First, the vehicle speed is compared whit the speed matrix by rows, so the first value of which speed is higher than the vehicle speed is selected. This corresponds to a certain gear and speed of the engine. Then, in the torque matrix, the torque corresponding to those gear and engine speed is compared with the torque required at the wheels (T_w). If the torque required at the wheels is higher than the torque at the selected gear and engine speed, a new value in the speed matrix is selected. If the torque required at the wheels is smaller than the torque at the selected gear and engine speed, the power given at the wheels at this engine speed is compared with the tractive power. If the power at the wheels is smaller than the tractive power, a new value in the speed matrix is selected. If the power at the wheels is higher than the tractive power, then the engine speed is suitable for the estimation.

With this method an excel Visual Basic function has been implemented. It is shown in Annex 1. Its arguments are both speed and torque matrix, the wheel power vector and vehicle speed, torque and tractive power. There are a few sections in which the combination of the speed, torque and power are too demanding. In these cases, a more powerful engine and with more torque would be needed. As this are very few cases, it has been supposed that the engine is working at the maximum possible speed, 2000 rpm. So, with this function called *Rev* a value for the engine speed is estimated for each of the sections in both routes.

7.4.4. Fuel consumption/Emissions

The three emission calculation models used in this work provide their estimates in liters of fuel, in this case diesel. To be able to compare the results provided by the different models with CO_2 emissions, it is necessary to establish a relationship between the fuel consumed and the quantity of gases emitted.

The conversion factor is established from the stoichiometric reaction of diesel combustion. However, the complete combustion reaction of diesel is too complex, therefore diesel has been considered dodecane. Thus, the adjusted reaction is as follows:

$$C_{12}H_{26} + {}^{37}/_{2}\ O_2 \rightarrow 12\ CO_2 + 13\ H_2O$$

The density of the diesel has been considered as 840.8 g/L. Thus, the ratio obtained is as follows:

$$1\ L\ Diesel = 2608.9\ g\ CO_2$$

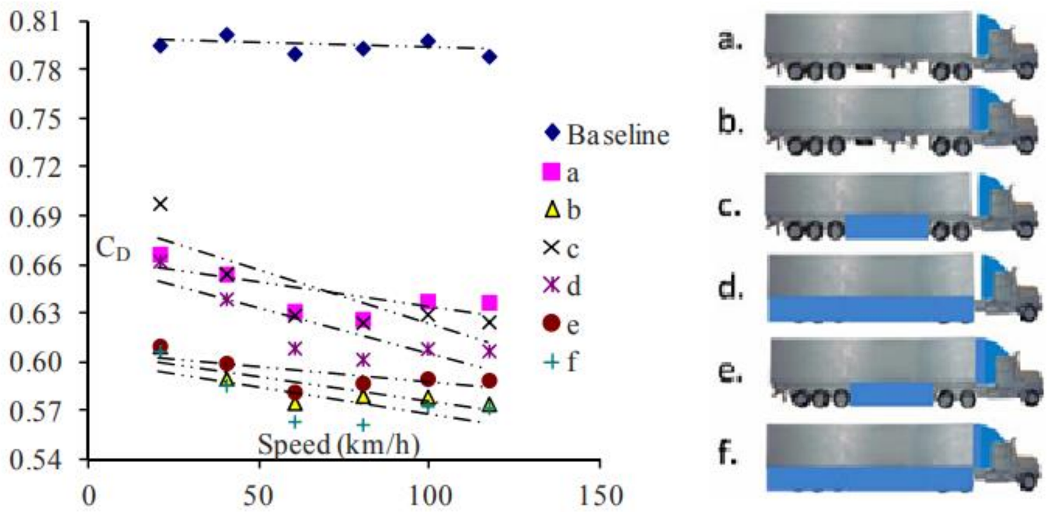
This factor indicates that the results obtained from the models are proportional to the grams of CO_2 emitted, and that it is therefore valid to compare fuel consumption in order to interpret the impact of routes at the level of emissions.

7.4.5. Truck parameters

To establish the fixed parameters that depend on the type of vehicle a specific truck model must be determined. The model chosen is the VOLVO FH 6x4 BITREN EVOLUTION PLUS 540, which has a power of 540 HP, a torque of 2600 Nm and a net cargo capacity of 51 tonnes. The rest of the parameters are shown in its data sheet (Annex 1). This model has been chosen as it has enough power and load capacity to simulate desired scenarios. In addition, it corresponds to the category of heavy-duty vehicles which are normally used on the studied routes.

The total weight of the truck chassis is 9,190 kg and its Gross Vehicle Weight is 28,500 kg. However, its maximum traction capacity is 75,500 kg and therefore it is a valid vehicle to simulate scenarios with high loads. For the calculation of the litres of fuel consumed per tonne transported, as well as for the kg of CO_2 emitted per tonne transported, the weight of the chassis and semitrailer have been subtracted from the mass considered for the simulated scenario.

To determine the aerodynamic parameters a paper published by Harun Chowdhur et al. (2013) which studies the aerodynamic coefficient for heavy trucks according to different aerodynamic configurations was consulted. The results of the study are shown below.



Graphic 14: Aerodynamic coefficient (Extracted from Harun Chowdhur et al., 2013)

The model of truck considered in this study has a frontal area of 9.7m^2 and the shape and fairing of this specific model is more likely to an b-type truck (Graphic 14), for which approximately 0.6 is the aerodynamic coefficient at the average of the roads.

About engine parameters, it has been extracted from the Center for Alternative Fuels, Engines & Emissions, that the efficiency of the diesel engine is estimated at 46%, while the air-fuel combustion ratio is 14.5:1. The engine mounted in this specific model is a VOLVO D13C Euro 5 SCR, with a max power of 540 HP between 1400 and 1900 rpm, 6 cylinders and an engine displacement of 12.8 L.

The value for the truck rolling coefficient has been extracted from the Minnesota Department of Transportation, which establishes an average rolling coefficient for heavy vehicles of 0.0055. The efficiency of the drive train has been considered to be 85%.The driving power, referring to drives such as air conditioning and others, has been considered to be 0 kW.

