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Informática y de Telecomunicación

Environmental impact study of the two alternative routes for freight transportation connecting Navarre and Gipuzkoa (Spain)

Máster Universitario en

Ingeniería Industrial

Trabajo Fin de Máster

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Gracias por todo.

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ABSTRACT

This work will try to solve a current issue on the logistics of vehicles for the transport of goods in the Community of Navarra in its connection with Gipuzkoa, taking into account the negative externalities that this transport produces (air pollution, greenhouse gases, noise, accidents ...).

To this end, two alternative routes from Pamplona to Irún will be compared:

- Pamplona-Irun connection via the AP15 motorway
- Pamplona-Irun connection via the N-121-A road

Focusing on the environmental impact due to its emissions that depend on the fuel consumed, which varies from one route to another by changing route characteristics such as distance, speed and gradient.

The calculation of fuel consumption will be carried out using an analytical mathematical emission model, called the MEET model, which estimates the kilograms of emissions based on controllable factors such as distance, speed and gradient of each route, obtaining an environmental comparison between both routes.

KEYWORDS

Freight Transportation

External cost

Air pollution

Greenhouse gases

GIS

Fuel consumption

MEET

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1. Introduction and objectives

This project is divided into two parts, the final master's project and the project complement. This document is the first part, the final master work (TFM), which includes an introduction and overview of the road transport and logistics in Navarre and Gipuzkoa, a description of the two alternative routes, and the estimation of emissions calculated with the MEET model. Thus, the application of two different estimation models (IFCM and CMEM) is included in the complement of TFM document, in addition to the comparisons between the three models with each result obtained, an economic study including the external costs of air pollution and greenhouses gases, and the final conclusion and future lines which are also included in the complement. This summary can be seen in the Figure 1.

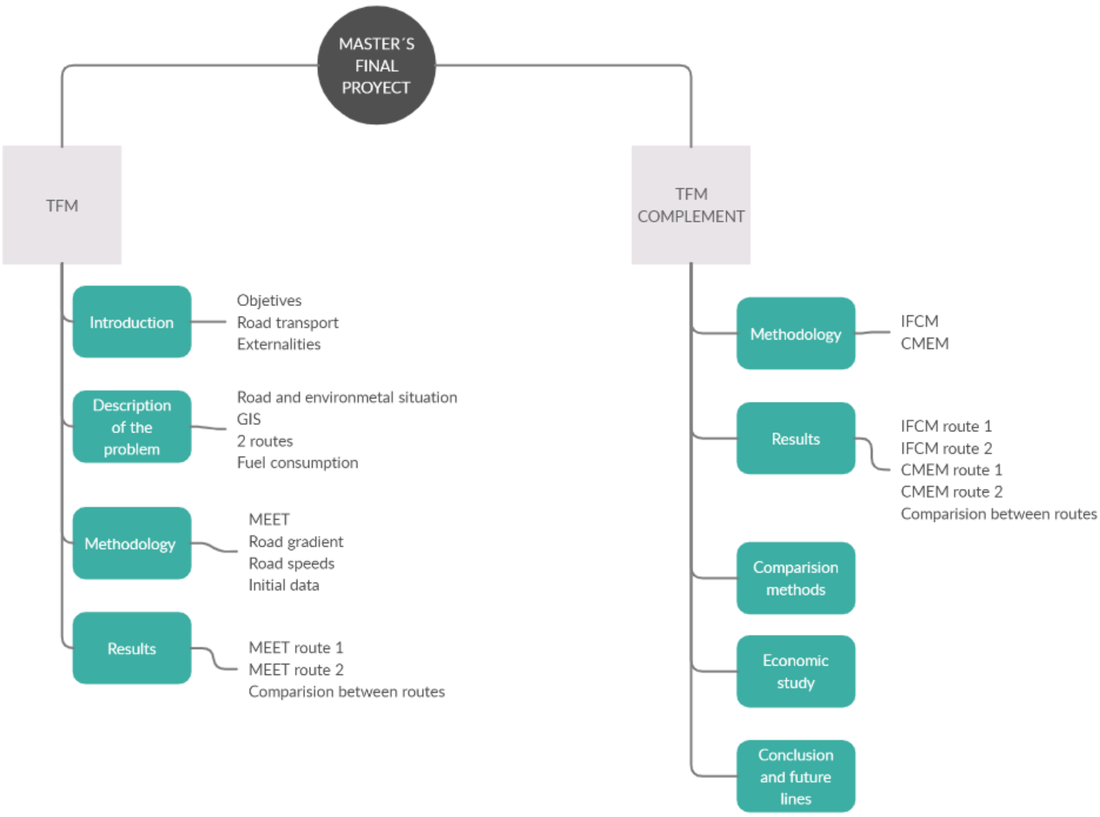


Figure 1: Overview of the total project (Source: Self production)

The aim of this project is to analyze and study one of the most current problems in the field of logistics and transportation, namely the negative consequences and externalities that occur in the environment at the expense of the freight transport by road. This study will focus mainly on the impact of air pollution, and greenhouse gases caused by fuel combustion, specifically in the transport connection Navarra-Gipuzkoa.

To this end, two alternative transport routes will be compared, the first Pamplona-Irún connection via the AP15 motorway, and the second Pamplona Irún connection via the N-121-A road. These routes will be analyzed using the Geographical Information System (GIS), obtaining the different characteristics that will enable compare the fuel consumption between the two routes, which is directly related to their environmental impact.

The fuel consumption for both routes will be estimated using different mathematical analytical emission methods, the methodology for calculating transportation emissions and energy consumption (MEET) (Hickman et al, 1999), the instantaneous fuel consumption model, and the comprehensive modal emission model. These methods allow the calculation of fuel consumption for both roads according to their permissible speed, road gradient, and distance.

From the approximate results obtained through the methodology used, the aim is to conclude which of the two routes allows for lower fuel consumption, knowing that there are a multitude of variables that affect fuel consumption such as the type of vehicle, the percentage of load, the driving mode, the condition of the asphalt, the climate..., which will be considered fixed and equal on both routes.

Fuel consumption translates into economic costs for the company, but this fuel consumption also is directly related to the environmental impact caused by the vehicle, such as polluted air and climate change. These negative impacts have an external cost that are not paid by those who generate them. In order to have a sustainable freight transport system, these costs must be taken into account by internalizing them on the part of the company. Therefore, an economic analysis comparing both routes will also be carried out, considering the direct costs (fuel, tires, repairs...), tolls and external costs of air pollution and greenhouse gasses that the company should pay.

Furthermore, the current policy of internalizing these costs is not suitable because less is paid than it should be, since taxes, tolls and fees do not cover all the external costs generated. Nevertheless, this study aims to give an overview of the economic and environmental costs of road freight transport in an approximate way.

The understanding of this study is also another parallel objective that will allow the elaboration of different continuation or new projects, for example, choosing different mathematical methods for the calculation of fuel consumption, or applying them to other routes with other characteristics. It is also possible to carry out different studies on the same routes by studying other types of externalities such as noise pollution, consequences on fauna and flora, accidents...

2. Transport and environment

The current globalization has brought with it processes of localization and delocalization of productive activities worldwide, which together with the exponential increase in population, has caused a considerable boom in all productive sectors, but especially in transport. Today's consumer societies are increasingly demanding more products and this geographical distance between the newly manufactured product and its final consumer is increasing. This is where the logistics sector comes into play, whose objective is to manage the transport of the product thousands of kilometers to reach the consumer.

According to the EEA (European Environment Agency, 2016), transport accounts for about one third of all final energy consumption in its member countries, which is more than one fifth of greenhouse gas emissions. Transport is also responsible for a high percentage of air pollution in urban areas, as well as noise pollution, land occupation with its necessary infrastructure affecting the local flora and fauna, water pollution, especially from maritime transport, traffic congestion and accidents, among other external problems caused by transport. And within the transport of goods, a comparison between road and other modes of transportation shows that, in 2010, the quantities of freight transported by road in the EU (European Union) equaled approximately nine times of the amount transported by the other modes of transportation (Demir et al, 2015), that is why this project will be centered in the freight transportation by road, specifically in trucks because are dominant mode of inland freight transportation.

Road transportation generally has the biggest impact on environment except the section of water pollution where the maritime transportation has greater impact. Rail and maritime transportation have some similarities to road transportation, but these modes can be categorized more environmentally friendly and less health threatening. This is summarized in Table 1:

Negative externalities	Road transportation	Rail transportation	Maritime transportation	Air transportation
Air pollution	***	**	**	**
Greenhouse gases	***	**	**	**
Noise pollution	***	**	**	**
Water pollution	*	*	***	*
Congestion	***	*	*	*
Accidents	**	*	*	*
Land use	**	**	*	*

*: low; ** Medium; *** High

Table 1: Relevance of the negative externalities per transportation mode (Source, Adapted from: Demir et al 2015)

European governments have an increasing consideration for the population that suffers all these problems derived from transport, and therefore each country and community publishes its own regulations that try to improve the well-being of the affected population.

Climate change is one of the most important issues that today's society must address. This climate change, caused by greenhouse gases, is strongly influenced by the transport sector, almost a quarter of Europe´s greenhouse gas emissions…

Therefore, there are numerous European regulations to fight climate change (European Commision, 2019a, 2019b) with the aim of being a climate-neutral continent by 2050, and other laws and policies such as:

-EU Emissions Trading Scheme (EU ETS) to reduce greenhouse gas emissions from the energy sector, industry, and flights within the EU

-National targets for sectors outside of emissions trading, such as transport, buildings, and agriculture

-Ensuring that our forests and lands contribute to the fight against climate change

-Reduce greenhouse gas emissions from transport, for example through CO2 emission standards for vehicles

-Boosting energy efficiency, renewable energies and governance of energy and climate policies in EU countries

-Promoting innovative hypocarbon technologies

-Gradually reduce fluorinated greenhouse gases that cause global warming

-Protecting the ozone layer

-Adapting to the effects of climate change

-Financing climate action

All these policies and laws are worked out and agreed internationally between different countries like the protocol of Kyoto 2020, the agreement of Paris, the European pact on the climate 2030, among others.

As far as the transport sector is concerned, there is a European Strategy for low emissions mobility with three priority areas of action:

-Increasing the efficiency of the transport system by making the most of digital technologies, smart pricing and further encouraging the shift to lower emission transport modes.

-Speeding up the deployment of low-emission alternative energy for transport, such as advanced biofuels, electricity, hydrogen and renewable synthetic fuels and removing obstacles to the electrification of transport.

-Moving towards zero-emission vehicles. While further improvements to the internal combustion engine will be needed, Europe needs to accelerate the transition towards low- and zero-emission vehicles.

Cities and local authorities will play a crucial role in delivering this strategy. They are already implementing incentives for low-emission alternative energies and vehicles, encouraging active travel (cycling and walking), public transport and bicycle and car-sharing /pooling schemes to reduce congestion and pollution. Apart from the effects of climate change, the gases emitted by vehicle combustion have other important effects on health, ecosystems, fauna and vegetation, the deterioration of materials, and therefore on the economy as they are considered external costs.

According to the EEA (2016), 29,980 people died prematurely in Spain last year due to air pollution. These deaths occur mainly in large cities where air pollution is much higher. In Spain there are different policies and laws to fight climate change, such as the *2020 roadmap, Plan de impulso al medio ambiente* (PIMA), *Plan nacional integrado de clima y energía 2030*, etc. Each autonomous community has its own plans and strategies to combat climate change.

As for other transport externalities, there are also policies, regulations, plans and strategies to be followed. Some of the most important laws are Royal Decree 1367/2007 regarding noise emissions, Law 34/2007 on air quality and atmospheric protection, the Law on civil liability and insurance in the circulation of motor vehicles, the traffic code and road safety, Law 10/1998 of 21 April on waste generation, among others.

These external consequences of transport have costs that are now becoming increasingly important and which companies must take into account. Until now, companies have only focused on minimizing the direct costs they produce, but now external costs are being considered and attempts are being made to internalize them in order to obtain greater benefits. It is therefore necessary to differentiate between internal costs and external costs.

The internal costs are those generated and supported by oneself, that is, the company that generates them is the one that pays them. They can be fixed costs such as the depreciation and financing costs of the company's vehicles, workers' salaries and allowances, insurance, and taxes; or variable costs such as fuel consumption, tires, tolls, maintenance and repairs. These are the costs that influence decision making, which are considered the internal costs of a company and therefore those that are tried to be minimized (Ranaiefar and Regan, 2006).

While the external costs are those generated and not supported by them (they fall on the rest of society), they are considered as the variation in welfare experienced by third parties due to someone's economic activity, in this case transport. Among the external costs studied in transport, we highlight the costs of climate change, the cost of accidents, noise, air pollution, congestion, the cost to nature, and land occupation and water pollution, among others. These costs do not influence a company's decision making, so if benefits have to be increased they must be taken into account and also minimized, i.e. they must be internalized and these costs must be supported by the company in order to improve its environmental image and obtain greater external benefits than external costs.

From a societal perspective, it is desirable for all transportation services to pay their full social (private and external) costs. If the full social cost were reflected in the prices shippers pay, transportation users could choose the amount of each form of service to consume on the basis of the true cost of this service to society. By internalizing external costs, policy makers would effectively create a market through which transportation users could weigh the benefits of consuming a particular transportation service against the true costs.

A company mainly values the economic cost as its main variable to be minimized. But there are many others that are very important such as the delivery time, the quality of transport, the environmental issue, the social issue... In this work we will focus on the economic costs and environmental consequences of road freight transport, which are detailed below.

2.1 Internal economic costs of transport

The purpose is to make an analysis of the internal economic costs to be supported by transport companies, particularly in the transport of freight by road. This section will describe the annual costs for the type of vehicle with a tractor head. These internal costs can be separated into fixed and variable costs.

Figure 2: Goods transport truck (Source: Google)

2.1.1 Fixed costs

Fixed costs are costs that do not depend on the route, nor on the load, but are fixed annual costs such as vehicle depreciation, staff salaries, insurance, and taxes among others. The main ones are detailed below:

- Amortization and financing

Amortization is the sum of the annual depreciation costs of the different elements (towing vehicle, bodywork of the towing vehicle, semi-trailer, trailer and auxiliary equipment).

Financing is the sum of the annual financing costs of the different items purchased (towing vehicle, bodywork of the towing vehicle, semi-trailer, trailer and auxiliary equipment).

- Salary of the driving staff

This is the total annual cost to the company of the personnel driving the vehicle.

- Insurance

This is the total annual cost of vehicle and driver insurances.

- Tax costs

This is the total annual cost of the tax costs that can be passed on to this vehicle.

The amortization and financing costs are considered capital costs, while the other three are operating costs. These costs are paid by all the different transport and logistic companies.

2.1.2 Variable costs

The variable direct costs depend on the route and vary with the activity carried out by the fleet of vehicles, they are called the kilometer costs. The main variable costs are the following:

- Fuel

It is the sum of the annual fuel costs (traction vehicle and equipment). Fuel consumption, i.e. the cost of fuel is directly related to the characteristics of the transport route used and as will be seen below depends on the distance travelled, the gradient of the road and the speed of the vehicle among other variables. Fuel consumption is one of the pillars on which this study is based, which is why this subject is developed in more detail in the following sections.

- Tires

It is the sum of the annual costs of the different types of tires on the vehicle. This cost also depends on the route used, although to a lesser extent than the fuel consumption. Nevertheless, it is a cost that will be taken into account, and it is calculated with the following formula:

$$N = \frac{p * n * k}{d}$$

Where:

N= annual cost of one type of tire (euros)

p= price without tax of the replacement of such a tire (euros)

n= number of tires of this type

k= kilometers traveled annually by the vehicle (kilometers)

d= average duration of this type of tire (kilometers)

- Maintenance and repairs

This is the total annual cost of vehicle and equipment maintenance and necessary repairs. Just as the cost of tires depends on the route chosen, although it is less important in the total economic cost, the formula for calculating the annual cost of maintenance and repairs is:

$$M = m * k$$

Where:

M= annual cost of maintenance and repairs (euros)

m= kilometer cost without tax of maintenance and repairs of the vehicle and equipment (euros / kilometer)

k= kilometers traveled annually by the vehicle (kilometers)

Another cost depending on the chosen route are the tolls, which can be considered as kilometer costs and will be taken into account in the calculation of economic costs, as well as those of fuel consumption, tires and maintenance.

Apart from fixed and variable costs, there are other types of direct costs called indirect costs, which are those not directly attributable to the operation of the vehicle, but which necessarily occur for the proper functioning of a company. These include infrastructure costs (offices, cleaning, rent, security, etc.), administration and management costs (staff, office equipment, communications, etc.) and commercial costs (staff and business expenses).

Variable or kilometer costs depend on the chosen transport route, while fixed and indirect costs do not. For this reason, fixed costs will not be taken into account in the present study due to the fact that the same type of vehicle, the same load, the same company, the same driver, the same insurance…, are considered equal, so their costs will be the same regardless of the route.

The following is an example of the direct economic costs of a general cargo articulated vehicle in 2019 with the following starting assumptions:

DATOS DE PARTIDA

Actualización a 31 de enero de 2019

Características técnicas:			
Vehículo articulado de carga general			
Potencia:	**455** CV	**335** kW	
Masa Máxima Autorizada:	**40.000** kg		
Carga útil:	**25.000** kg		
Número de ejes:	**5**		
Número de neumáticos:	**12**	6 tractor (2 direccionales y 4 motrices)	
		6 semirremolque	
Características de explotación:			
Recorridos en carga superiores a 200 km			
Kilometraje anual:	**120.000** km anuales		
Recorrido anual en carga:	**85,0** %	102.000 km anuales	
Recorrido anual en vacío:	**15,0** %	18.000 km anuales	
Días trabajados al año:	**225** días al año		
Horas trabajadas al año:	**1.800** horas anuales		
Consumo medio:	**35,0** litros/100 km		
Hipótesis:			
Precio de venta de la cabeza tractora según tarifa (sin IVA):	**113.982,69** €	Descuento sobre tarifa:	**10** %
Precio de venta del semirremolque según tarifa (sin IVA):	**35.440,32** €	Descuento sobre tarifa:	**5** %
Vida útil de la cabeza tractora:	**6,0** años		
Vida útil del semirremolque:	**8,0** años		
Valor residual sin IVA de la cabeza tractora sobre el precio de tarifa:	**20** %		
Valor residual sin IVA del semirremolque sobre el precio de tarifa:	**15** %		
Capital a financiar sobre el precio real de adquisición:	**100** %		
Período de financiación:	**5,0** años		
Interés de la financiación:	**3,85** %		
Coste anual del conductor (incluida Seguridad Social y otros):	**29.968,68** € / año		
Dietas y plus de actividad anuales:	**14.247,87** € / año	Dieta media:	**33,15** € / día
		Número de días:	**225** días
		Plus de actividad:	**0,056576** € / km
Coste anual de seguros (Responsabilidad Civil del tractor, semirremolque y mercancías, seguro de la mercancía, accidente del conductor, retirada de carné, daños propios, asistencia en viaje, rotura de lunas y defensa jurídica):	**6.356,44** € / año	RC cabeza tractora:	**1.548,58** € / año
		RC semirremolque:	**488,55** € / año
		RC mercancía:	**116,08** € / año
		Accidente del conductor:	**53,88** € / año
		Retirada del carné:	**134,11** € / año
		Seguro mercancías:	**657,09** € / año
		Daños propios:	**2.894,34** € / año
		Asistencia en viaje:	**290,47** € / año
		Rotura de lunas:	**118,30** € / año
		Defensa jurídica:	**55,04** € / año
Coste fiscal anual (visados, ITV, IAE, IVTM y revisión tacógrafo):	**774,24** € / año	Visados:	**14,55** € / año
		ITV:	**99,66** € / año
		IAE:	**315,28** € / año
		IVTM:	**271,43** € / año
		Revisión Tacógrafo:	**73,32** € / año
Precio del gasóleo A en surtidor (con IVA):	**1,1581** € / litro	Descuento:	**0,0576** € / litro
		IVA:	**21,0** %
		Devolución por gasóleo profesional:	**0,0490** € / litro
Coste anual por consumo de disolución de urea (sin IVA):	**1.686,85** € / año		
Precio medio de un neumático (sin IVA):	**562,11** € / unidad		
Duración media de los neumáticos:	**150.000** km		
Coste de mantenimiento (sin IVA):	**0,015334** € / km		
Coste de reparaciones (sin IVA):	**0,030186** € / km		
Coste anual de peajes (sin IVA):	**1.955,02** € / año		
Costes indirectos (estructura, comercialización, ...):	**6,5%** de los costes directos		

Table 2: Starting assumptions for the direct economic costs (Source, Reprinted from: Observatorio de costes del transporte de mercancias por Carretera 2019). In Spanish.

VEHÍCULO ARTICULADO DE CARGA GENERAL

Costes a 31 de enero de 2019

	COSTES ANUALES	
	Euros (€)	Distribución (%)
Costes totales	128.194,07	100,0%
Costes directos	120.370,02	93,9%
Costes por tiempo	55.480,45	43,3%
Amortización del vehículo	15.858,32	12,4%
Financiación del vehículo	2.522,77	2,0%
Personal de conducción	29.968,68	23,4%
Seguros	6.356,44	5,0%
Costes fiscales	774,24	0,6%
Costes kilométricos	64.889,57	50,6%
Combustible	36.141,17	28,2%
Consumo de disolución de urea	1.686,85	1,3%
Neumáticos	5.396,26	4,2%
Mantenimiento	1.840,08	1,4%
Reparaciones	3.622,32	2,8%
Dietas	14.247,87	11,1%
Peajes	1.955,02	1,5%
Costes indirectos	7.824,05	6,1%

Table 3: Total direct costs (Source, Reprinted from: Observatorio de costes del transporte de mercancías por Carretera 2019) In Spanish

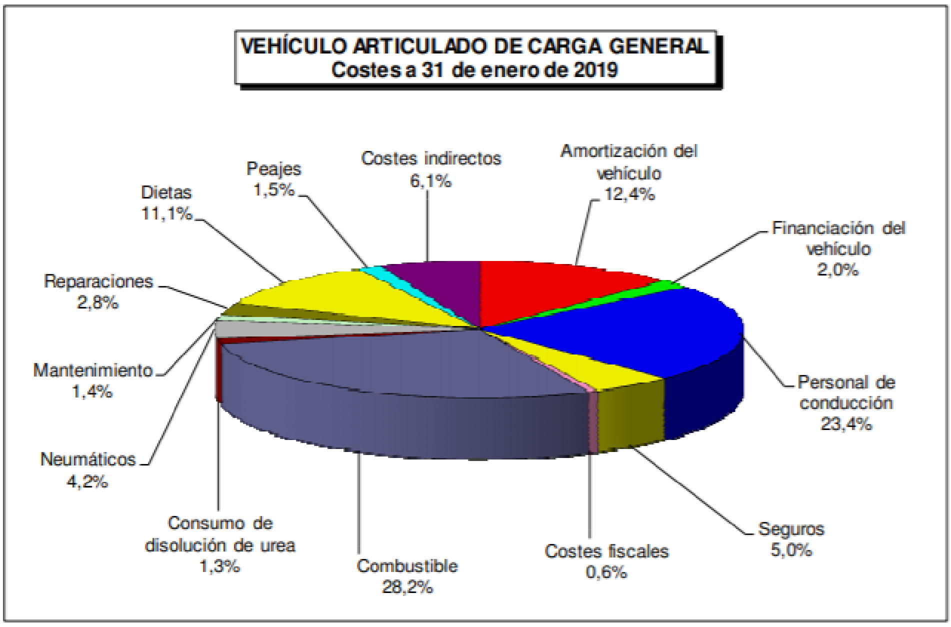


Figure 3: Graph representing the percentage of each of the direct costs (Source, Reprinted from: Observatorio de costes del transporte de mercancías por Carretera 2019) In Spanish

As can be seen in the Figure 3, the main cost is fuel consumption and this is where this work will be focused, because it depends on the characteristics of the route. Other costs such as tires, tolls, maintenance and repairs are less important in the total cost but will be considered approximately when the economic cost balance for the different transport routes will be done in the following sections.

2.1.3 Techniques to reduce variable costs

To reduce these variable costs, there are different techniques that allow us to improve efficiency by reducing them. Some of these techniques are explained below:

- Vehicle maintenance and care

Proper maintenance of the fleet is key to its operation, affecting vehicle safety, availability and fuel consumption. Since an incorrect maintenance can give rise to mechanical failures, increase of fuel, increase of stops... all this contributing to an increase of costs.

It is therefore necessary to check the tires every little time since they must have the right pressure. Low pressure results in higher rolling resistance with worse curve behavior and increased working temperature, increasing the probability of blowouts and considerably increasing consumption. On the other hand, with a high pressure the tread is concentrated in the central area of the tire, increasing consumption, and producing a greater tire wear.

It is also necessary to control the oil, air and fuel filters, because if there are not, greater load losses in the filters causing an increase in fuel consumption, and probability of failure or engine breakdown.

The load must be properly protected with well-tensioned and fixed canvases, and thus achieve a reduction in the aerodynamic resistance of the vehicle contributing to significant savings in fuel consumption.

Other systems to consider when reducing energy consumption are air conditioning and heating systems, which increase consumption.

These aspects mentioned are summarized in the fact that the driver or transporter must be perfectly aware of the vehicle and its characteristics, and thus be able to maintain it in the most optimal conditions, reducing fuel consumption, the deterioration of tires, and reducing the problems or breakdowns that may appear, minimizing the cost.

- Route optimization

Route optimization allows us to reduce fuel consumption by studying and analyzing different alternatives in terms of vehicle choice, route selection and occupancy rate.

Knowing the place of collection and delivery, the vehicle that can cover the needs and is closer to the point of collection will be used, thus reducing the kilometers made. In the event of having several vehicles that meet the above conditions, the one with the lowest consumption will be selected to cover the task.

When choosing the route, we will study which of them minimizes fuel consumption according to their orographic characteristics, if the time requirements are met. This will be the basis of the present work, in which fuel consumption between two routes is compared depending on how the characteristics of these routes affect them.

Another aspect of route optimization is to ensure that vehicles run as few empty kilometers as possible, since these journeys only generate unnecessary fuel consumption. To do this it is necessary to optimize the space of the vehicle and try to get 100% of the load and minimize the number of journeys.

- Telematic systems for management assistance

These systems allow to know the position of each vehicle and to decide how to cover the work. In addition, they have information on the state of the roads in real time that allows to anticipate the inconveniences of traffic saturation such as accidents, traffic jams, road repairs, retentions..., achieving a reduction in costs.

- Efficient driving

Efficient driving can be summarized in a series of rules by the driver, that allow to reduce fuel consumption, reduce maintenance, reduce emissions, increase comfort, reduce the risk of accidents, transforming all this in an economic saving.

These rules can be summarized as follows:

  - Knowledge of vehicle characteristics
  - Start the engine without stepping on the gas pedal and wait a minute
  - Use 1st gear only to start the vehicle
  - Perform gear changes in the maximum engine speed range
  - Use the gear that allows the engine to run in the lower part of the maximum torque range
  - Uniform and stable speed avoiding unnecessary acceleration and braking
  - Take advantage of the inertia of the vehicle, decelerate by taking your foot off the accelerator
  - Make greater use of the engine brake
  - During long stops, turn off the engine
  - Leave a safe distance

- Rest well and not drive for many hours at a time

All these rules must be applied if the vehicle is adapted to them and as long as the traffic circumstances allow it without reducing safety.

This efficient driving on the part of the driver can be reinforced by training drivers and by incentive systems that reward low fuel consumption to the drivers.

There are studies (Government of Canada, 2020), that conclude that with efficient driving, trying to have the engine at its optimum speed of revolution, up to 25 % of fuel consumption is saved.

2.2 External costs of transport

In the basic general equilibrium model economic agents interact only through their effect on prices. When the actions of one agent affect the environment of another agent other than by affecting prices, we say that there is an externality implying an imbalance in the market which is less efficient, leaving the option of intervention by the public sector to increase this market efficiency and reach the lost balance. By this definition (Forkenbrock, 1999), external costs and benefits are outside normal market processes and are not reflected in prices.

External costs are side effects of transport and, "without policy intervention they are not taken into account by the transport users" (Maibach et al, 2007). External costs (or negative externalities) must be added to private costs to arrive at full social costs. Thus, to achieve full social cost pricing of transportation services, one must first comprehensively and accurately estimate relevant external costs. If external costs are greater than external benefits, not considering externalities may lead to over-consumption of transportation.

In economic terms, the external costs of a product or service can be a source of market failure because these occur outside the market. It is desirable to internalize all costs of transportation, first because the demand-and-supply equilibrium will occur at a more sustainable level, and second because providers are more likely to be more responsible for their decisions and customers will use the services more efficiently. Therefore, corrective measures would be proposed by governments, designing taxation and regulation policies to compensate for this externality, achieving the internalization of external costs and thus reaching the lost balance in the market.

The internalization of external costs forms part of a package of initiatives aimed at making transport more sustainable (Schroten et al, 2019). It consists of including external transport costs (pollution, noise, congestion, etc.) in the price paid by the user to encourage them to change their behavior. Placing an appropriate monetary value on external costs is vital to internalizing them; that is, requiring those who generate these costs to compensate society in an amount equal to the external costs. Internalizing external costs makes it possible to return to society an amount equal to the costs one imposes; it also gives a clear signal of the actual full cost of an activity, so that consumption decisions can be made based on this cost. In other words, externalities should be paid by companies that generate them; this may be realized by government, market, or private organizations.

External costs are not easy to evaluate and to monetize. Indeed, it is difficult to measure physically the damage because the scope of the externality is not totally known, the effect is uncertain and can vary a lot from an individual to another, and externalities happen with different time horizons. Moreover, for most externalities, there are no markets on which they can be exchanged at a commercial value (Mostert and Limbourg, 2016).

External costs thus deal with two main steps: determination and valuation of the impact. When there is no market price, different methods of evaluation exist: damage cost (consists in defining the real damages caused by the external costs), avoidance cost (is based on scenarios and determines which costs are generated for avoiding a specific amount of externalities in the future) or opportunity (or willingness-to-pay) cost method (identifies the external cost value as the price that should be paid to an economic agent, who suffers from the externalities, in order to accept to support the external effect).

That is why there are so many different articles or documents related to the identification and computation of external costs of road and intermodal transport. They differ in terms of their perspective (academic or project-oriented), the type of externality (air pollution, climate change, noise, accidents, congestion) and the type of cost (marginal, average, total) that they consider, and as we see the different method of evaluation of the cost (damage, avoidance or opportunity cost).

Author	Air pollution	Climate change	Noise	Accidents	Congestion	Costs: Average (A) Marginal (M) Total (T)	Perspective: Academic Project-based	Objective Prescription Application Projection
Forkenbrock (1999)	X	X	X	X		A	Academic	Application
Forkenbrock (2001)	X	X	X	X		A	Academic	Application
Sansom (2001)	X	X	X		X	A, M	Project-based	Application
Mayeres (2001)	X	X		X	X	M	Project-based	Application
RECORDIT (2001)	X	X	X	X	X	M	Project-based	Application
Beuthe et al. (2002)	X	X	X	X	X	M	Academic	Application
INFRAS/IWW (2004)	X	X	X	X	X	A, M, T	Project-based	Application
CAFE (2005)	X					M	Project-based	Application
HEATCO (Odgaard et al., 2005)	X	X	X		X	A, M, T	Project-based	Prescription
ExternE (Bickel et al., 2005)	X	X		X		M	Project-based	Prescription
HEATCO (Bickel et al., 2006a, 2006b)	X	X	X		X	A	Project-based	Application
Bickel et al. - UNITE(2006c)	X	X	X			M, T	Project-based	Application
Janic (2007)	X		X	X	X	A	Academic	Projection
Janic (2008)	X		X	X	X	A	Academic	Projection
Maibach et al. (2008)	X	X	X	X	X	A, M	Project-based	Application
Van Essen et al. (2008)	X	X	X	X	X	M	Project-based	Prescription
Delucchi and McCubbin (2010)	X	X	X	X	X	M	Academic	Prescription
Macharis et al. (2010)	X	X	X	X	X	M	Academic	Application
Janic and Vleugel (2012)	X	X	X	X	X	A	Academic	Application
Michiels et al. (2012)	X					M	Academic	Application
Cravioto et al. (2013)	X	X	X	X	X	A, T	Academic	Application
Moliner et al. (2013)			X			A	Academic	Application
Pérez-Martínez and Vassallo-Magro (2013)	X	X		X		M	Academic	Application
Ricardo-AEA (2014)	X	X	X	X	X	A, M	Project-based	Application
van Lier (2014)	X	X	X	X	X	M	Academic	Prescription
Agarwal et al. (2015)	X	X			X	M	Academic	Application
Austin (2015)	X	X		X	X	A, M	Project-based	Application

Table 4: Summary of the main external costs characteristics studied in the literature (Source, Reprinted from: External costs as competitiveness factors for freight transport – a state of the art. M. Mostert (2016))

In transport, marginal cost refers to the additional cost provoked by the transport of one additional unit. If a freight carrier pays marginal user charges that equal the marginal social cost of the unit of freight, the provider of transportation service is paying appropriately, from a societal perspective. Average cost refers to the total transport costs divided by the number of units transported, average cost studies need less data but provides worse precision results while these estimates provide an overall sense of the magnitude of various types of external costs generated by freight trucks.

The general steps in estimation of freight transportation externalities are:

- Define a quantifiable variable that measures a specific externality
- Estimate different damages caused by each externality
- Estimate monetary value of damages

Negative routing externalities can be classified into four different impact areas:

- Economy. Which include congestion, road damage, building damage and longer travel times.

- Society. Where accidents, visual intrusion and noise pollutions are included.
- Ecology. Comprising biodiversity destruction, fauna and flora, and climate change.
- Environment. Including waste, air and water pollution.

The main externalities caused by road freight transport are air pollution, greenhouse gases (GHG), noise pollution, water pollution, congestion and accidents, which are going to be explained in the following sections.