8. Results and conclusions

Once the simulations are performed, the results are discussed. It should not be forgotten that this paper is a comparative study of the impact of two alternative routes, and therefore the main objective is to determine if there are significant differences between these two routes and not so much to estimate with great precision the fuel consumption or the emission of gases of each route.

			Model 1		Model 2		Model 3	
	Route		1	2	1	2	1	2
Simulated scenario	Regular speed Regular slope	1	22,59	19,04	29,28	23,58	36,22	25,27
		2	27,77	23,73	36,94	29,94	40,17	28,91
		3	32,95	28,42	44,59	36,31	44,13	32,64
		4	38,13	33,11	52,25	42,68	48,08	36,44
		5	46,59	40,77	64,77	53,09	54,55	42,72
	Regular speed 0 % slope	6	24,47	21,68	29,57	23,62	36,26	26,98
		7	30,35	27,34	37,34	30,00	40,23	30,55
		8	36,23	33,01	45,09	36,38	44,20	34,12
		9	42,11	38,67	52,86	42,77	48,17	37,69
		10	51,73	47,93	65,56	53,20	54,67	43,57
	Constant speed Regular slope	11	23,91	18,40	28,44	22,64	32,90	24,76
		12	29,79	22,81	36,00	28,62	36,83	28,01
		13	35,67	27,23	43,56	34,61	40,77	31,39
		14	41,55	31,65	51,12	40,60	44,71	34,81
		15	51,17	38,87	63,48	50,39	51,16	40,43

Table 23: Fuel consumption in liters estimated for Route 1 (A-15) and Route 2 (N-121-A) in each simulated scenario

In general terms the fuel consumption of Route 1 (AP-15) is higher than that of the Route 2 (N-121-A), as it can be seen in Table 23. Also, in all the proposed scenarios, increasing the load increases fuel consumption proportionally, i.e. there is a linear relationship between the load and fuel consumption. This linear behavior can be observed for the scenario with regular slopes and speeds (Graphic 15, Graphic 16 and Graphic 17) but is the same for scenarios that keep the speed and slope constant. As for this observed linear behavior, the model 1 and the model 2 have more close results, which seems logical since the two models start from a common base and their functions to estimate consumption are analogous. Regarding to the excess fuel consumed for Route 1 versus Route 2, this is, on average, between 20 and 30%, although depending on the simulated scenario it varies from 8% to 43% (Table 24).

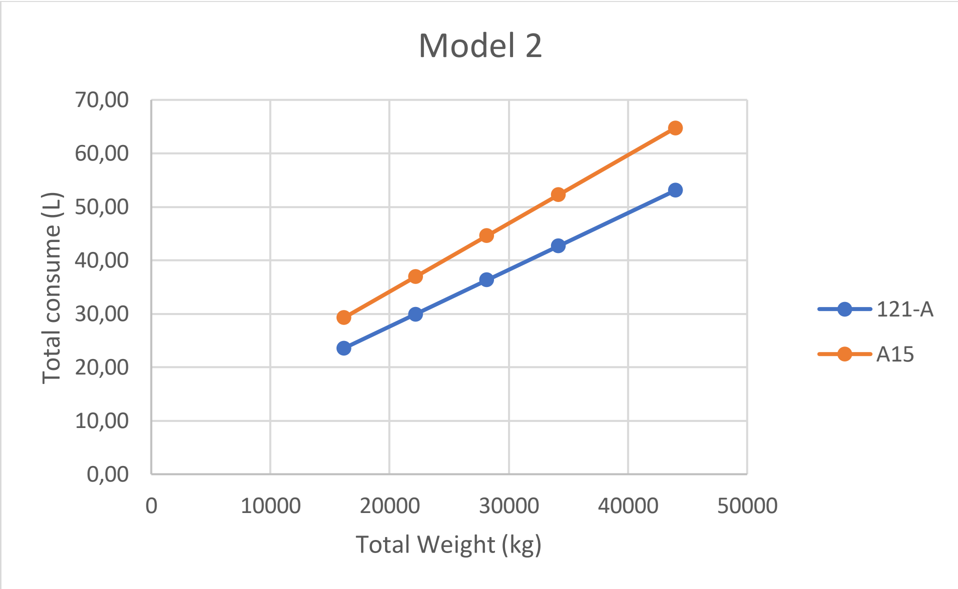
			Model 1	Model 2	Model 3	Average
Simulated scenario	Regular speed Regular slope	**1**	19%	24%	43%	29%
		2	17%	23%	39%	26%
		3	16%	23%	35%	25%
		4	15%	22%	32%	23%
		5	14%	22%	28%	21%
	Regular speed 0 % slope	**6**	13%	23%	34%	23%
		7	11%	22%	32%	22%
		8	10%	21%	30%	20%
		9	9%	21%	28%	19%
		10	8%	20%	25%	18%
	80 km/h speed Regular slope	**11**	30%	26%	33%	30%
		12	31%	26%	32%	30%
		13	31%	26%	30%	29%
		14	31%	26%	28%	28%
		15	32%	26%	27%	28%

Table 24: Excess fuel consumption of Route 1 (AP-15) versus Route 2 (N-121-A)

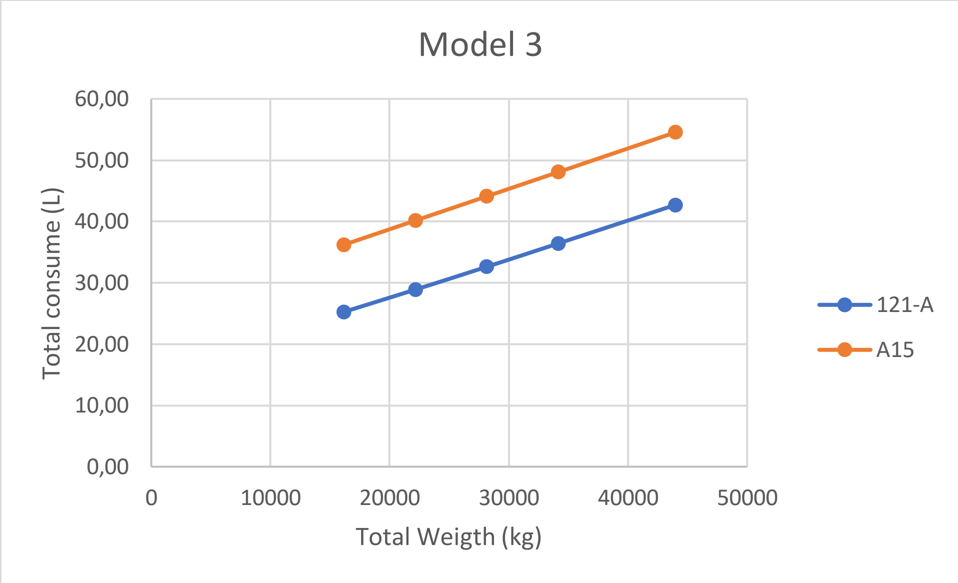
- Regular speed and regular slope

The fuel consumption estimated by the model 2 is in all cases simulated higher than the consumption estimated by the model 1 and the model 3. This seems reasonable, since it agrees with what was published in the paper by Demir et al. (2011). In this study, the model 2 overestimates fuel consumption in a range of between 69% and 82% compared to road measurements, whereas models 1 and 3 overestimate fuel consume about 15-30%.

Graphic 15: Fuel consumption estimation, Model 1 (Scenarios 1-5)

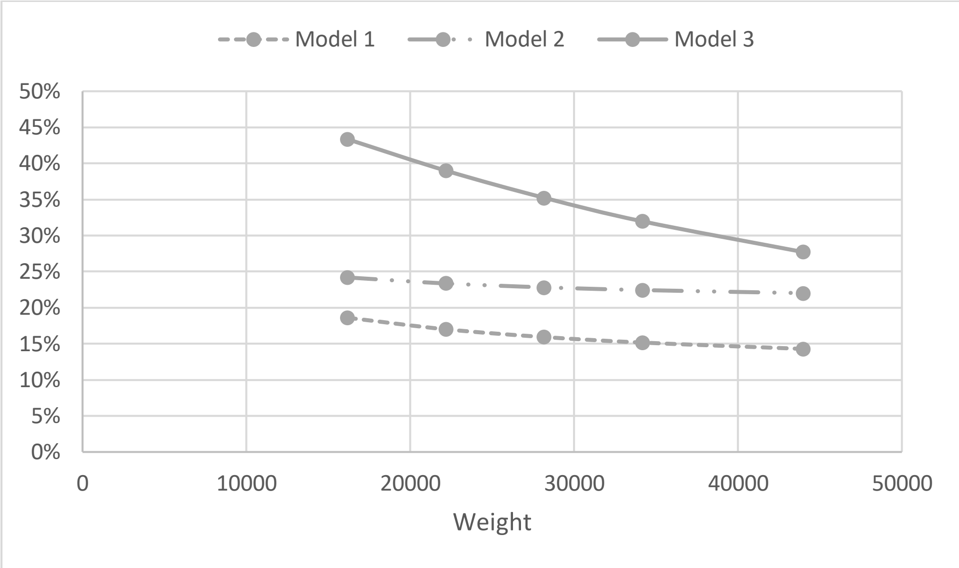


Graphic 16: Fuel consumption estimation, Model 2 (Scenarios 1-5)



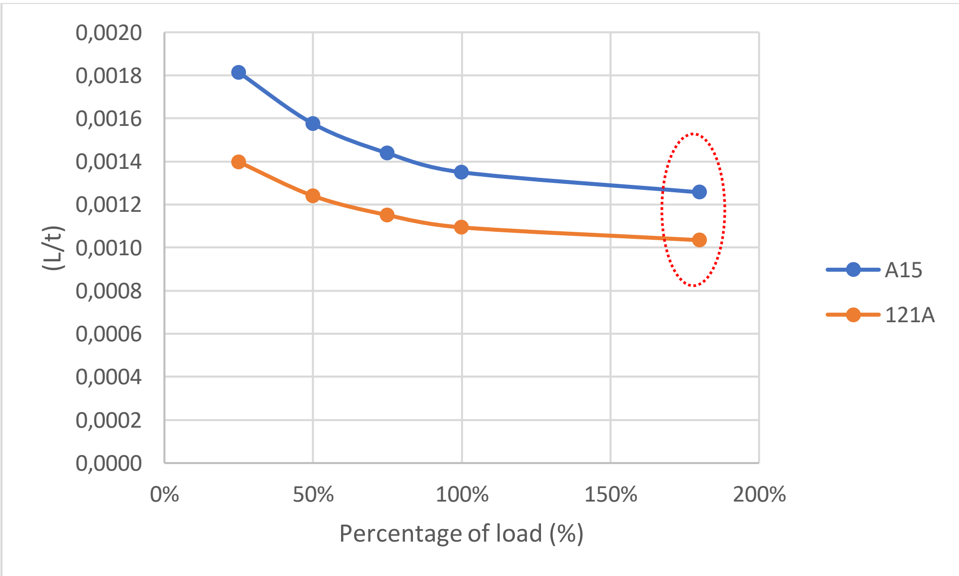
Graphic 17: Fuel consumption estimation, Model 3 (Scenarios 1-5)

As indicated in Table 24, the difference in fuel consumption between the two routes decreases slightly as the percentage of load increases. When the truck is loaded at 25%, the Route 1 has a 19% higher fuel consumption according to model 1 and a 24% higher according to model 2. By increasing the load of the truck up to 100% the difference is slightly reduced: the route 1 consumes 14% more according to model 1 and 22% more according to model 2. As for model 3, it presents slightly different results. For case 1, in which the truck is loaded at 25%, estimates a fuel consumption of 36.22 L for Route 1 and 25.27 L for Route 2. This means that for Route 1 would consume 43% more fuel than for route 2, which is a more noticeable difference between the routes than the estimated by models 1 and 2, which for case 1 estimate differences of 19% and 24% respectively. As the load continues to increase, it can be seen in Graphic 18 as in the model 3 the difference between the routes is reduced more quickly than in the model 1 and the model 2, in which the difference in consumption between the routes is not reduced so much by increasing the load. This behavior is interesting, as all models indicate that for lighter trucks, route 2 is particularly more efficient in terms of fuel consumption.