According to the report of INFRAS (2004), the greenhouse gases or climate change is most important part of the external costs 30%, while air pollution and accident costs account for 27% and 24% respectively. The congestion costs are also important but are studied in a different way.

2.2.1 Air pollution

Emissions cause damage to the environment on local and global scales, affecting people, materials, vegetation, animals, and soil. Local when the effects linked to the focus are suffered in the surroundings of the same, and global when, because of the characteristics of the pollutant, areas far from the sources of pollution are affected. This air pollution is formed by the combustion of hydrocarbon fuels in internal combustion engines of vehicle, with the formation of toxic and carcinogenic substances.

Air pollution from cars and trucks can be primary or secondary pollution. Primary pollution is emitted directly into the atmosphere, and secondary pollution results from chemical reactions between pollutants in the atmosphere. Pollutants are harmful in terms of their direct damage to environment and health and are also associated with a number of health issues, such as asthma in children and other respiratory diseases, heart disease, cancer, and increased rates of premature death in adults.

The principal emissions are particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), Sulphur dioxide (SO2), Volatile organic compounds (VOCs) and other gases. The magnitude of this air pollutants depends on vehicle characteristics (engine type and condition, fuel type, vehicle age…), road characteristics (speed, traffic congestion, gradient road…), and driver behavior (idling, acceleration profile…).

- Particulate matter (PM)

This particulate matter have different sizes, the heavier particles are quickly deposited in the soil, buildings and vegetation causing deterioration damage, but the fine particles may pose more severe health risks, due to the fact that they are easily inhaled and penetrate deeper into the lung associated with a number of serious health issues.

- Nitrogen oxides (NOx)

These pollutants form ground level ozone and particulate matter (secondary). Also harmful as a primary pollutant, NOx can cause lung irritation and weaken the body's defenses against respiratory infections such as pneumonia and influenza.

- Carbon monoxide (CO)

This odorless, colorless, and poisonous gas is formed by the combustion of fossil fuels such as gasoline and is emitted primarily from cars and trucks. When inhaled, CO reduces bloods oxygen-carrying capability; this can lead to acute effects or chronic effects, such as, headaches, increasing the risk of heart disease and damage in other vital organs.

- Sulphur dioxide (SO2)

Power plants and motor vehicles create this pollutant by burning sulfur-containing fuels, especially diesel and coal. Sulphur oxides cause breathing problems and acid rain. Regional impacts derive from acidification and ground level ozone.

- Volatile organic compounds (VOCs)

These pollutants react with nitrogen oxides in the presence of sunlight to form ground level ozone, a main ingredient in smog. Though beneficial in the upper atmosphere, at the ground level this gas irritates the respiratory system, causing coughing, choking, and reduced lung capacity. VOCs emitted from cars, trucks and buses, which include the toxic air pollutants benzene, acetaldehyde, and 1,3-butadiene, are linked to different types of cancer.

Besides the direct harms of CO, VOCs, and NOx, they are precursors to ozone (O3) formation (the formation of smog in cities) and indirect contributors to global warming.

The main source sectors contributing to emissions of air pollutants in Europe are transport, the commercial, institutional and households sector, industry, energy, agriculture and waste.

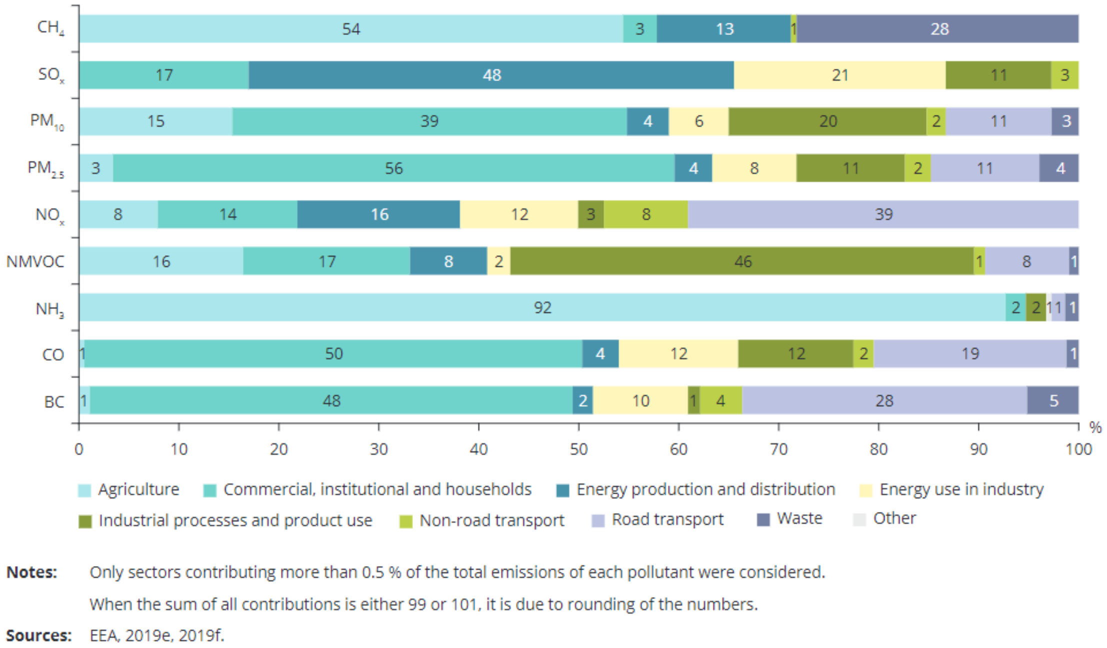


Figure 4: Contributions to EU emissions from main source sectors (Source, Reprinted from: EEA 2019)

Transport is the source of nearly 11% of particulate matter, 20% of CO, and 40% of NOx. Here is included the passenger and freight transport. These emissions have decreased significantly, although transported passenger and freight volumes have been gradually increasing. Even the transport sector is the largest contributor to NOx emissions knowing that diesel vehicles produce more, so must be reduced.

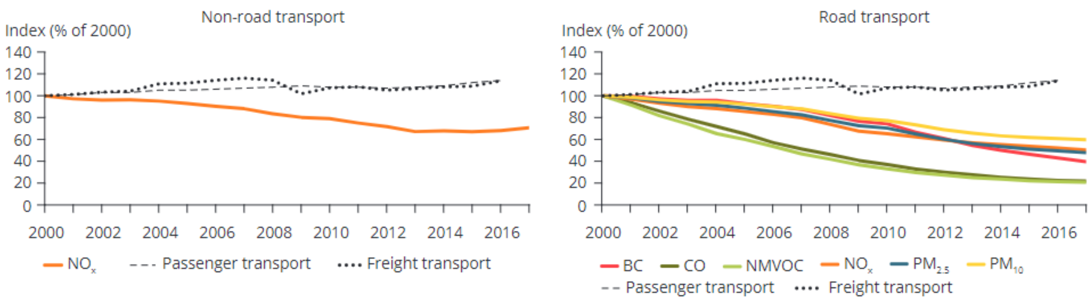


Figure 5: Trends in EU emissions. (Source, Reprinted from: EEA 2019)

As we see in the Figure 5, the emissions have decrease significantly during the last years due to the new European policies and regulations that will be explained at the end of this chapter.

As we see, there are different pollutants but each one has a different external impact so their external cost are different between them.

Define the quantifiable variable is done measuring the different air pollution emissions. But the estimation of the damages caused by these emissions and his monetary value is hard to make. For these external costs produced by the air pollution there are several studies as we saw in the Table 5.

STUDIES	COST
ECORYS (2004)	0,89 cents/ton-km
Maibach et al. (2008)	1,4-38,3 cents/vehicle-km
McAuley (2010)	0-0,38 cents/ton-km
Delucchi and McCubbin (2010)	0,05-8,36 cents/ton-km
Swarts et al. (2012)	0,31 cents/ton-km
VTPI (2013)	0-2,39 cents/ton-km
Korzhenevych et al. (2014)	0,3-56,6 cents/vehicle-km
Lemp and Kocklman (2008)	0,07-0,95 cents/ton-km
Parry et al (2007)	0,8 cents/ton-km
Zhang et al (2004)	0,32 cents/ton-km
Forkenbrock (2001)	0,051 cents/ton-km
Levinson et al (1998)	0,44 cents/ton-km
Small and Kazimi (1995)	5 cents/vehicle-km
Transportation Research Board	1,7-2,5 cents/ton-km

Table 5: Estimations costs for air pollution from different studies (Source: Self production)

As will be seen later, the monetary cost of air pollution used in this work includes a table with the value in euros/kg for each type of pollutant or emission. This will be explained in more detail in the following sections.

2.2.2 Greenhouse gasses (GHG)

Greenhouse gasses are not classified as pollutant in the classical sense. However, they are danger to human health. GHG emissions constitute a threat to society by contributing to global climate change. There are different GHG emissions such as CH_4, O_3, NO_2, and other gasses, but CO_2 is the dominant one, and the impacts of all these gasses are calculated based on carbon dioxide equivalent. So, CO_2 equivalent can be expressed as:

$$CO_{2e} = CO_2 + 25CH_4 + 298N_2O$$

The black carbon (BC) is not a gas, is a solid particle that also contributes to warming of the atmosphere. Is consider as a particulate matter (PM).

Greenhouse gases vary in their relative contributions to global warming; i.e. one ton of methane does not have the same impact on warming as one ton of carbon dioxide. But CO_2 is by far the most important greenhouse gas released by human activity, accounting for about 85% of total emissions weighted by global warming potential.

Greenhouse gases in the atmosphere trap heat and make the planet warmer. Human activities are responsible for almost all the increase in greenhouse gases in the atmosphere over the last 150 years, increasing the temperature by more than one degree. The largest source of greenhouse gas emissions from human activities are from burning fossil fuels for electricity, heat, and transportation.

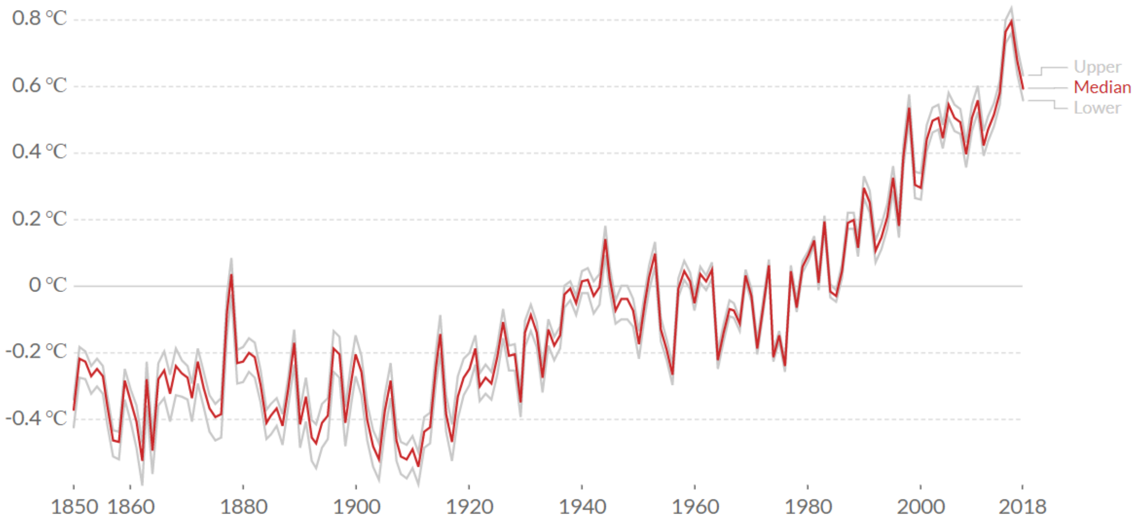


Figure 6: Temperature evolution over the years (Source, Reprinted from: Hadley Center)

CO_2 is a byproduct of any engine that burns carbon-based fossils fuels. As air pollutants share the same emission sources. That is why the air pollution and CO_2 emissions in transportation are studied in a similar way and are the most studied external costs of the freight transportation.

As in the air pollution case, the difficulty lies in calculate the monetary value of these negative impacts from the greenhouse gasses. There are different studies that estimate this monetary value.

STUDIES	COST
Climate Framework (FUND)	5-20 € per ton CO2 equivalent
Maibach et al. (2008)	20-85 per ton of CO2
Delucchi and McCubbin (2010)	0,0002-0,0188 $ per ton-km
Forkenbrock (2001)	0,1 $ per ton-km
ECORYS (2004)	0,26 cent/ ton-km
McAuley (2010)	0,04-0,07 cent/ton-km
VTPI (2013)	0,07 cents/ ton-km
Korzhenevych et al. (2014)	2,3-13,2 cents/vehicle-km

Table 6: Estimations costs for GHG from different studies (Source: Self production)

In this project, the impacts of the air pollution and the greenhouse emissions will be studied by applying two different mathematical methods that estimate fuel consumption and CO_2 emissions.

These methods will be explained in the following sections, as well as the monetary conversion of these emissions into economic costs.

2.2.3 Noise pollution

Noise is a serious problem because can disturb sleep, disrupt activities, hinder work, cause stress, changes heartbeat frequency. Noise pollution in more of a concern in urban than rural transportation areas. Lower levels of noise, below 55 dB, can be acceptable in a short time duration, but harms to human health may occur as the duration increases. Noises in moderate levels (61–85 dBA) may increase the risks of cardiovascular diseases and result in nervous stress reactions. Noises above 85 dBA could cause severe hearing damages.

How disruptive traffic noise is at nearby locations depends on the volume, speed, and composition of the traffic. Medium to heavy trucks are 10-18 decibels (dB) louder than passenger cars. Also is know that the noise decreases with the distance, is less noise pollution when the traffic flow increases. Conditions like topography, trees, buildings can also influence noise levels.

There are different international organization that published noise regulations and policies, such as International organization for standardization (ISO), United Nation’s Economic Commission for Europe (UNECE), which limits the dB depending on the type of vehicle. For years to come these limits will be decreased considerably, that is why the silent vehicle is taking importance in the automotive industry.

MOTOR VEHICLE TYPE	LIMIT (dB)
Vehicles intended for the carriage of passengers and having not more than 9 seats including the driver's seat	74
Vehicles intended for the carriage of passengers, having more than 9 seats including the driver's seat, a maximum permissible mass exceeding 3.5 tons and: - An engine power of less than 150 kW - An engine power of 150 kW or more	 78 80
Vehicles intended for the carriage of passengers, with more than 9 seats at most including the driver's seat, and vehicles intended for the carriage of goods: - with a maximum authorized mass not exceeding 2 tons - with a maximum authorized mass of between 2 and 3.5 tons	 76 77
Vehicles intended for the carriage of goods, with a maximum authorized mass exceeding 3.5 tons and: - engine power less than 75 kW - engine power of 75 kW or more, up to 150 kW - engine power of 150 kW or more	 77 78 80

Table 7: Sound limits in the EU (Source, Adapted from: TFG Miguel Angel Sola Freire)

These limits can change in certain areas during the night that is why there are certain hours when trucks are not allowed to drive.

As we see, the noise pollution has consequences on the human health but due the non-linear characteristics of noise pollution, the monetary estimation is rather complex. In the case of noise, its diffusion and range are known to be related to the distance from the source to the receiver. This fact, assimilated by all as something natural, makes it interesting to look for routes that do not cross or pass near population centers, if this is possible. The geometric dispersion of sound energy in space is the result of the propagation of the sound wave, which always suffers an attenuation in the sound level when the distance from the receiver to the observer is increased.

When the dispersion is spherical (all directions) the decrease in noise by making the distance double the surface of the wave front becomes four times greater, and the sound pressure decreases by 6dB (Embleton, 1996).

On the other hand, if we consider the propagation of the noise in cylindrical form, the emission of the noise is along an axis, and in this case the area of the cylinder is proportional to the distance, and therefore the decrease in the level of noise is 3dB by doubling the distance.

In the second case, if we consider a receiver close to the road, the noise level it receives will depend almost exclusively on the vehicle driving in front of it, since the rest are relatively far away. This would be the case of a vehicle passing alone on the road. Therefore, a receiver close to the road will be affected by a fluctuating noise level between maximum and minimum. If the receiver is moved away from the road, the other vehicles start to play an important role, since the distances between the receiver and the different transmitter sources are comparable.

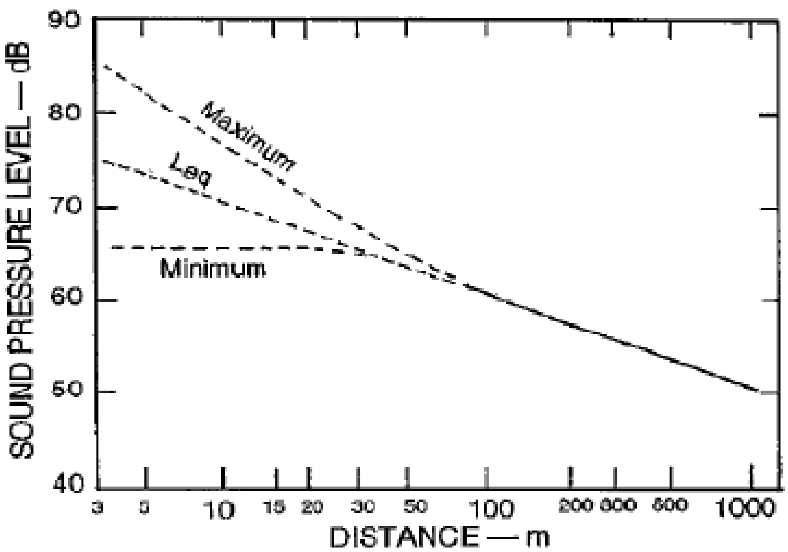


Figure 7: Noise attenuation with distance (Source, Reprinted from: Embleton 1996)

Noise pollution in road transportation is mainly caused by the sound of the vehicle engine and the sound of rolling. There are different models for the calculation of noise pollution depending on the vehicle type, payload, speed, road gradient, road surface and impact duration, such as Imagine that provides a noise emissions model in terms of a sound power level in dB. For the monetary estimation of these emissions we have several studies as we can see in the next table:

STUDIES	COST
Eropean Commission studies	0.08-0.26$ / vehicle-km
Federal Highway Administration (FHWA)	0.0713$ / vehicle-km
Forkenbrock (1999; 2001)	0.05 $ / ton-mile
Delucchi and Hsu (1998)	LDVs: 0-3.45$ /passenger-mile HDTs: 0-5.48$ /ton-mile
Levinson et al. (1997, 1998)	0.87$ / passenger-mile

Table 8: Estimations costs for noise pollution from different studies (Source: Self production)

As can be seen, the cost estimation of the noise pollution is complex and that is why there are different studies which conclude in different units and cost values, due to each one considers different parameters or characteristics.

Today, the government bodies, whether at the municipal or regional level, are taking measures in this respect, by modifying the infrastructures and creating new ones, such as the bypasses and the ring roads that surround towns of a certain size. The problem is that there are still many smaller towns that are directly crossed by roads, and in some cases with large volumes of traffic.

Other measures that are being taken in more specific cases are the installation of noise barriers between roads and residential areas. In this way, the sound waves that reach homes are softened, although not completely reduced.

The main difference between noise pollution and air pollution is the duration over time.

Noise pollution is pollution that affects people instantly and disappears when the source of the noise is gone, while emissions are cumulative and their health consequences do not disappear quickly, as these emissions accumulate over time and stay in the air regardless of whether or not vehicles pass through the area.

This is why greenhouse gases and air pollution are said to have worse long-term health consequences than noise pollution, leading to more studies than noise.

2.2.4 Water pollution

Fuels and chemicals from transportation modes can spill and leak into oceans, rivers, lakes, and groundwater. This water pollution can harm human health, injure and kill wildlife or corrode materials. Transportation modes also can cause water pollution indirectly: emissions of nitrogen oxide from fuel combustion can eventually deposit as nitrate and cause nitrogen pollution in aquatic systems, also the air pollution that causes acid rain impact in the water pollution.

However, the impact of the road transportation in water pollution is not as important as other external impacts, and many times is not considered. That is why there are not many studies that quantified this economic cost on road transportation. For example, estimate the water pollution costs by road freight transportation as 0.003-0.051$ per ton mile (Delucchi and McCubin, 2004), where the indirect water pollution such as nitrogen pollution and acid rain are excluding.

This impact gains importance in the maritime transportation where is the most important external cost.

2.2.5 Congestion

The congestion or crowding of vehicles happens in transportation networks when entities compete individually for a limited capacity, and generates external impacts including increased travel times, operating cost, uncertainty on the reliability of arrival and delivery times, boarding or disembarking time…

Numerous reasons can be responsible for delay on transportation infrastructure, such as, road works, accidents, driving behavior, and high flow/capacity ratios. Consequently, vehicles have to move slower than expected, and users need more time than they would have without the obstacles. From an economic point of view, time losses can be expressed in monetary terms.

The direct impact of congestion, as a freight transportation externality, refers to increased travel times to other entities in the transportation system. This costs for the congestion delay on the road are equal to hours of delay multiplied by value of opportunities foregone during an hour of delay. The value of an hour of delay depends on the type and value of the activity being displaced and the conditions of the delay.

Because the theory is relatively well developed and most of the parameters (e.g., traffic volumes, average speed, and personal income) are relatively easy to estimate (compared, for example, with the estimation of parameters in the calculation of climate-change externalities), estimates of national average-annual delay costs for roads tend to be relatively robust. There are several studies that resume this costs depending on the conditions of the delay and the value of the activity (Zhang et al, 2016; Calfee and Winston, 1998; Meng et al, 2010; Uchida, 2014).

Although, the congestion in road transportation could also indirectly cause different costs such as, increased fuel and energy costs, increased air pollution and greenhouse gasses, increased stress levels and uncomforting of passenger travel, wasted time, affect the frequency and severity of accidents, increases vehicle wear and tear…, which are not considered in the monetary value, but as the rest of externalities costs, its practically impossible to calculate the real cost accurately and therefore we work with estimations. In this way, the congestion external cost is studied differently from other externalities because these delays can include or cause other external cost.

2.2.6 Accidents

Accidents are unfortunate incidents that occurs unexpectedly and causes material or load damages, production losses, delay times and congestions, personal injuries, or fatal human life losses.

These fatalities have their monetary and nonmonetary cost. The monetary cost of accidents is paid by affected road users, so these are viewed as internal costs, including automobile insurance and medical and emergency service. But the biggest challenge is the estimation of the value of non-monetary impacts such as pain and suffering and lost quality of life or human life, also the increased travel time and emissions.

For this nonmonetary estimation there is a large literature on this. The accident costs can be quite uncertain due to the type of accident and its effects. One of the most used points of view to estimate the external cost, is to view the cost as the amount of money that people would pay to reduce the risk of that type of accident happen, which can be translated into contracting an insurance.

All these costs can be internalized by contracting different types of insurance that will cover all the possible consequences of an accident that are not cover with the mandatory insurances. For example, to cover protection of vehicles, mechanical guarantee, civil liability for your activity, civil liability of directors and administrators, civil liability for accidental pollution and environmental risks, damage to transported goods, insurance of the death of employee, permanence award and severance payments for the employee.

Other external costs from an accident mentioned before such as the increases of emissions, congestion and increases time travel, should be taken into account in their respective external costs of air pollution and congestion, but its known that is difficult to estimate them exactly.

In addition, the goods that they transport when suffering an accident can be polluting, toxic, ignitable..., causing other external impacts that have not been taken in consideration when estimating their cost such as fires, land contamination, water pollution...

2.2.7 Other external costs

There are other external costs beyond those estimated here, such as land use, construction and maintenance of transportation elements (roads, bridges, tunnels…), vehicle construction, …

These external costs are less important and include all users of the road, so can't be estimated as externality of the freight transportation because are considered as global transportation externalities.

2.3 Policies to reduce externalities

In summary, air pollution, climate change or greenhouse gasses, and accidents, are the most important externalities of freight transportation. That is why there are more documents talking about these externalities.

Air pollution and climate change are closely interrelated because share the same emission source and can be estimated in a similar way calculating the fuel consumption. Comparing with other externalities, these external costs are easier to estimate although they are not exact.

However, all the external costs must be considered for those who generate these costs to compensate the society or the one who suffer these externalities. For these to happen, it is imperative to placing an appropriate monetary value on external costs to internalizing them. As we see before, there exits many studies and documents that estimate the external monetary cost.

An overview of external cost figures.

		AP	GHGs	NP	WP	CN	AC
Road							
1	€ct/tkm	0.89	0.26	0.28	–	2.26	0.43
2	€ct/vkm	1.4–38.3	1–2.9	0.13–12.7	1.05	2–3.5*	0.09–27.54
3	€ct/tkm	0–0.38	0.04–0.07	0–0.02	–	0–9.21	−0.01–1.27
4	€ct/tkm	0.05 –8.36	0.0–0.21	0.0–2.37	0.0–0.02	0.24	0.05–0.89
5	€ct/tkm	0.31*	–	0.13	–	0.13	0.32
6	€ct/tkm	0.0–2.39	0.07	0.02	–	0.01–0.29	0.07–0.26
7	€ct/vkm	0.3–56.6	2.3–13.2	0.7–35.8	–	0.0–404	0.1–46.2
Rail							
1	€ct/tkm	0.46	0.46	0.09	–	–	0.14
2	€/km	0.14–7.19	0.31–0.35	0.05–1.71	0.01	−1–0.2	0.08–0.30
3	€ct/tkm	0.0–0.13	0.02	0.0–0.01	–	0.0–1.30	0.03
4	€ct/tkm	0.0–0.07	0.0–0.09	–	–	0.01	0.05
5	€ct/tkm	0.05	–	0.0	–	–	0.03
6	€ct/tkm	0.02–1.13	–	0.01	–	–	0.01–0.03
7	€ct/tkm	0.08–0.9	0.26	0.02–0.90*	–	0.2	0.02
Maritime							
1	€ct/tkm	0.56	–	–	–	–	–
2	€/km	0.89–12.60	0.08–1.14	–	–	–	–
4	€ct/tkm	0.04–0.76	0.0–0.10	–	–	–	–
6	€ct/tkm	0.43	–	–	–	–	–
7	€ct/tkm	0.87–6.40	0.5–0.41	–	–	–	–
Air							
2	€/LTO	45–300	130–3710	90–1200	–	−16–10*	12–309
4	€ct/tkm	0.0–0.85	0.20	–	–	–	–
7	€/LTO	75–416	465–13,308	0.0–702	–	0.9–1.0**	–

1: ECORYS (2004); 2: Maibach et al. (2008); 3: McAuley (2010); 4: Delucchi and McCubbin (2010); 5: Swarts et al. (2012); 6: VTPI (2013); 7: Korzhenevych et al. (2014); **€/minute; tkm:tonne-kilometer ; vkm: vehicle-kilometer; LTO: Landing/take-off cycle.
* €/kilometer.

Table 9: Overview of external costs (Source, Reprinted from: Demir et al 2015)

Internalizing external costs makes it possible to return to society an amount equal to the costs one imposes, and the company pays his real costs and ensure a sustainable transport. Current taxes do not cover all external costs, so action must be taken with different taxes or by raising current taxes.

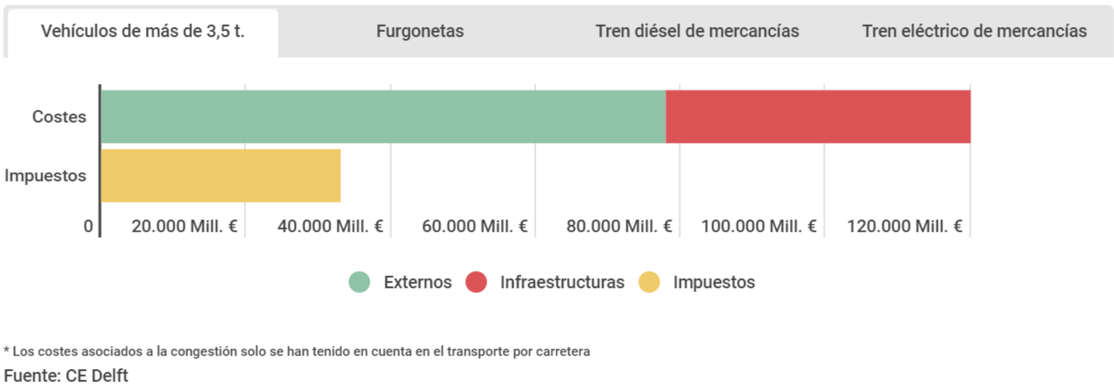


Figure 8: Difference between external costs and taxes (Source, Reprinted from: DELF) In Spanish

For a real internalization of external costs can be considered different policies such as:

- Introduction of a tax based on the number of kilometers travelled by freight vehicles throughout Europe and considering the type of vehicle according to its fuel consumption, taking into account not only the costs caused by accidents but also the environmental costs resulting from air pollution, climate change and noise. The application of this tax should be extended beyond the highways.
- Implementation of car tolls, especially in urban areas, to solve congestion problems.
- The eco-tax imposed to achieve Kyoto's climate targets of CO_2 should increase to be suitable with its external real cost.
- Forcing companies to take out insurances for covering all external consequences costs of an accident.
- Green tax, that is a road user charge for heavy vehicles to account for external costs of air and noise pollution, this toll is Europe is called Eurovignette.
- Green toll, that is paid when a vehicle crosses a high quality environmental area, according to the category of this area and the type of vehicle.

With these different policies and regulations in each country, are internalized different external costs. So, if negative externalities are reduced, the company's economic costs will be reduced.

Green logistics is the process by which all logistics and transport techniques carried out by a company are developed around protecting the environment and making efficient use of available resources, reducing the negative externalities. These types of initiatives are closely linked to the corporate social responsibility of companies, which provides numerous competitive advantages, such as ecological benefits by reducing the impact on the environment, translated into economic benefits because making more efficient use of resources will reduce many unnecessary expenses, allowing you to work more efficiently. This allows the business to work with a more sustainable strategy, gaining a greener image that today is highly valued by customers.

Some techniques that can reduce the costs of externalities are explained below:

- Promote the use of electric or less polluting vehicles.
- Reduce fuel consumption with route optimization and efficient driving.
- Optimize the load on each truck to reduce the number of trips, taking advantage of return trips. This is called the optimization of backhauls in the vehicle routing problem.
- Use the technology that allows to know the state of the road and traffic in real time, avoiding wasting time and congestion.
- Whenever possible use intermodal transport, because road transport has the greatest environmental impact.

If a company reduces its external impacts, there will be benefits for society (ecological, social, and economic) and for the company itself.

3. Description of the problem

Once the characteristics of freight transport, its direct costs and the cost of its external impacts have been described, this chapter will provide a justification for this project, the characteristics of the two alternative routes for transport between Pamplona and Irun, and the relationship between fuel consumption with air pollution and greenhouse gasses.

3.1 Justification of the project

Globalization, relocation, and economic development have led to an increase in international freight traffic in recent years. Road transport between Spain and the rest of Europe is inevitably done by crossing the mountain range of the Pyrenees. On average, 141,820 vehicles crossed the French-Spanish border each day in 2015. All these flows are currently channeled through two routes through the Pyrenees: La Jonquera AP7 (Girona)- Le Boulou A9 (France) and Irun AP8 (Guipuzcoa)-Biratou A63 (France). 90.3% of truck traffic was on these 2 roads, nearly about 40% on Irun and 50% on La Jonquera.

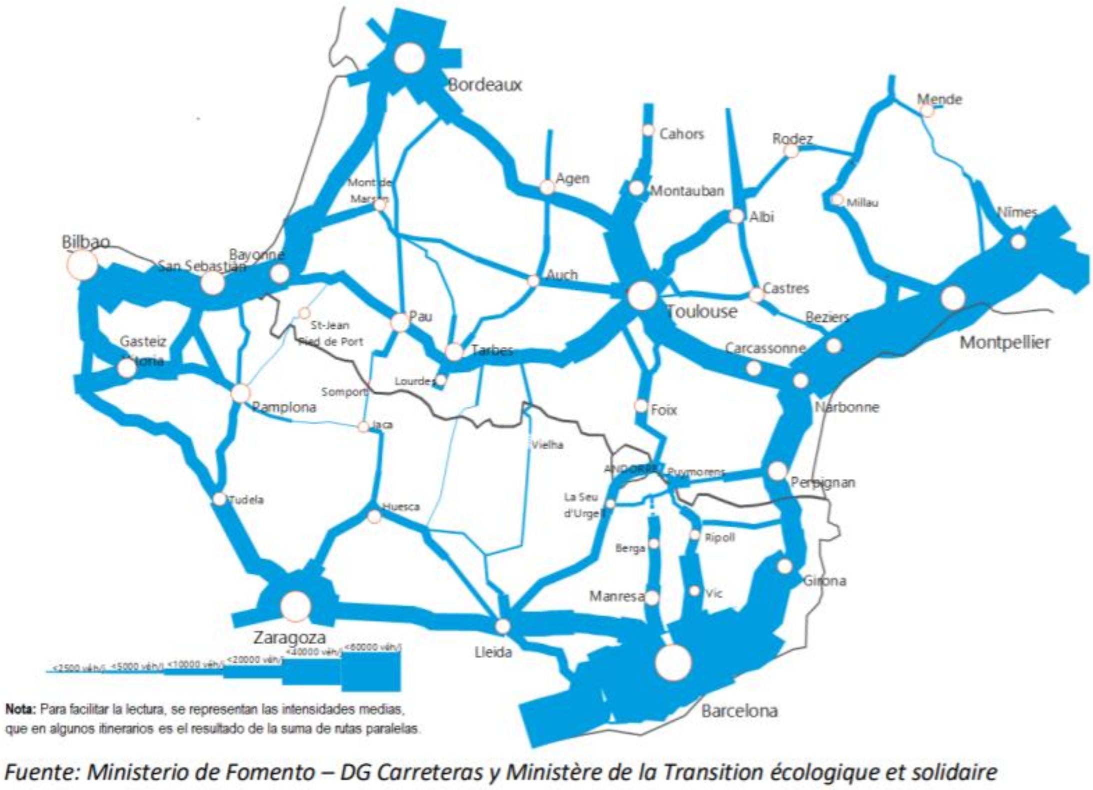


Figure 9: Average daily vehicle intensity on the different roads (Source, Reprinted from: Observatorio Hispano-Frances del tráfico en los Pirineos) In Spanish

According with the French-Spanish Observatory of Traffic in the Pyrenees, 2019, an average of 28,000 freight vehicles per day cross Irun in 2015, which 8,640 are heavy vehicles.