Graphic 18: Excess fuel consumption of Route 1 (AP-15) over Route 2 (N-121-A), Scenarios 1-5

When we analyzed the liters of fuel used to transport a ton of cargo, we found large differences between the truck's load levels. The difference between using low-load trucks is very noticeable when it comes to using fully loaded trucks. The save in L/tonne of carrying a truck loaded at 75% compared to a truck loaded at 25% is 26% for route 1 and 22% for route 2. However, the savings are not as noticeable when using trucks 100% loaded, 6% on Route 1 and 5% for route 2, regarding a truck loaded at 75%. In the case of the STruck with respect to the 100% loaded truck, the savings are again the same, 6% and 5%.



Graphic 19: Liters of fuel consumed per tonne cargo as function of the percentage of load. Struck case rounded in red.

- Regular speed and constant slope

	Model 1		Model 2		Model 3	
	Route 1	Route 2	Route 1	Route 2	Route 1	Route 2
6	24,47	21,68	29,57	23,62	36,26	26,98
7	30,35	27,34	37,34	30,00	40,23	30,55
8	36,23	33,01	45,09	36,38	44,20	34,12
9	42,11	38,67	52,86	42,77	48,17	37,69
10	51,73	47,93	65,56	53,20	54,67	43,57

Table 25: Fuel consumption in liters, simulated scenarios 6-10

	Model 1		Model 2		Model 3	
	Route 1	Route 2	Route 1	Route 2	Route 1	Route 2
6	8%	14%	-0.99%	0.17%	0.11%	6.77%
7	9%	15%	-1.08%	0.20%	0.15%	5.67%
8	10%	16%	-1.12%	0.19%	0.16%	4.53%
9	10%	17%	-1.17%	0.21%	0.19%	3.43%
10	11%	18%	-1.22%	0.21%	0.22%	1.99%

Table 26: Fuel consumption variation in cases 6-10 respect cases 1-5

In these scenarios where the slope is constant and of value 0% (scenarios 6-10), the fuel consumption increases for all cases except for Route 1-Model 2, which seems to be less sensible to slopes changes (Table 25 and Table 26). These results are explained, since both routes save a negative slope of 415 meters, while in scenarios 6-10 the slope is 0 meters since the slope is constant and of value 0 throughout the routes. In all cases 6-10 the increase in fuel consumption is greater for route 2, which indicates that the slope factor makes Route 2 more efficient. By analyzing the positive and negative elevation of each route (Table 27), it is turned out that the Route 1 has more than twice the positive elevation compared to the Route 2, which has a negative impact on fuel consumption. The elevation profile that the Route 2 follows is more efficient than the elevation profile of the Route 1 and this is shown by comparing the excess fuel of Route 1 versus Route 2. In all cases 1-5 the excess fuel consumption has been reduced compared to their homologues where the slope factor has been eliminated (cases 6-10).

	Positive elevation	Negative elevation	Total elevation
Route 1 (AP-15)	981.73	1396.92	-415.19
Route 2 (N-121-A)	415.75	831.23	-415.48

Table 27: Elevation of the routes in meters

- Constant speed and regular slope

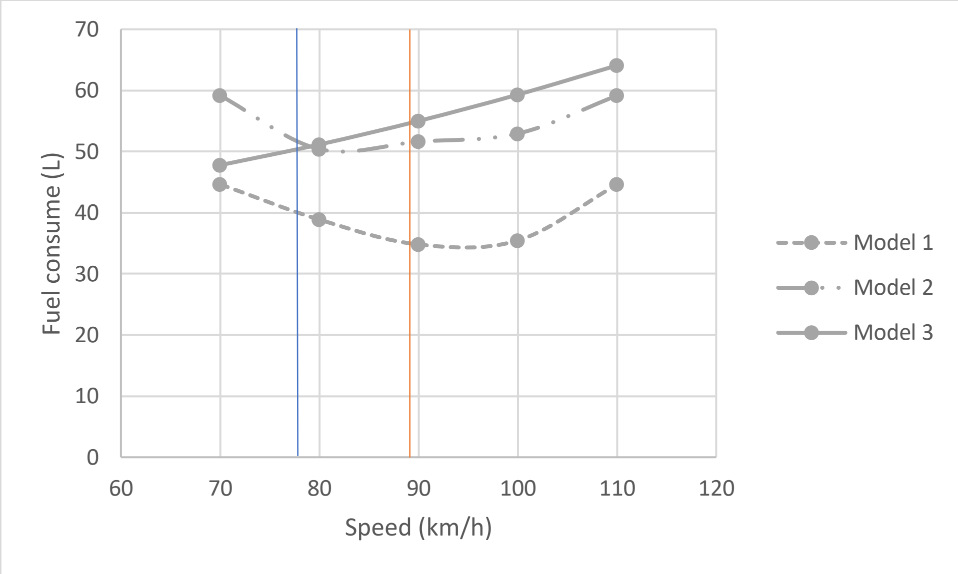
	Model 1		Model 2		Model 3	
	Route 1	**Route 2**	**Route 1**	**Route 2**	**Route 1**	**Route 2**
11	23,91	18,40	28,44	22,64	32,90	24,76
12	29,79	22,81	36,00	28,62	36,83	28,01
13	35,67	27,23	43,56	34,61	40,77	31,39
14	41,55	31,65	51,12	40,60	44,71	34,81
15	51,17	38,87	63,48	50,39	51,16	40,43