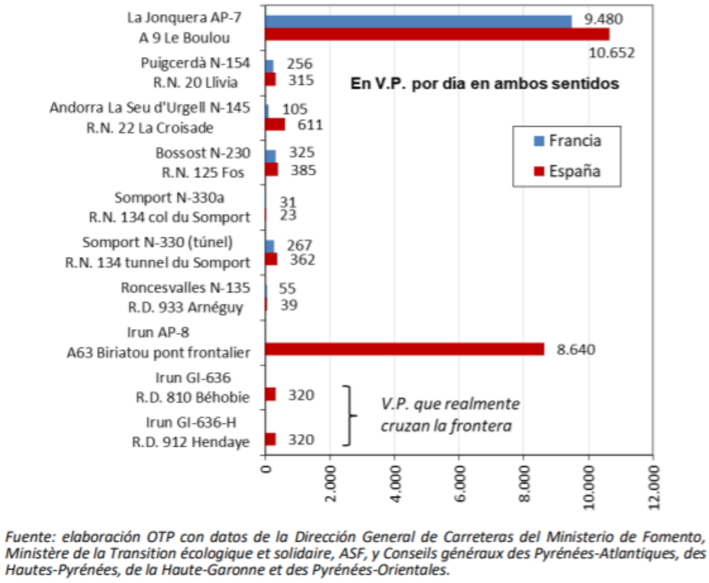


Figure 10: Graph showing the average daily intensity of heavy vehicles at the various border crossings between Spain and France (Source, Reprinted from: Observatorio Hispano-Frances del tráfico en los Pirineos) In Spanish

Due to its proximity to Irun, Navarre has an important role in the freight transport from Spain to France. Therefore, many transporters cross Navarre to reach Irun. This trip from Pamplona to Irun can be made by two alternative routes, through the AP15 motorway or by the N-121-A road.

Not all the route is in Navarre, as the final part is in Gipuzkoa. Although the work is for the Public University of Navarre (UPNA) and will focus more on the sections of the routes as they pass through Navarre, the sections that run through Gipuzkoa will also be studied.

To reduce their direct costs many transport companies, choose to drive on national roads avoiding motorway tolls. This has led to an increase in heavy goods vehicle traffic on the N-121-A. Therefore, this project will try to compare the external impact of these two alternative routes.

The environmental impact will focus only on air pollution and greenhouse gasses. Comparing fuel consumption between the two routes. For this, there will be used three mathematical model that estimate the fuel consumption based on the road characteristics.

The aim of this project is not to be a simply informative environmental document, so an economic balance will be done for both routes, including the direct costs, tolls and the external costs of air pollution and greenhouse gasses, internalized with the incorporation of a fictitious tax for the use of one or another road, subject to the principle of environmental responsibility (the one who pollutes pays). Allowing any company to decide which route to use according to its criteria and corporate social responsibility.

3.2 The Navarre geographical location

Navarre is slightly over 10,000 square kilometers and has around 650,000 inhabitants. The territory of Navarre presents very diverse orographic conditions. The northern half has a mountainous relief, due to the fact that it is in the western end of the Pyrenees mountain range. In contrast, the southern half of the found on the banks of the Ebro river, a mainly flat area. Between the two halves a transit sector can be seen that leads to a smooth passage between the plain and the Pyrenean mountain.

Figure 11: Location of Navarre in Europe (Source: Google Maps)

Navarre has a 163 kilometers border with France, surrounded by Aragon (Zaragoza and Huesca) to the east, La Rioja and Castilla y Leon to the south, and the Basque Autonomous Community (Alava and Gipuzkoa) to the northwest.

For this project it is important to know the functioning and situation of the roads of Navarre, their environment, and their transport and environmental policy.

3.2.1 Characteristics of Navarre's roads

Navarra has a radial structure, with its center in Pamplona from where the main roads start. There are two practically parallel roads that cross the Community from north to south and connect it with the A-I (Autovía del Norte), one of the main axes that connect Spain with Europe:

- N-121-A and N-121: Behobia - Pamplona and Pamplona - Tudela.
- AP-15: Navarra Highway (Tudela - Pamplona - Irurtzun)

On the other hand, it has several motorways (free roads) that provide connections with the main neighboring cities, facilitating access where the geography is more abrupt.

At the beginning of 2010, the road system of Navarra is made up of 3.821,73 kilometers, divided into two large groups: the High Capacity Roads, with 418.36 kilometers, and the Conventional Roads, with 3,403.37 kilometers. The following table shows the different types of road networks, as well as their length and percentage of the total system.

VARIACIÓN DE TRÁFICO E INTENSIDAD MEDIA DIARIA REGISTRADA EN NUESTRAS CARRETERAS

RED	LONGITUD	2016	2017	VARIACIÓN	LIGEROS	PESADOS
AUTOPISTAS	118,25	18.013	20.008	11,08%	11,31%	10,11%
AUTOVÍAS	223,74	12.698	13.674	7,69%	6,73%	12,67%
VÍAS DESDOBLADAS	25,60	30.228	31.321	3,62%	4,19%	-4,68%
CARRETERAS DE ALTAS PRESTACIONES	50,77	9.480	10.010	5,59%	3,55%	11,23%
TOTAL VÍAS DE GRAN CAPACIDAD	**418,36**	**14.850**	**16.100**	**8,42%**	**7,85%**	**11,23%**
CARRETERAS DE INTERÉS GENERAL	232,34	4.653	5.115	9,93%	7,41%	26,69%
CARRETERAS DE INTERÉS DE LA COMUNIDAD FORAL	1.021,04	1.818	1.808	-0,55%	-0,83%	3,65%
CARRETERAS LOCALES AFORADAS	1.011,76	730	718	-1,64%	-1,88%	2,70%
TOTAL CARRETERAS LOCALES	2.149,99	730	718	-1,64%	-1,88%	2,70%
TOTAL CARRETERAS CONVENCIONALES	**3.403,37**	**1.321**	**1.345**	**1,82%**	**0,82%**	**12,26%**
TOTAL	**3.821,73**	**1.767**	**2.961**	**67,55%**	**6,02%**	**13,44%**
IMD TOTAL RED AFORADA	**2.683,50**	**3.645**	**3.866**	**6,06%**	**5,16%**	**11,73%**

Table 10: Traffic variation and average intensity on Navarre's roads (Source, Reprinted from: Seguridad vial y centro de control Navarra 2017) In Spanish

As we see in the Table 10, traffic on Navarra's roads has increased from one year to the next, but to a greater extent on high-capacity roads than on conventional roads.

The characteristics of each type of road is explain below:

HIGHWAYS

- They consist of different roadways for each direction of traffic, separated from each other by a strip of land not intended for traffic, except in singular sections or on a temporary basis.
- They do not cross or are not crossed at the same level by another communication route, pedestrian crossings, bicycle paths, railway lines or other infrastructure.
- Neighboring properties do not have direct access to them.

- They are surrounded by a fence on both sides along their entire length.
- They have access control to the infrastructure. They are included in this class the toll-free sections of highways

MOTORWAYS

- They consist of different carriageways for each direction of traffic, separated from each other by physical elements of a longitudinal nature or a strip of land not intended for traffic, except for sections singular or temporary character.
- They do not cross or are not crossed at the same level by another communication route or right-of-way, pedestrian crossings, bicycle paths, line of railway or other infrastructure.
- Neighboring properties have limited access to them.
- They are fenced on both sides, along their entire length

UNFOLDED ROADS

These are the roads, generally of an urban nature, which meet the following conditions:

- They consist of different roadways for each direction of traffic, separated from each other by an urban-type central reserve, by a strip of land not intended for traffic, or by longitudinal physical elements, except in singular sections or on a temporary basis.
- Their intersections are preferably level with roundabout characteristics.
- They can be crossed at level by pedestrian crossings or cycle paths, unless road safety reasons justify crossings at a different level.
- Neighboring properties have limited access to them.
- No longitudinal fencing, except on specific stretches.
- They can be equipped with urban integration elements on their margins.

The unfolded roads are made up of the accesses to Pamplona, both the rounds and the accesses from the South and West.

HIGH-PERFORMANCE ROADS

- Two-way traffic on a single roadway, with the following available of separation elements for both directions of traffic.
- They have a significant percentage of the length of their route with a third lane for easy overtaking, and a fourth lane for slow vehicles on steep descents.
- Intersections with other roads will preferably be by means of links at different levels.
- Partial limitation of direct access from adjacent properties.
- No longitudinal fencing, except in specific sections.

The only road included in the High-Performance Roads category is the N-121A, from Pamplona to Behobia, with third overtaking lanes on the ramps.

GENERAL INTEREST ROADS

These are the ones that make up interautonomic or international routes and that support a significant volume of traffic.

ROADS OF INTEREST TO THE FORAL COMMUNITY

They are those that, without being of general interest, structure internally the territory of the Autonomous Community of Navarre, as well as those that structure the connections with neighboring Autonomous Communities or Regions.

LOCAL ROAD NETWORK

These are the ones that make up the capillary communications network, allowing connection between higher level roads and access to population centers, as well as non-structural connections with territories bordering the Autonomous Community of Navarre. The local road network are conventional roads, which characteristics are described below:

- Two-way traffic on a single roadway.
- The intersections with other conventional roads will preferably be at the same level.
- No limitation on access from adjacent properties, subject to the provisions of road safety regulations and design of roads.
- No longitudinal fencing.

The current situation and the evolution of traffic on the road network of Navarre is different for each type of road. The road network is lightly trafficked. More than 40% of the roads register intensities of less than 1,000 vehicles/day and only 11.6% support more than 10,000 vehicles/day.

However, the distribution is not uniform. The networks with the highest geometric performance and capacity (High Capacity Roads) record practically all intensities above 10,000 vehicles/day and most intensities above 4,000 vehicles.

On the other hand, conventional roads serve itineraries that rarely reach 4,000 vehicles per day. This pattern is accentuated until it reaches the local road network, which has the most limited geometric and capacity conditions, where almost has an average daily intensities less than 1,000 vehicles per day.

As we see in Figure 12, average daily intensities (IMD) are not uniform in all the region. They are higher in the highway AP15 Pamplona-Irurtzun, the unfolded roads surrounding Pamplona by these types of roads called rounds, and the N-121 coming from the south; which have an IMD above 20.000 vehicles/day.

The motorways connecting Pamplona-Estella A12, Tafalla-Tudela AP15, the A10 and A15 that appear when the highway AP15 end, connecting Irurtzun with Alsasua and San Sebastian respectively, and the beginning of the N-121A road; these roads have an IMD between 10.000 and 20.000 vehicles per day.

The connecting roads from Sangüesa to Pamplona, Estella to Logroño, Pamplona to Behobia, and Tafalla to Tudela by de N-121; are roads where the IMD is between 4.000 and 10.000 vehicles per day.

The central roads that run and divide Navarre from north to south and east to west are the most frequented. The rest of the roads which are practically all conventional roads, have less than 4.000 vehicles per day of average daily intensity.

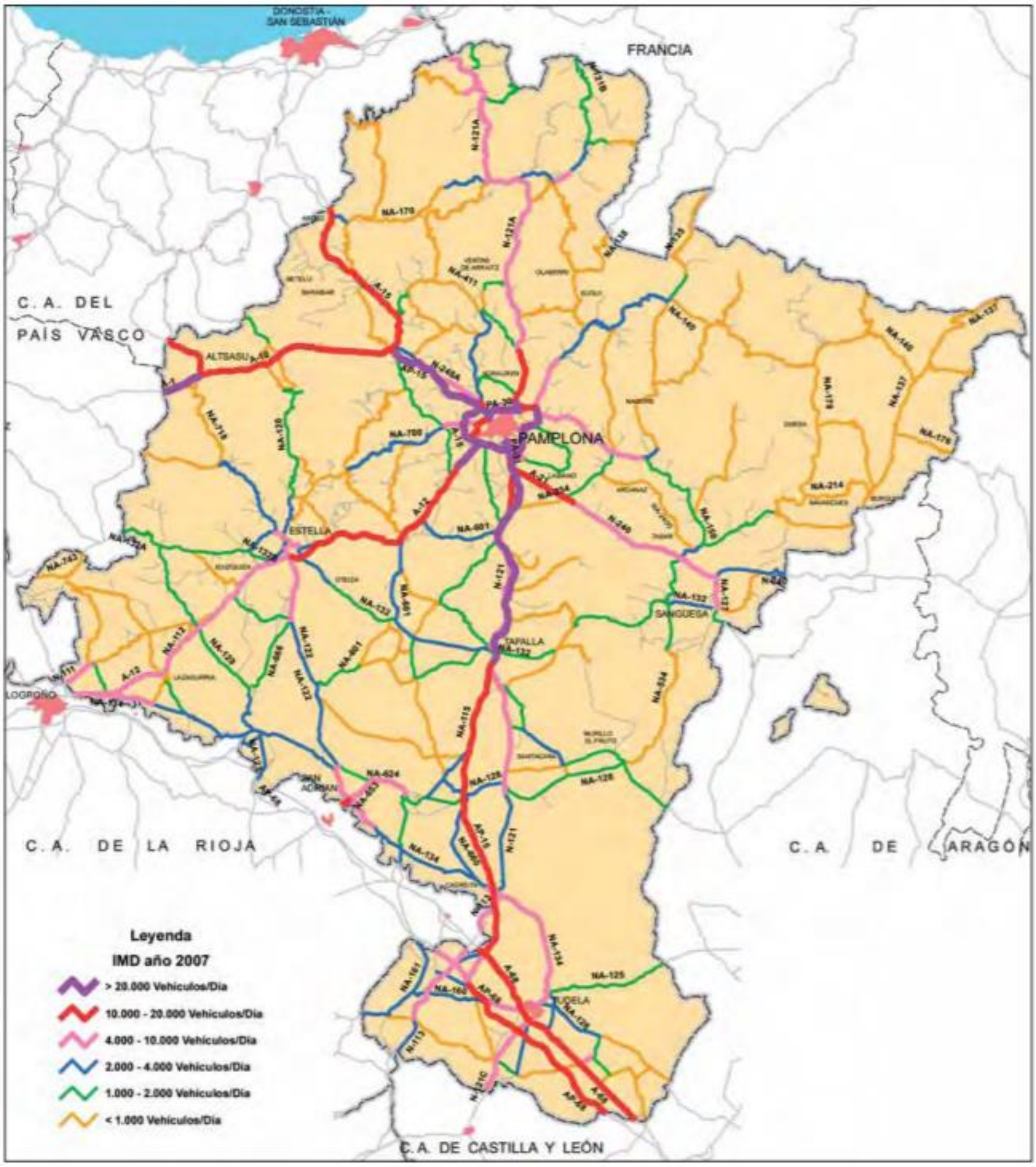


Figure 12: Map with the average daily intensity on Navarre's roads (Source, Reprinted from: III Plan director de carreteras de Navarra 2010-2018) In Spanish

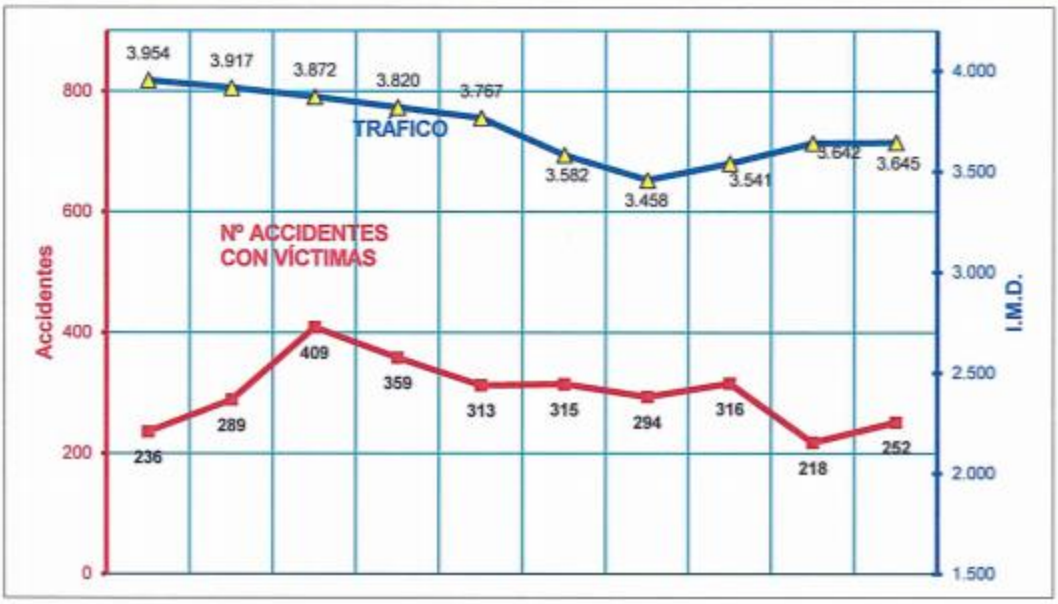
As in most developed countries, in Navarre deaths on the roads have decreased due to the regulations and policies imposed to improve the control and quality of roads, road safety, and improvements in vehicle safety in the event of accidents, although average traffic on Navarre's roads has increased. Also number of accidents have increased from 2016 to 2017 contributing the increasing of injured victims but reducing the mortal victims from 18 to 13.

YEAR	A.D.I.	N.º OF ACCI-DENTS WITH VICTIMS	Nº VICTIMS (DEAD AND IN-JURED)	N.º DEAD
1993	2,147	526	938	101
1994	2,334	587	1,056	63
1995	2,431	552	1,011	72
1996	2,539	405	755	69
1997	2,656	433	815	77
1998	2,858	515	963	97
1999	3,034	531	932	98
2000	3,195	463	914	99
2001	3,325	454	819	86
2002	3,462	415	767	79
2003	3,479	428	663	70
2004	3,649	362	608	62
2005	3,640	360	577	76
2006	3,808	253	403	42
2007	3,954	236	360	37
2008	3,917	289	439	35
2009	3,872	409	585	35
2010	3,820	359	564	31
2011	3,767	313	472	24
2012	2,772	315	489	32
2013	3,458	293	480	24
2014	3,541	316	484	36
2015	3,642	218	324	20
2016	3,645	252	385	18
2017	3,866	277	443	13

Table 11: Accidents on Navarra's roads (Source, Adapted from: Seguridad vial y centro de control Navarra 2017) In Spanish

According to the III Road Master Plan of Navarre 2010-2018, studying the evolution of traffic and accident rates in recent years shows an improvement in both accident and mortality rates in the Network as a whole and in each of them separately. It has gone from an average intensity of 2,858 vehicles/day in 1998 to 3,954 vehicles/day in 2007, an increase of 38.3%.

RELACIÓN	INTENSIDAD MEDIA DIARIA (vehículos/día) - ACCIDENTES CON VÍCTIMAS									
AÑO	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
ACCIDENTES	236	289	409	359	313	315	294	316	218	252
I.M.D.	3.954	3.917	3.872	3.820	3.767	3.582	3.458	3.541	3.642	3.645



RELACIÓN	INTENSIDAD MEDIA DIARIA (vehículos/día) - VÍCTIMAS MORTALES									
AÑO	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
MUERTOS	37	35	35	31	24	32	24	36	20	18
I.M.D.	3.954	3.917	3.872	3.820	3.767	3.582	3.458	3.541	3.642	3.645

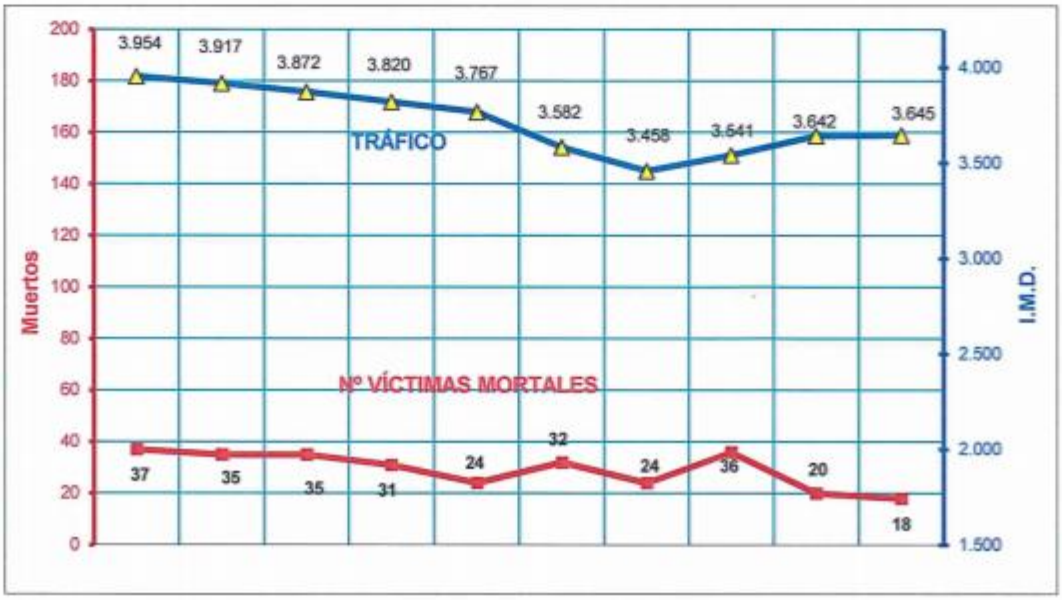


Figure 13: Graphic with the evolution of accidents and fatalities on Navarra's roads (Source, Reprinted from: III Plan director de carreteras de Navarra 2010-2018) In Spanish

These road accidents and deaths do not have the same frequency and consequences on one type of road or another. For this reason, the danger rate (IP) and mortality rate (IM) for each type of road are studied.

- Danger rate (IP):

$$IP = \frac{NAV * 10^8}{IMD * 365 * L}$$

Where NAV is the number of accidents with victims, IMD is the average daily intensity and L is the length of the section.

	INDICE DE PELIGROSIDAD EN LAS CARRETERAS DE LA COMUNIDAD FORAL									
AÑO	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Autopistas y autovías	2,9	3,6	5,0	3,7	3,2	4,0	3,6	4,0	2,0	2,7
Desdobladas	5,5	8,7	9,4	16,1	13,0	18,9	17,3	11,0	4,8	9,9
Altas Prestaciones	11,4	8,1	11,1	7,2	10,38	6,162	9,06	4,768	5,4	9,7
Red Interés General	7,3	13,3	12,4	12,3	14,4	13,5	12,9	14,7	9,7	10,9
Red Interés Com. Foral	8,2	9,3	14,8	13,6	10,9	11,3	10,2	12,6	11,2	9,2
Red Local	8,7	8,0	13,2	11,4	16,9	15,7	10,6	12,3	8,8	9,4

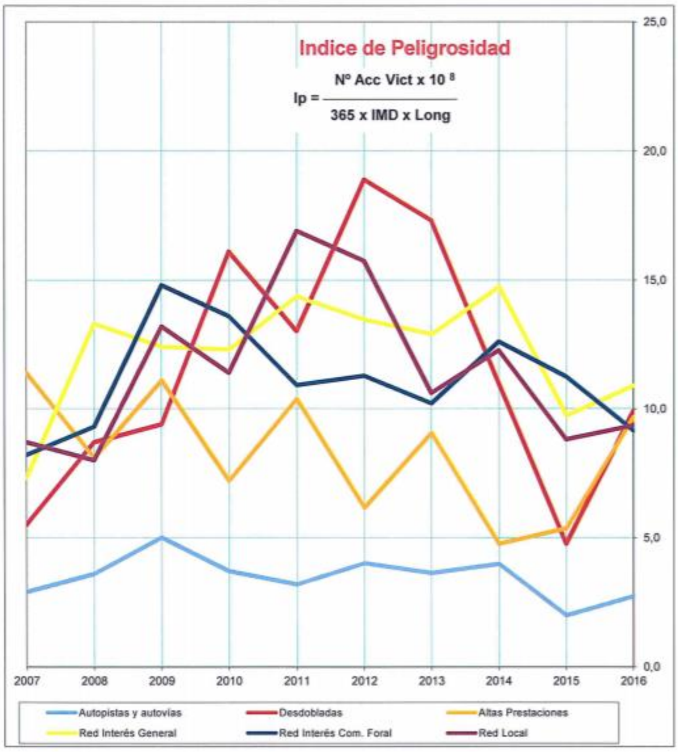


Figure 14: Graph with the evolution of the danger rate according with the type of road in Navarra (Source, Reprinted from: III Plan director de carreteras de Navarra 2010-2018) In Spanish

- Mortality rate (IM):

$$IM = \frac{VM * 10^8}{IMD * 365 * L}$$

Where VM is the death victim, IMD is the average daily intensity and L is the length of the section.

	INDICE DE MORTALIDAD EN LAS CARRETERAS DE LA COMUNIDAD FORAL									
AÑO	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Autopistas y autovias	0,3	0,4	0,4	0,3	0,3	0,7	0,4	0,4	0,1	0,3
Desdobladas	0,4	0,0	0,0	0,0	0,4	0,0	0,7	0,0	0,0	0,0
Altas Prestaciones		2,0	0,9	2,4	0,0	0	0,6	1,2	0,0	1,1
Red Interés General	1,8	1,9	1,1	0,7	2,5	1,6	1,3	3,2	1,8	0,5
Red Interés Com. Foral	0,9	0,3	1,2	0,6	0,3	1,7	0,9	1,8	1,2	0,9
Red Local	1,1	0,9	0,9	1,5	1,3	0,8	0,5	0,7	0,5	0,5

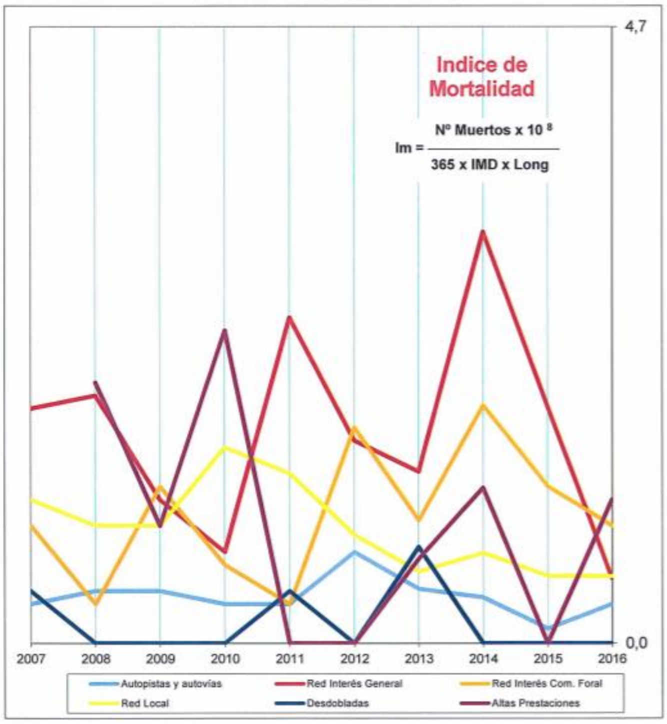


Figure 15: Graph with the evolution of the mortality rate according with the type of road in Navarra (Source, Reprinted from: III Plan director de carreteras de Navarra 2010-2018) In Spanish

These parameters are used to assess and make specific road safety assessments to reduce the number of accidents and fatalities in the different roads. As we see before in the Figure 14 and 15, the danger rate is quite similar in every type of road, around 10, except in the highway and motorway roads where the danger rate is 2,7 in 2016. The mortality rate is different in each type of road where the High-performance road have the higher rate with 1.1, and the unfolded road have a 0 mortality rate.

Accidents can be of different nature and due to the characteristics of each type of road, permitted speed, number of rails, size of roadside, separation between rails... also change their consequences. In Navarre, the principal types of accident are vehicle collision, road exit and animal run over which can be seen in the Figure 16:

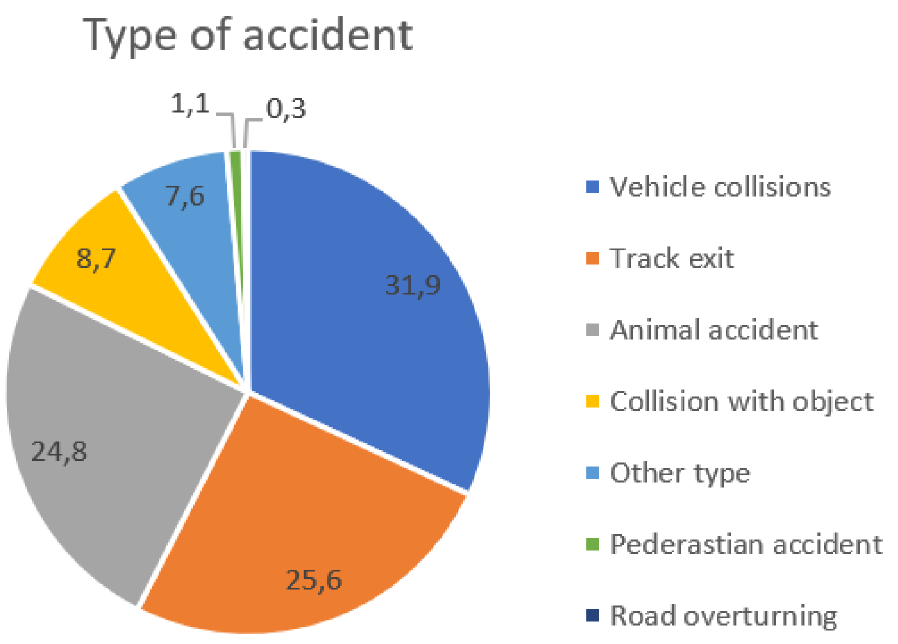


Figure 16: Graph according to the type of accident in Navarra (Source, Adapted from: Ministerio de Fomento)

The type of vehicle involved in the accident is usually a car or van, but there are also accidents with motorcycles, trucks, and bicycles, as can be seen in the following Figure:

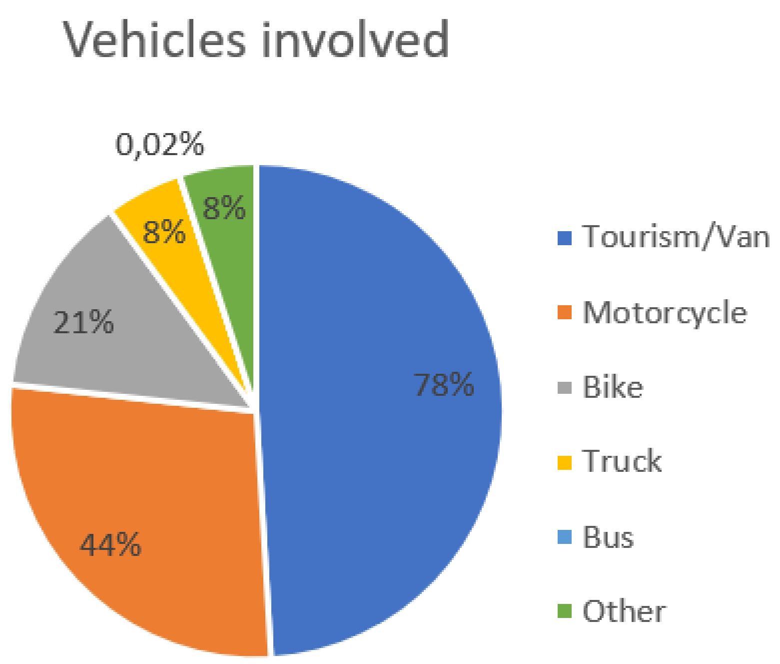


Figure 17: Graph showing the percentage of each type of vehicle involved in an accident in Navarre (Source, Adapted from: Ministerio de Fomento)

This is because accidents do not occur with the same frequency on different types of road. Neither is a two-car accident in the city the same as a two-car collision on the motorway, because their consequences are very different.

Therefore, the following Table shows the number of accidents and the number of fatalities for each type of road:

TYPE OF ROAD	Length (km) 2016	No. OF ACCIDENT S 2015	MORTAL VICTIMS 2015	No. OF ACCIDENT S 2016	MORTAL VICTIMS 2016
Highways-Motorways	371,9	34	2	48	5
Unfolded roads	25,6	13	0	28	0
High-Performance roads	50,8	9	0	17	2
General interest roads	232,3	37	7	43	2
Roads of interest to the foral community	1021	74	8	62	6
Local road	2166,4	51	3	54	3
TOTAL	3868	218	20	252	18

Table 12: Accidents with fatalities according to the type of road (Source, Adapted from: Seguridad y centro de control 2016. Dirección General de obras públicas)

As can be seen from Table 12, the greatest number of accidents occurs on the roads of interest to foral community due to their characteristics, as they are two-way roads with one lane each, where the speed limit is 90 km/h. The main accidents that occur on these roads are frontal collisions and road exits, which is why they have the highest number of fatalities. These is similar in the general interest roads and the local roads.