Table 28: Fuel consumption in liters, for simulated scenarios 11-15 with 80 km/h constant speed

	Model 1		Model 2		Model 3	
	Route 1	**Route 2**	**Route 1**	**Route 2**	**Route 1**	**Route 2**
11	6%	-3%	-3%	-4%	-9%	-2%
12	7%	-4%	-3%	-4%	-8%	-3%
13	8%	-4%	-2%	-5%	-8%	-4%
14	9%	-4%	-2%	-5%	-7%	-4%
15	10%	-5%	-2%	-5%	-6%	-5%

Table 29: Fuel consumption variation in cases 10-15 respect cases 1-5

Analyzing the influence of the cruise speed on the different routes has obtained a different behavior for each of the models. Both the Model 1 and the Model 2 have an optimal speed with which the fuel consumption is lower: for the Model 1 this speed is close to 90 km/h, while for the Model 2 the optimal speed is close to 80 km/h, although there is not a big difference. However, the Model 3 does not have an optimal speed, the speed, the higher fuel consumption. This behavior is observed in Graphic 20 for Route 1, but it is also valid for Route 2.



Graphic 20: Effects of speed on fuel consumption for Route 1 (average speed of Route 2 in blue, average speed of Route 1 in orange)

If a speed of 80 km/h is set, the results shown in Table 28 are obtained. Now, analyzing Table 29, in the Model 1 an increase in fuel consumption is observed for Route 1, since the fixed speed of 80km/h is less efficient than the average speed of the Route 1 (89km/h), closer to the optimal speed of model 1 (90km/h). However, as the average speed of Route 2 is 77 km/h, for Route 2 the consumption drops slightly. In the case of the Model 2 in both routes the consumption is slightly reduced, having fixed the speed at 80 km/h, optimal speed for model 2. Finally, in Model 3, the consumption is significantly reduced for Route 1, as the speed is reduced from 89 km/h (Route's 1 average speed) to 80 km/h. On the route 2 there is a very slight decrease in consumption, despite increasing the average speed from 77 km/h (Route's 2 average speed) to 80km/h, which is due to the fact that the acceleration parameter is eliminated, as the speed is constant. Each of the routes has a different average speed and depending on which model is chosen, one or the other will prove to be more efficient in terms of speed. Initially, it is logical to think that the lower average speed of Route 2 will contribute to lower fuel consumption, as indicated by models 2 and 3.

We conclude this section by saying that the Route 2 corresponding with the N-121-A road has a lower fuel consumption and therefore, lower emissions than Route 1, corresponding to the AP-15. This is thanks to the characteristics that make up Route 1. Both its length, which is about 15%, and its elevation profile, which is less abrupt and reaches a lower altitude, are determining factors that make this route more efficient and have less environmental impact. It should also be noted that this route has a lower average speed of about 77km/h as it is a road and not a motorway, although this also means that it has more acceleration and braking sections, as a negative point. Therefore, the diversion of lorries along the AP-15 motorway would be a measure which would increase the $C0_2$ emissions associated with the transport of goods from Pamplona to Irún.

Case	**Speed**	**Slope**	**Total Weight (kg)**
1	Regular	Regular	16,190
2	Regular	Regular	22,190
3	Regular	Regular	28,190
4	Regular	Regular	34,190
5	Regular	Regular	44,000
6	Regular	0%	16,190
7	Regular	0%	22,190
8	Regular	0%	28,190
9	Regular	0%	34,190
10	Regular	0%	44,000
11	70-110 km/h	Regular	16,190
12	70-110 km/h	Regular	22,190
13	70-110 km/h	Regular	28,190
14	70-110 km/h	Regular	34,190
15	70-110 km/h	Regular	44,000

Table 30:Summary of the simulated scenarios in each of the models

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10. Graphic index

11. Table index

12. Figure index

ANNEX 1

Function 1: Road speed in Route 1

```
Function VelA15(km As Double) As Integer

    If (km < 3400) Or (km > 53700 And km < 64000) Then

        VelA15 = 80

    Else

        VelA15 = 90

    End If

End Function
```

Function 2: Road speed in Route 2

```
Function Ve(k As Double) As Integer

    If (k < 300) Or (k > 720 And k < 1100) Or (k > 2210 And k < 2500) Or (k > 2900 And k < 2920) Or (k > 3620 And k < 3820) Or (k > 4430 And k < 4630) Or (k > 5230 And k < 5430) Or (k > 6540 And k < 6840) Or (k > 76000 And k < 76500) Then

        Ve = 40

    ElseIf (k > 11400 And k < 12000) Or (k > 26000 And k < 27000) Then

        Ve = 50

    ElseIf (k > 700 And k < 720) Or (k > 1100 And k < 2210) Then

        Ve = 60

    ElseIf (k > 7450 And k < 7950) Or (k > 8820 And k < 9360) Or (k > 9760 And k < 10200) Or (k > 12000 And k < 12500) Or (k > 13000 And k < 13400) Or (k > 14000 And k < 14400) Or (k > 17100 And k < 17700) Or (k > 185000 And k < 19000) Or (k > 35800 And k < 38400) Or (k > 50200 And k < 50800) Or (k > 52100 And k < 52400) Or (k > 65000 And k < 66000) Then

        Ve = 70

    Else

        Ve = 80

    End If

End Function
```

Function 3: Engine Speed

```
Function Rev(DataRange1, DataRange2, DataRange3, DataRev, Vel, Force, Power)

Rev = 2000

Dim nRows1 As Integer

Dim nCols1 As Integer

Dim i As Integer, j As Integer

Dim indi As Boolean

nRows1 = DataRange1.Rows.Count

nCols1 = DataRange1.Columns.Count

For i = 1 To nRows1

    For j = 1 To nCols1

        If DataRange1.Cells(i, j) > Vel And DataRange2.Cells(i, j) > Force And DataRange3.Cells(i) > Power And indi = False Then

            Rev = DataRev.Cells(i)

            indi = True

        End If

        Next j

    Next i

End Function
```