The number of accidents in the motorways is less than in the roads mentioned before however the mortality is similar due to the high speed is carried in these roads and the fatal consequences of it. In the high performance roads the number of accidents is much less than on the other roads because there is only one road included in this type of road (the N-121-A road). Most accidents here involve a truck because on this road the traffic of heavy freight transport in higher. Including pedestrian and bicycle accidents, which take place in towns and cities, and the section of the N-121-A that runs through Gipuzkoa, a high percentage of those killed in accidents occur on this road, specifically 9%. This can be seen in the Figure 18:

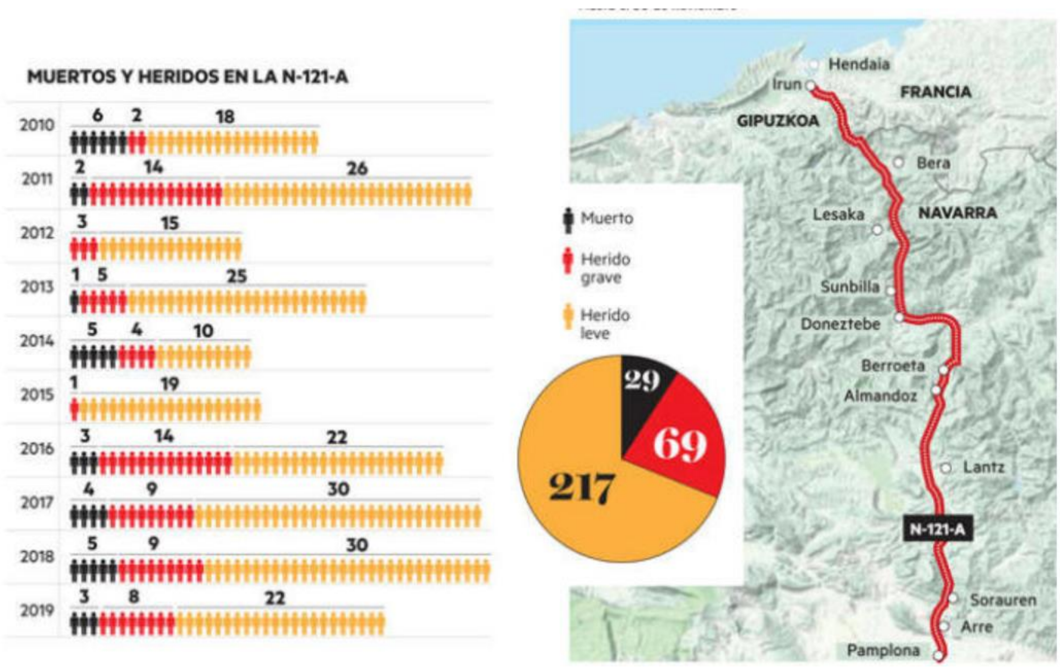


Figure 18: Evolution of accidents and deaths on the N-121-A (Source: Diario de Noticias. DGT) In Spanish

It is therefore worth noting that the total number of people killed between 2010 and 22 November 2019 on the N-121-A road is 29, while in the whole of Navarre a total of 327 deaths have been recorded in road accidents in the same period, which indicates that almost one in ten people who lose their lives in a road accident in the region do so on the N-121-A, a road that is 65 kilometers long, representing 1.7% of the road network in Navarre, as it is 3,821 kilometers long.

This is one of the worst aspects of this route, and work is being done to improve and reduce this number of accidents, trying to transform this road into a highway and reduce the flow of heavy vehicles, which although they are related in a minimum part of the accidents, they do favor overtaking by increasing its danger.

3.2.2 Environmental condition

Although it is a small community, three important geomorphological units converge in the territory of Navarre: the Pyrenean massif to the north, the Cantabrian mountain range to the northwest and the Ebro Valley to the south. This gives rise to a territory of great topographical and climatic contrasts and a diversity of natural environments between the north and south of Navarre. One third of Navarre's territory has altitudes between 600 and 1,000 meters above sea level. More than half is between 200 and 600 meters.

Due to its geographical location, there are three main types of climate in Navarre: the alpine or mountain climate characterized by low temperatures and strong snowfalls in winter, the oceanic climate with high rainfall and milder temperatures, and the continental Mediterranean climate with cold winters and hot summers. The first two ones are basically defined in the area of the Mountain of Navarre, in the north, the third in the Ribera and the Central Zone. There are intermediate areas, such as the Pamplona Basin, which participates in all the influences.

Biological diversity is the main feature of Navarre's natural wealth. This high level of biodiversity is largely due to its unique location, where three bio-geographical regions converge: the Alps, the Atlantic and the Mediterranean. However, it is also the result of the low population density (50 h/km2 compared to 77 in Spain), of a harmonious development that has combined economic and social growth with respect for nature, of the high environmental sensitivity of its inhabitants and of an advanced policy of habitat management.

Navarre is therefore a mosaic of landscapes that are home to countless species of animals and plants. Nine main ecosystems can be distinguished: alpine systems, river areas and wetlands, woodlands, Mediterranean scrublands, non-steppe grasslands and heaths, rocky areas, steppes, peat bogs and tufa, as well as salt marshes and endorheic lagoons. These ecosystems are home to species as varied as the brown bear, the European mink, the otter, the bearded vulture, the eagle, or the vulture to name a few.

The territory of Navarre is characterized by the importance of its natural resources, such as: forest land 363,000 Ha are wooded, cultivated areas represent 33.5% of the territory, and water resources with effective contributions of 5,000 hm3/year of water. The mountains of Navarre, in addition to maintaining the integrity of the water systems, supply clean water to the rest of the territory. Thanks to this, it can satisfy its needs and export more than 3,000 Hm3 a year to the Ebro basin, which represents 25% of its flow in Navarre.

Navarre has a Network of Protected Natural Areas made up of

- 3 Natural Parks (64,933 Ha)

- 3 Integral Reserves (487 Ha)

- 38 Natural Reserves (9,178 Ha)

- 28 Natural Enclaves (931 Ha)

- 2 Natural Recreational Areas (459 Ha)

- 17 Special Protection Areas for Birds, also called ZEPAS (79,950 Ha)

- 14 Wildlife Protection Areas (2,815 Ha)

ESPACIOS NATURALES PROTEGIDOS DE LA COMUNIDAD FORAL DE NAVARRA

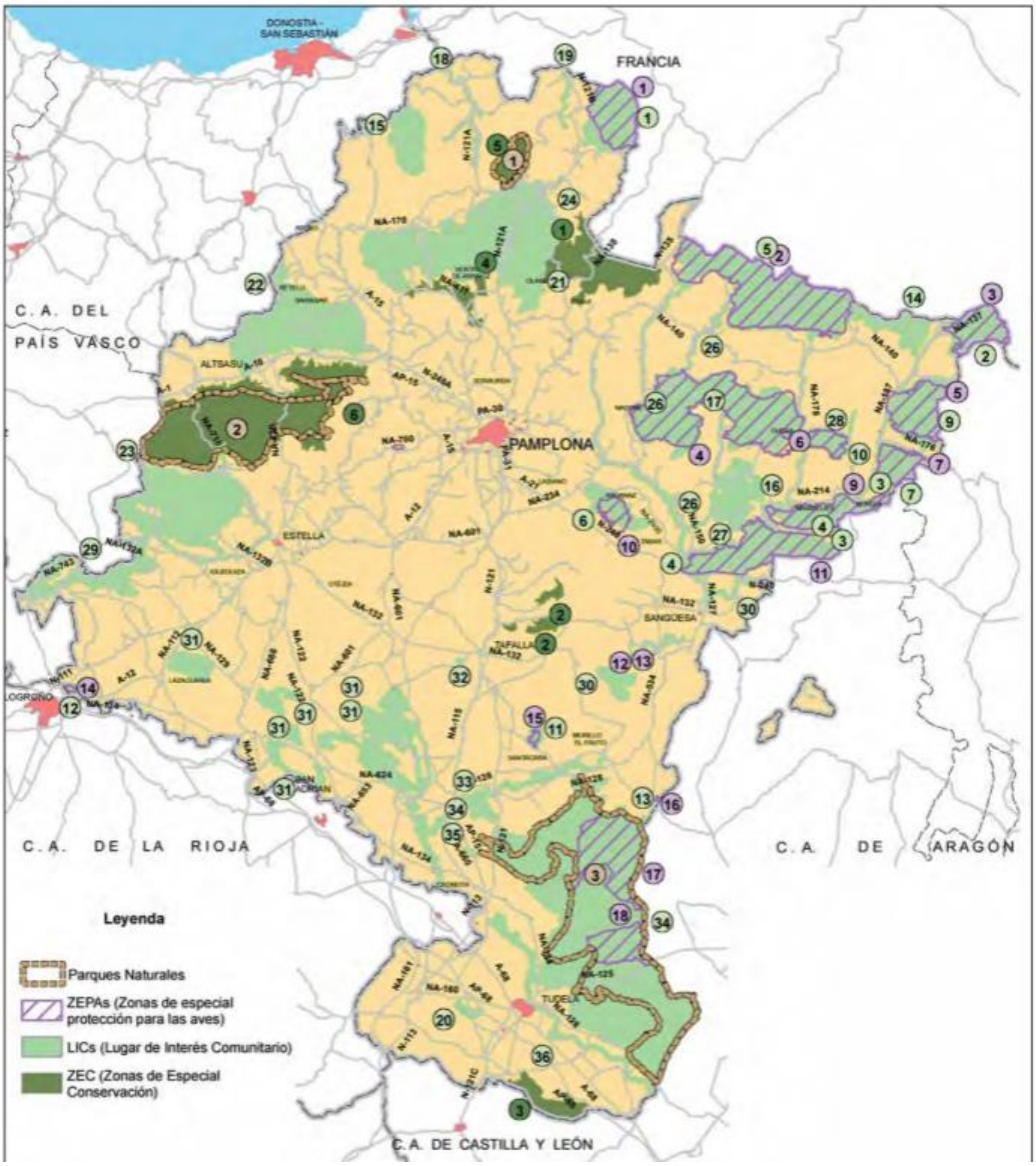


Figure 19: Map of protected natural areas in Navarre (Source, Reprinted from: III Plan Director de Carreteras de Navarra) In Spanish

All these natural areas are protected by different policies and laws which, are explain in the III Road Master Plan of Navarre 2010-2018, such as:

- Espacios protegidos por la ley foral 9/1996 (Natural areas protected by local law 9/1996)
- Espacios protegidos por la ley foral 2/1993 (Natural areas protected by local law 2/1993)
- Espacios protegidos por la ley foral 13/1990: MUP (Natural areas protected by local law 13/1990 MUP)

- Espacios protegidos por el decreto foral 4/1997: inventario de zonas húmedas (Natural areas protected by local law 4/1997: inventory of wetlands)

- Espacios protegidos por la directiva 79/409/cee: ZEPAS (Natural areas protected by Directive 79/409/cee ZEPAS)

- Espacios protegidos por directiva 92/43/cee: red natura 2000 (LICS) (Natural areas protected by Directive 92/43/cee nature network (LICS)).

Due to their size and importance, the three Natural Parks stand out declared: the Señorío de Bértiz (1 in yellow on the map of the Figure 19), Urbasa-Andía (2) and the Bardenas Reales (3).

The Señorío de Bértiz Natural Park covers an area of 2,040 hectares and is located in the municipality of Bertizarana, in Northern of Navarre, on the banks of the Bidasoa River. The park constitutes a unique complex due to its landscape, being one of the few valleys in the area that has a complete and continuous tree cover. It has a high-altitude gradient, as in just six kilometers there is a difference in height of over 700 metres between the banks of the Bidasoa and the Aizkolegi peak. Its vegetation and fauna are representative of the pre-Pyrenean valleys of Atlantic influence, although there are no endemic species.

The Sierras of Urbasa and Andía (21,408 Ha of Natural Park) are a natural area with a wide range of geological, biological, ecological, aesthetic, landscape, archaeological and socio-cultural values. They are located in the west of Navarre, in an intermediate position between the so-called Humid Navarre of the Northwest and the Western Middle Navarre or Tierra Estella. It is a plateau where the Atlantic world, which penetrates from the north, and the Mediterranean world, which penetrates from the south, converge. All this makes up a suggestive landscape of oaks, beeches, holm oaks and grasslands inhabited by a fauna that is valuable for its diversity. The park is a model of karstic landscape and a large part of Navarre's water resources are preserved in this area, as it constitutes a large underground reservoir, whose natural drainage flows outside to through hatcheries as spectacular as that of the Urederra.

The Bardenas Reales (40,000 Ha. of Natural Park) is an extensive territory in the south-east of Navarre, characterized by its climate of limited and torrential rainfall, hot summers and fairly cold winters. The vegetation is steppe and Mediterranean. The botanical interest of the flora and fauna of Bardenas is related to the unique climate of the Ebro depression, and has deserved to be included in the National Inventory of Habitats, drawn up under the auspices of Directive 92/43, CEE, of 21 May, on Habitats. This park was declared a World Biosphere Reserve in 2000.

As mentioned above, Navarre has a great biodiversity and has many species of native fauna and flora. Many of these species are threatened and in danger of extinction, which is why there are laws for the protection and conservation of the species.

ESPECIES DE VERTEBRADOS PROTEGIDOS Y SUS CATEGORÍAS

	Total	Autóctona	Alóctona	P.E.	S.	V.	I.	Ex.	%
Peces	27	21	6	-	-	-	6*	-	22
Anfibios	17	17	-	-	2	-	5	-	41
Reptiles	26	26	-	-	1	-	6	-	27
Aves	236	234	2	11	12	12	48	-	35
Mamíferos	78	75	3	5	1	5	12	3	33

Tabla: Especies de vertebrados protegidos y sus categorías

** El gobio, sólo en la vertiente cantábrica*

P.E.: En Peligro de Extinción. S: Sensibles a la alteración de su hábitat.

V: Vulnerables. I: De interés especial. Ex: Extinguidas

Table 13: Protected vertebrate species of Navarra (Source, Reprinted from: III Plan Director de Carreteras de Navarra) In Spanish

In addition, the Camino de Santiago (St James' Way) passes through Navarre. Pilgrimages to Santiago de Compostela began in the wake of the timely discovery of the tomb of the apostle St. James and his disciples in Compostela in the year 813. Christianity and the Christian kingdoms, embarked on the spirit of the Crusade against the Muslims, set out on a pilgrimage to visit the tomb of the apostle. This is how the Jacobean Way was created -the Main Street of Europe- which is culturally and religiously influenced by all of Europe, making roads that converge on the two main ones that crossed the Pyrenees at Roncesvalles and Somport. The Navarrese King Sancho III the Great (1004-1035), who exercised effective dominion over all Hispanic Christian kingdoms, was the one set the definitive route of the Camino. That is why there are also laws for the protection and conservation of the Camino de Santiago as it passes through Navarre.

As in the rest of the world, the average temperature in Navarre is rising due to climate change caused by greenhouse gases. In spite of having different types of climate, there are studies (Hoja de ruta cambio climatico Navarra, 2017) that demonstrate these climatic changes that are taking place in the area, such as a decrease in frosts, an increase in warm nights, a greater number of heat waves, less rains and an increase in the average temperature of 0.2ºC per decade.

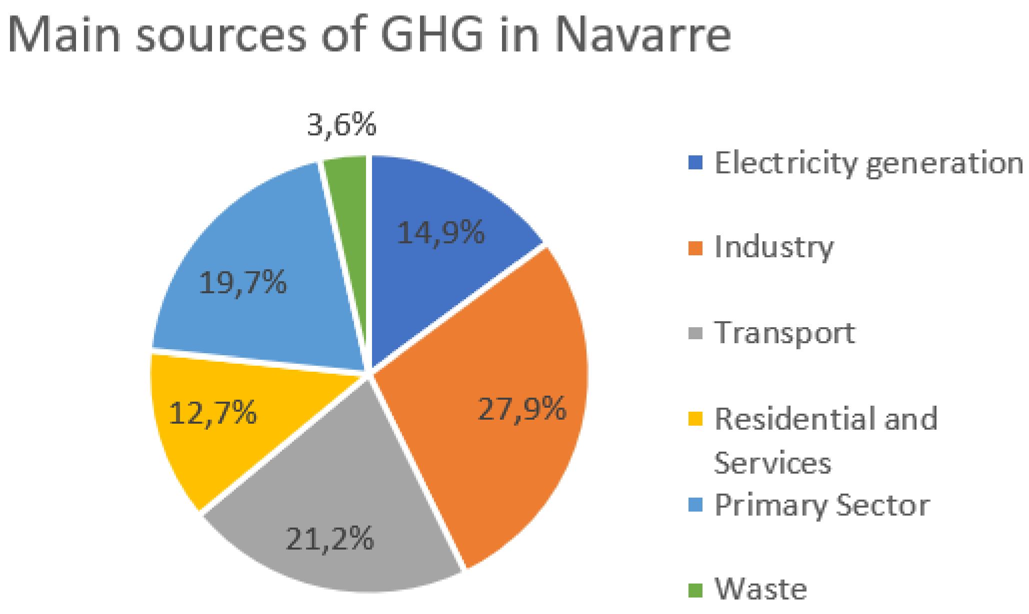


Figure 20: Graph of main sources of GHG in Navarra (Source, Adapted from: Hoja de ruta para el Cambio Climatico de Navarra 2030)

As we see in the Figure 20, the main source of greenhouse gas emissions is industry with a 27,9%, followed by transport 21,2%. Although emissions in Navarra have been reduced in recent years due to autonomous and national rules and regulations, to comply with European policies for curbing climate change.

Navarre has developed a short- and long-term strategic plan called the Roadmap for Climate Change in Navarre 2017-2030-2050, where measures and actions to be carried out in the coming years are explained, in order to reduce greenhouse gas emissions in the different economic sectors, as well as to raise awareness.