<u>Speed matrix</u>

	Gear	1	2	3	4	5	6	7	8	9	10	11	12
	i	14,95	11,73	9,04	7,09	5,54	4,35	3,44	2,7	2,08	1,63	1,27	1
rpm													
1000		4.39	5.59	7.25	9.25	11.84	15.08	19.06	24.29	31.53	40.23	51.64	65.58
1050		4.61	5.87	7.62	9.71	12.43	15.83	20.02	25.50	33.10	42.24	54.22	68.86
1100		4.83	6.15	7.98	10.17	13.02	16.58	20.97	26.72	34.68	44.25	56.80	72.13
1150		5.04	6.43	8.34	10.64	13.61	17.34	21.92	27.93	36.26	46.27	59.38	75.41
1200		5.26	6.71	8.70	11.10	14.20	18.09	22.88	29.15	37.83	48.28	61.96	78.69
1250		5.48	6.99	9.07	11.56	14.80	18.84	23.83	30.36	39.41	50.29	64.54	81.97
1300		5.70	7.27	9.43	12.02	15.39	19.60	24.78	31.57	40.99	52.30	67.13	85.25
1350		5.92	7.55	9.79	12.49	15.98	20.35	25.74	32.79	42.56	54.31	69.71	88.53
1400		6.14	7.83	10.16	12.95	16.57	21.11	26.69	34.00	44.14	56.32	72.29	91.81
1450		6.36	8.11	10.52	13.41	17.16	21.86	27.64	35.22	45.71	58.34	74.87	95.09
1500		6.58	8.39	10.88	13.87	17.76	22.61	28.59	36.43	47.29	60.35	77.45	98.37
1550		6.80	8.67	11.24	14.34	18.35	23.37	29.55	37.65	48.87	62.36	80.03	101.64
1600		7.02	8.94	11.61	14.80	18.94	24.12	30.50	38.86	50.44	64.37	82.62	104.92
1650		7.24	9.22	11.97	15.26	19.53	24.87	31.45	40.07	52.02	66.38	85.20	108.20
1700		7.46	9.50	12.33	15.72	20.12	25.63	32.41	41.29	53.60	68.39	87.78	111.48
1750		7.68	9.78	12.69	16.19	20.71	26.38	33.36	42.50	55.17	70.40	90.36	114.76
1800		7.90	10.06	13.06	16.65	21.31	27.14	34.31	43.72	56.75	72.42	92.94	118.04
1850		8.11	10.34	13.42	17.11	21.90	27.89	35.27	44.93	58.33	74.43	95.53	121.32
1900		8.33	10.62	13.78	17.57	22.49	28.64	36.22	46.15	59.90	76.44	98.11	124.60

Torque matrix

		Gear	1	2	3	4	5	6	7	8	9	10	11	12
		i	14.95	11.73	9.04	7.09	5.54	4.35	3.44	2.7	2.08	1.63	1.27	1.00
Tm	rpm													
2600	1000		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1050		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1100		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1150		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1200		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1250		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1300		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1350		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1400		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1450		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2600	1500		102092	80103	61733	48417	37832	29706	23491	18438	14204	11131	8673	6829
2525	1550		99147	77792	59952	47020	36741	28849	22814	17906	13794	10810	8423	6632
2450	1600		96202	75482	58172	45624	35649	27992	22136	17374	13385	10489	8172	6435
2375	1650		93257	73171	56391	44227	34558	27135	21459	16842	12975	10168	7922	6238
2300	1700		90312	70860	54610	42830	33467	26278	20781	16311	12565	9847	7672	6041
2225	1750		87367	68550	52829	41434	32376	25421	20103	15779	12155	9526	7422	5844
2150	1800		84422	66239	51049	40037	31284	24564	19426	15247	11746	9205	7172	5647
2075	1850		81477	63928	49268	38640	30193	23707	18748	14715	11336	8883	6921	5450
2000	1900		78532	61618	47487	37244	29102	22851	18070	14183	10926	8562	6671	5253

VOLVO FH 6X4 BITREN
EVOLUTION PLUS
540 CV

TCI
TECNOLOGÍA DE CONSUMO INTELIGENTE

Volvo Trucks. Acelerando el futuro.

- ✔ CABINA GLOBETROTTER
- ✔ EBS, ESP Y CONTROL DE TRACCIÓN
- ✔ ACC + FRENADO DE EMERGENCIA
- ✔ AIRBAG
- ✔ EJE ELEVABLE Y DESEMBRAGABLE
- ✔ LLANTAS DE ALUMINIO

DATOS TÉCNICOS

MOTOR
Modelo: VOLVO D13C Euro 5 SCR
Características: 12,8 lts, 6 cilindros en línea y 4 válvulas por cilindro. Unidades individuales de inyector bomba. Sistema de inyección con gerenciamiento electrónico.
Potencia: 540 CV (1400 - 1900 rpm)
Torque: 2.600 Nm (1000 - 1400 rpm)

CAJA DE VELOCIDADES
Modelo: Volvo AT2612F
Tipo: Automatizada sin sincronizados.
Sistema: I-Shift
Marchas: 12 velocidades adelante + 4 atrás
Opcional: : I-Shift con 2 marchas súper reducidas (32,04:1 y 19,38:1)

SUSPENSIÓN DELANTERA
Tipo: Ballestas parabólicas de 3 hojas con amortiguadores y barra estabilizadora.
Capacidad: 7.500 Kg

SUSPENSIÓN TRASERA
Tipo: : Suspensión neumática de 8 fuelles con amortiguadores y barra estabilizadora.
Capacidad: 21.000 Kg

FRENOS
Tipo: Frenos a disco con control electrónico. EBS/ABS, control de tracción y control de estabilidad ESP.
Freno auxiliar: Freno de motor VEB a través de válvulas y retardador (1120 CV de potencia de frenado combinada).

DIFERENCIAL
Modelo: RTS2370A
Relación de reducción: 3,09:1 y opciones
Capacidad de arrastre: 75 Tn
Opcional: Eje con reductor de cubos

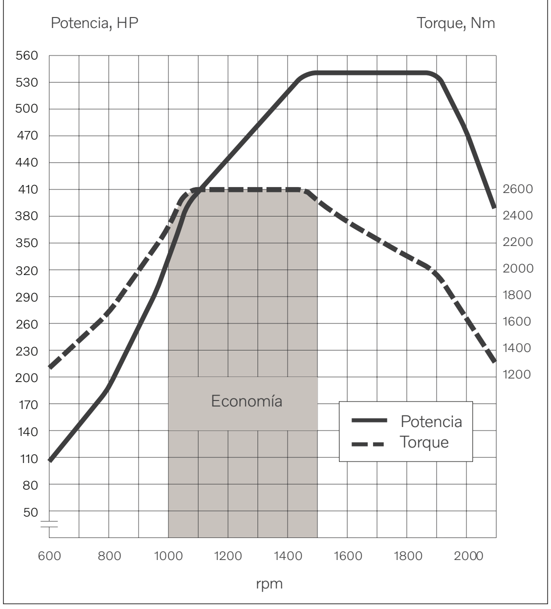
TANQUES DE COMBUSTIBLE
Combustible: Aluminio D-Shape de 895 litros*
Aditivo SCR: Bajo cabina de 65 litros
*Para e/e 3.200 mm. Distintas opciones de capacidades.

CHASIS
Material: Acero especial LNE60
Quinta rueda: Jost JSK 37CX-Z
Altura de quinta rueda: 185 mm*
Diámetro perno: 50 mm (2")
*Opcional 150 mm

NEUMÁTICOS Y LLANTAS
Neumáticos: 295/80R22,5
Llantas: Aluminio 9"
Opcional: Llantas de Acero

D13C540 Potencia/Torque

Potencia según ISO 1585, Dir. 89/491/EEC, ECE Reg 85



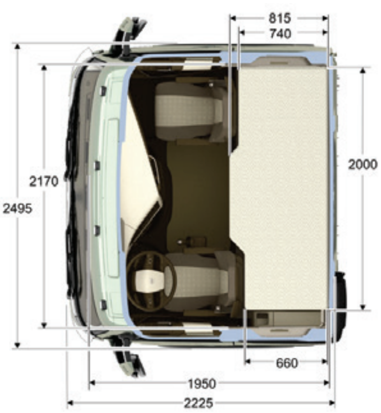
PESOS Y CAPACIDADES (Kg)

	Eje delantero	Eje trasero	Total
Capacidad técnica	7.500	21.000	28.500
Límite legal	6.000	18.000	24.000
Peso del chasis*	5.419	3.771	9.190
Capacidad máxima de tracción			75.000

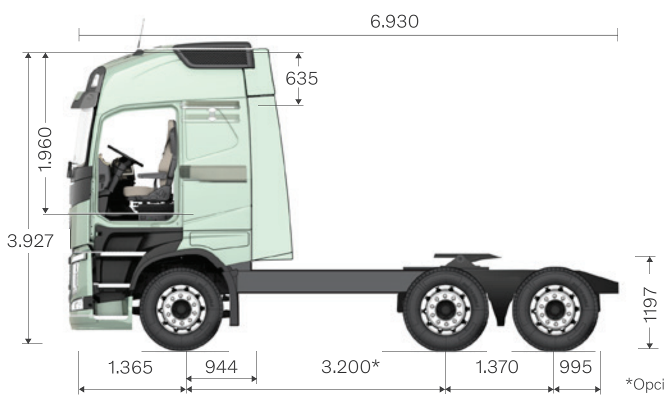
*Pesos estimados con 100 lts de combustible, sin chofer y con rueda de auxillio. Llantas de aluminio, frenos a disco y cabina techo alto.

MEDIDAS

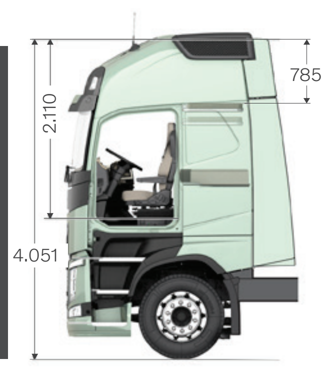
Cabina: Techo Alto (Globetrotter) / Techo Extra Alto (Globetrotter XL). Deflectores laterales. Suspensión neumática de 4 puntos.



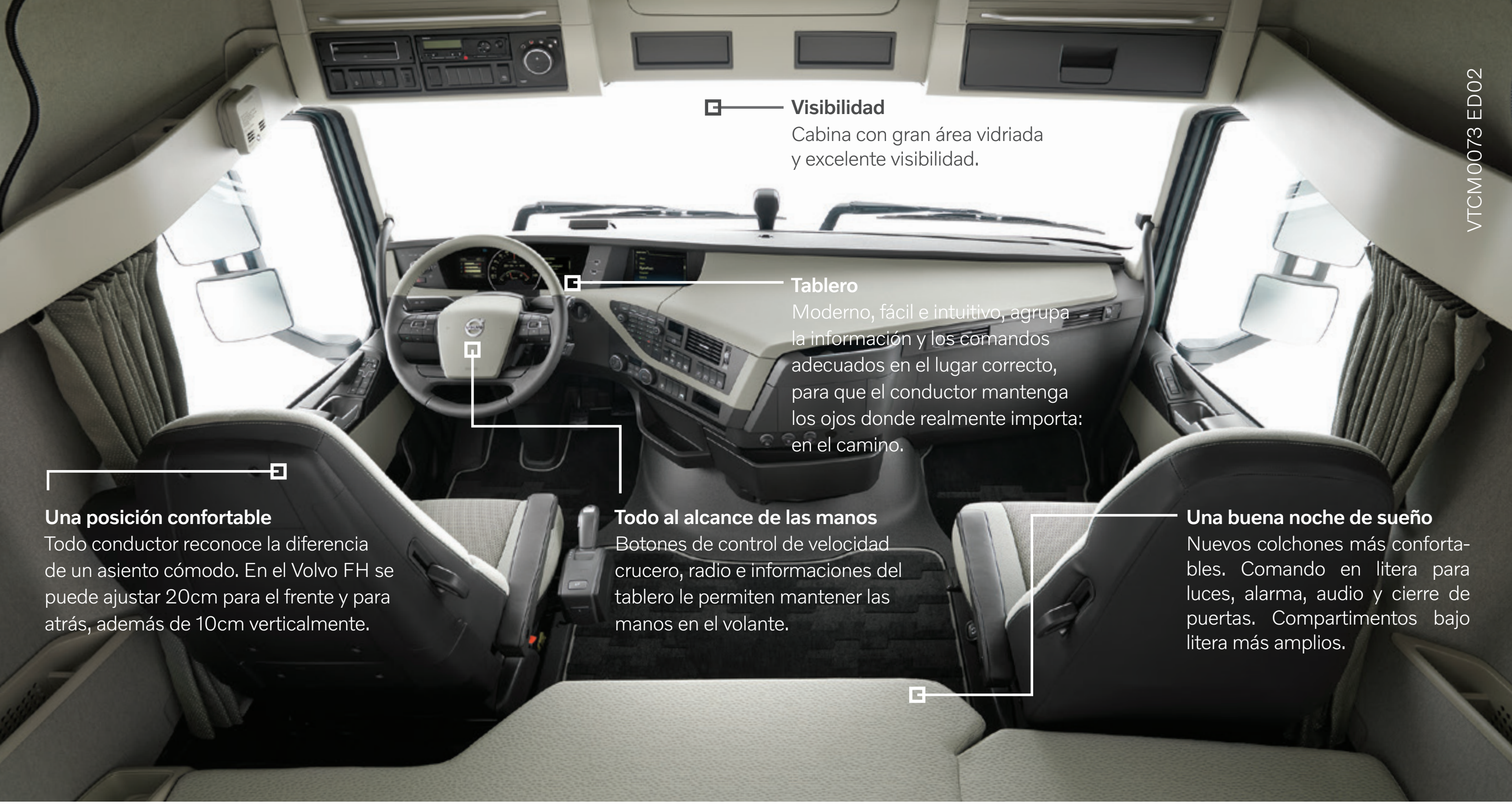
CABINA TECHO ALTO



CABINA TECHO XL



*Opcional 3.600 mm



PUESTO DE CONDUCCIÓN

Asiento de lujo con suspensión neumática. Asiento pasajero neumático. Volante de cuero multifunción con mandos para audio y computadora de abordo. Columna de dirección ajustable en altura, profundidad y ángulo. Radio, MP3 y Bluetooth. Tablero color y display secundario versión High de 7" color touch, con navegación GPS y aplicaciones. Espejos con gran angular de ambos lados con control eléctrico y calefacción. Espejo lateral auxiliar (cunetero) y espejo frontal.

DESCANSO Y CONFORT

Panel de control multifunción de lujo en litera. Cortinas en ventanas y parabrisas. Parasoles tipo persianas. Volteo hidráulico de cabina. Cierre de puertas a distancia. Iluminación interior día y noche con dimmer.
Portaobjetos superior trasero, litera reclinable y asiento de pasajero neumático.

CLIMATIZACIÓN

Aire acondicionado digital. Techo solar con accionamiento eléctrico. Climatizador de techo.

SEGURIDAD

Cabina de última generación construida bajo el concepto de módulo de supervivencia. Sistema anti empotramiento frontal FUP. Cinturones de seguridad rojos. Control de velocidad crucero. Luces traseras de LED con aviso de frenada de emergencia y alarma de marcha atrás. Luces diurnas de LED. Limpia faros delanteros. Frenos a disco con ABS, EBS, ESP y control de tracción. Alarma, inmovilizador, traba de parrilla eléctrica y sensor de lluvia.

Pack de Seguridad S2:

- Airbag
- EBS, TCS (Control de tracción)
- ESP (Control de estabilidad)
- Advertencia de colisión frontal
- ACC (Control Crucero Adaptativo)
- Sistema de Frenado de Emergencia
- Aviso de frenada brusca
- LKS (Alerta de desvío de carril)
- DAS (Alerta de cansancio)
- LCS (Sensor de punto ciego)
- Faros auxiliares de esquina

SISTEMA ELÉCTRICO CON ADR

Blindaje del sistema eléctrico contra el desgaste mecánico, empalmes estancos en todas las conexiones eléctricas y acoplamientos. Cortes de corriente dentro y fuera de la cabina.

EQUIPAMIENTO Y SERVICIOS OPCIONALES

PACKS / OPCIONALES

OPCIONALES

- Eje trasero con reductor de cubos
- Dirección dinámica
- Calefactor de estacionamiento
- Tomas de fuerza (caja/motor)
- Paragolpes delantero HD
- Heladera
- Escape vertical
- Deflector de techo

PACK CONFORT

- Litera eléctrica
- Levantacabina eléctrica
- Parasol eléctrico
- Heladera
- Asiento pasajero giratorio
- Preparacion TV
- Mesa
- Caja fuerte

PACK SEGURIDAD S3*

- Dirección Dinámica con asistencia

* Incluye equipamiento del Pack de Seguridad S2

PACK CONFORT MANEJO

- Dirección Dinámica
- Cámara Visión Trasera

SISTEMA DE GESTIÓN DE FLOTAS

DYNAFLEET

Seguimiento y optimización del desempeño del camión en forma remota.

CONTRATOS DE MANTENIMIENTO

PROGRAMA AZUL

Mantenimiento preventivo básico: 12 meses.

PROGRAMA AZUL PLUS

Mantenimiento preventivo completo: 12 meses.

PROGRAMA ORO

Mantenimiento preventivo y reparación: 36 meses.