Navarra is committed to sustainability and the fight against climate change, in the direction of a new socio-economic and energy model with a low and adapted to the climate effects, to be a reference for sustainable development, with an environmentally responsible and resource-efficient territory, with a balance between people, their activity and the environment in which they are based, in line with the Intelligent specialization and the social policies of the Government of Navarre. All this in direct relationship with the United Nations Agenda 2030 (ODS).

In relation to transport and the environment, in which this work is carried out, in 2016, transport was the sector with the highest energy consumption. Only the road transport, was responsible for the consumption of 52 % of the total fossil fuels consumed in Navarre and 82% of oil derivatives.

Due to the geographical location, a large part of this consumption is due to transport of goods across Navarre. Despite this, the transport by road for passengers and goods, both urban and interurban, accounted for 21 %. of total emissions in 2016, being the second source of emissions after industry.

This sector is of great relevance since the from the point of view of its energy dependence and the growing cost of imported fuels, in addition to all the external environmental effects mentioned above, such as air pollution, noise, land use, etc.

For this reason, Navarre is committed to a sustainable transport model, it aims at three lines of action:

- Renewal of the vehicle fleet by low emission vehicles (MI-L6)

- Introduction of second-generation biofuels in transport (MI-L7)

- Promotion of public transport and emission-free vehicles (MI-L8)

These tasks are listed and explained in more detail in the Roadmap for Climate Change in Navarre 2017-2030-2050, which are summarized in the next Table:

TRANSPORTE (TR)
MI-L6 RENOVACIÓN DE LA FLOTA DE VEHÍCULOS POR VEHÍCULOS DE BAJA EMISIÓN
Nueva regulación para el vehículo eléctrico / Administración.
Renovación anual de la flota de la administración a vehículo eléctrico.
Instalación de puntos de recarga normal de acceso público. Interconexión y Corredores de movilidad / Iberdrola + Ingeteam + proyecto STARDUST.
Promoción de puntos de recarga en centros comerciales, empresas, parkings público de rotación, taxis, casas rurales, etc. / MOVEA + Iberdrola + Ingeteam.
Instalación de 10 puntos de recarga de alta potencia en el área de Pamplona / Iberdrola + Ingeteam.
Instalación de 10 puntos de recarga de alta potencia en el resto de Navarra (Alsasua, Estella, Liédena, Tafalla, Tudela, etc.) / Iberdrola + Ingeteam.
Ayudas MOVELE / MOVEA (taxis y MCP) y deducciones fiscales de hasta el 30%.
Ayudas MOVELE / MOVEA (coches particulares) y deducciones fiscales de hasta el 30%.
Ayudas a motos eléctricas y deducciones fiscales de hasta el 30%.
Integración del VE en el autoconsumo (filosofía del teléfono móvil). Deducciones fiscales de hasta el 30%.
Información, sensibilización y difusión del VE.
Reducción (o exención) del peaje en autopistas para los Ves.
Reducción del 75% del impuesto de circulación para los Ves.
Puntos de recarga vinculados. Smart Cities.
Mejora de la Infraestructura eléctrica de transporte (varios proyectos).
Proyectos de I+D+i de mejora de la tecnología para el VE (varios proyectos).
MI-L7 INTRODUCCIÓN DE BIOCOMBUSTIBLES DE SEGUNDA GENERACIÓN EN EL TRANSPORTE
Coches de Biogás: Adaptación de coches y aprovechamiento en origen / MCP, explotaciones ganaderas.
Varios proyectos para continuar fomentando la producción y uso de biocarburantes.
Proyectos de I+D+i de promoción de energías renovables (varios proyectos).
MI-L8 PROMOCIÓN DEL TRANSPORTE PÚBLICO Y VEHÍCULOS SIN EMISIONES
Uso de autobuses eléctricos en alguna línea con recorrido céntrico en Pamplona.
Ayudas a "First Movers" + proyectos innovadores, taxis y flotas de autobuses.
Incentivar los contratos de transporte laboral en las empresas.
Fomentar la inversión en vehículos pesados y autocares de combustibles fósiles más eficientes. Euro 6 y siguientes. Furgonetas N1 y N2.
Gestión y renovación de las flotas eléctricas / Ayuntamientos.
Adquisición o alquiler de bicis eléctricas para trabajadores públicos.
Cambio modal. Transporte compartido Public e-car-sharing.

Table 14: Objectives to be met in order to have a sustainable transport model (Source, Reprinted from: Hoja de ruta para el Cambio Climatico de Navarra 2030) In Spanish

3.3 Situation in Gipuzkoa

Gipuzkoa is a province of the Basque Country, and part of the two routes that connect Pamplona with Irun run through it. The situation of roads, its environment and environmental policies will be explained in the next paragraphs.

Gipuzkoa is one of the three Spanish provinces that make up the Autonomous Community of the Basque Country. Its capital and most populous city is San Sebastian. It is located at the Eastern corner of the Bay of Biscay and borders the French department of Pyrénées-Atlantiques to the Northeast, Navarra to the South and Southeast, Biscay to the West, Alava to the Wouthwest and the Bay of Biscay to the North.

Gipuzkoa is organized in 88 municipalities incorporated in seven regions. With a surface area of 1997 km^2, it is the smallest province in Spain. It is the twenty-first most populated province (720,592 inhabitants) and the fourth in population density (354.18 inhabitants/km^2). More than half of the population lives in the metropolitan area of San Sebastian.

3.3.1 Characteristics of Gipuzkoa's roads

The transport system of the Basque Autonomous Community is structured around the corridors that channel north-south flows, especially Madrid-Irun-France and Madrid-Bilbao, and those that respond to east-west relations through the coastal and Ebro corridors.

Gipuzkoa's road system is like that of Navarre, with its capital San Sebastian as the center of connections. It has a total of 1.096 km of road. The two main axes of connection are the east west road that links Bilbao San Sebastian with the AP8; and the south north connection that connects Spain with the rest of Europe through Irun passing through San Sebastian.

Figure 21: Main roads in Gipuzkoa (Source, Reprinted from: Ministerio de Fomento)

As in Navarre, average daily vehicle intensities change from one type of road to another. They are higher in highways near the capital San Sebastian where the average in near 45.000 vehicles per day in the proximities of the A1 reaching San Sebastian. Around 35.000 vehicles per day cross Gipuzkoa from west to east through the AP8, which in Irun are nearly 28.000 freight vehicles per day. In the rest of conventional roads the average is far less, with a 12.000 daily average in the national roads connecting Bizkaia-Gipuzkoa and Alava-Gipuzkoa, but less than 5.000 in the rest of local roads.

The Basque Country, as a key link in the Atlantic Arc and an imminently industrial country, has a high activity in terms of freight transport. Carrying out a much higher percentage of goods transport by road, as can be seen in the Figure 22:

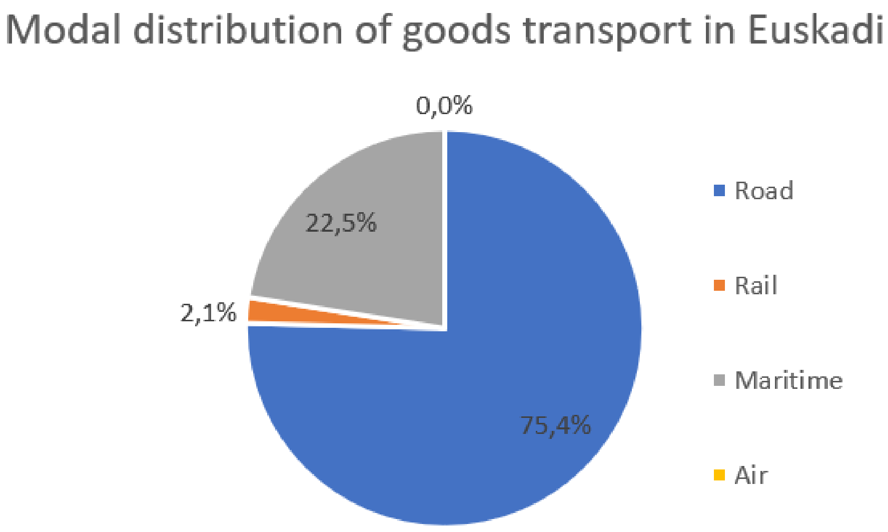


Figure 22: Modal distribution of goods transport in the Basque Country (Source, Adapted from: Plan Director transporte sostenible euskadi 2030)

On the roads of the Basque Country the number of deaths is higher than in Navarre because it is an autonomous community with more inhabitants, greater economy, bigger territory, more km of road... with a total of 39 deaths in 2017.

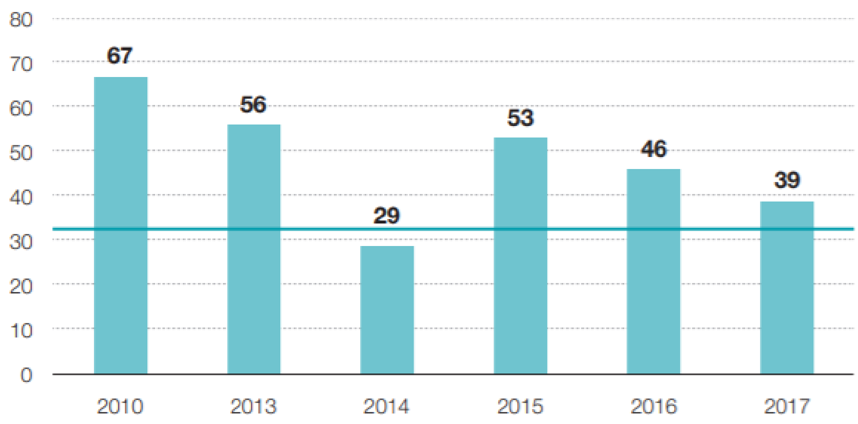


Figure 23: Evolution of the number of deaths on the roads of the Basque Country (Source, Reprinted from: Plan Director transporte sostenible Euskadi 2030)

As we see in Figure 23 the number of deaths in the Basque Country has decrease in the last years, excluding 2014 with 29 deaths. Since the regulations and policies changed to improve the control and quality of roads, road safety, and improvements in vehicle safety in the event of accidents.

Focusing on Gipuzkoa, the number of road accidents in 2018 was 3.010 compared to 7.763 in the whole of the Basque Country. With a total of 12 deaths, 131 seriously injured and 1.156 slightly injured. This data can be seen in the following Table:

Tabla 1.1. Distribución de los accidentes por Territorio Histórico, según el tipo de accidente

	Con Víctimas		Sin Víctimas		Total Accidentes	
	Nº	%	Nº	%	Nº	%
Álava	422	16,2	1.152	22,3	1.574	20,3
Bizkaia	1.191	45,8	1.988	38,5	3.179	41,0
Gipuzkoa	988	38,0	2.022	39,2	3.010	38,8
CAPV	**2.601**	**100**	**5.162**	**100**	**7.763**	**100**

Table 15: Distribution of accidents Basque Country (Source, Reprinted from: DGT) In Spanish

Tabla 1.2. Distribución de las personas implicadas en accidentes por Territorio Histórico, según la lesividad

	Fallecidas		H. Graves		H. Leves		Ilesas		Total Personas	
	Nº	%	Nº	%	Nº	%	Nº	%	Nº	%
Álava	10	27,0	75	25,0	518	16,0	2250	18,8	2.853	18,3
Bizkaia	15	40,5	94	31,3	1565	48,3	5247	43,8	6.921	44,5
Gipuzkoa	12	32,4	131	43,7	1156	35,7	4476	37,4	5.775	37,1
CAPV	**37**	**100**	**300**	**100**	**3.239**	**100**	**11.973**	**100**	**15.549**	**100**

Table 16: Distribution of people involved in accidents Basque Country (Source, Reprinted from: DGT) In Spanish

As can be seen from Figure 24, the types of accidents on the roads of Gipuzkoa are varied, the main cause being vehicle collisions, followed by collisions with objects. Compared with the type of accidents in Navarre, the first cause is the same, but the second and third causes of accidents are very different, being collisions with objects and overturning on the road instead of road exits and running over animals in Navarre.

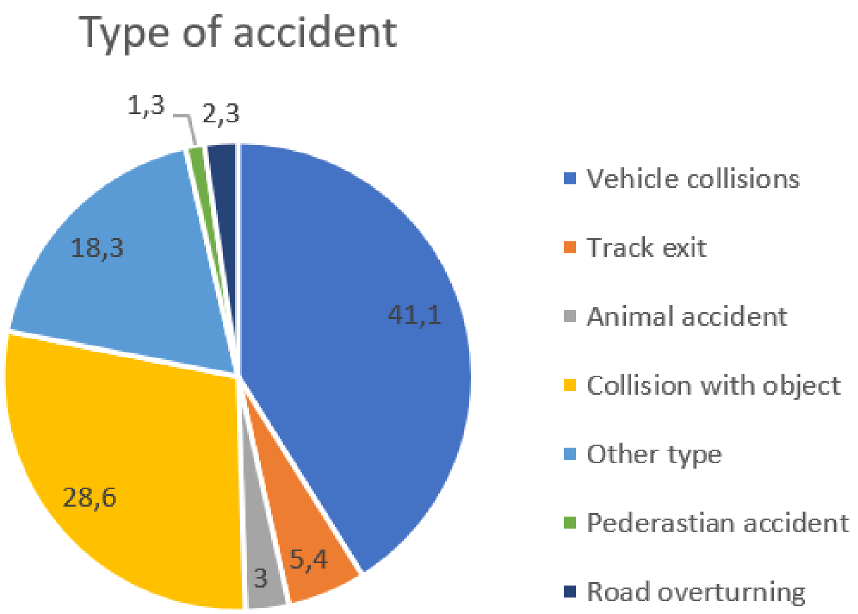


Figure 24: Graph according to the type of accident in Gipuzkoa (Source, Adapted from: Ministerio de Fomento)

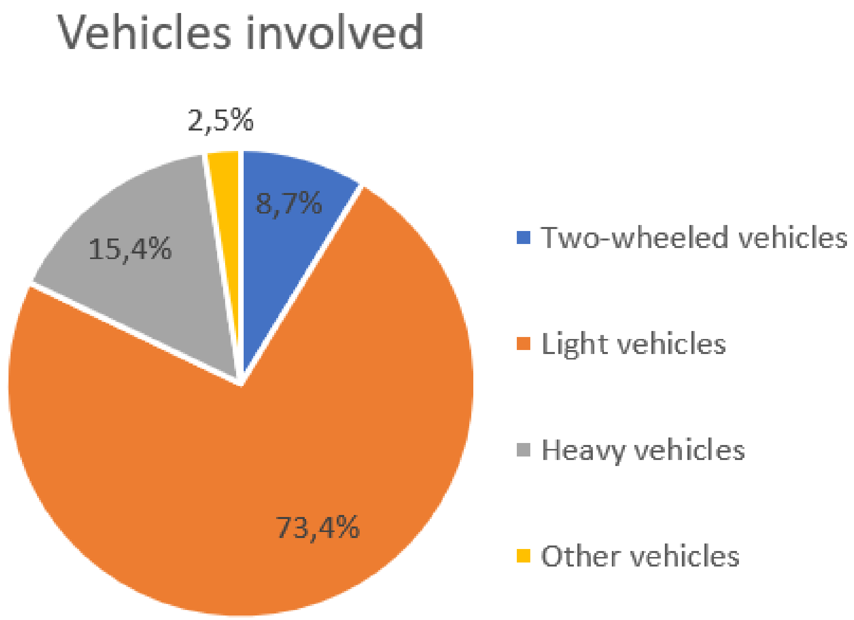


Figure 25: Graph showing the percentage of each type of vehicle involved in an accident in Gipuzkoa (Source, Adapted from: Ministerio de Fomento)

The vehicles involved in these accidents also change with respect to Navarra, increasing the percentage of heavy vehicles involved from 8% to 15,4% in Gipuzkoa, with is summarized in Figure 25.

3.3.2 Environmental conditions in the Basque Country

The environmental characteristics of the Basque Country are very similar to those of Navarre. The morphological relief could be divided, like the hydrological relief, into two sets marked by the Atlantic and Mediterranean area.

The water divide between the Atlantic and Mediterranean slopes is home to the most important in the Basque Country. These include the Gorbea, Urkiola, Aizkorri and Aralar.

The flattest area in the whole of the Basque Autonomous Community is located in the Llanada Alavesa to the south of the waters and among the most important massifs in the Basque Autonomous Community. Within the Llanada Alavesa are the reservoirs of the Zadorra System (Urrunaga and Ullibarri-Gamboa reservoirs). This plain presents an important agricultural tradition and its relief does not harbour major structural changes.

The southern part of the functional area of central Alava forms another strip of land, surrounded by more scattered mountains but not so important, in terms of size. In this area there is a sinuous morphology with significant ups and downs.

Between the Sierra de Toloño and the Ebro river another flat morphological area with gentle hills is marked. The Sierra de Cantabria partly restricts access to this area from the north.

Three types of climate are established in the Basque Autonomous Community: the Atlantic slope to the north without dry season is representative for its milder winters and abundant rainfall, the middle zone with a sub-Atlantic climate and sub-Mediterranean, these lands are not very cold, and the summers are quite hot and dry, with more than a month of summer drought; and the Mediterranean zone similar to the sub-Mediterranean, it is more continental, dryer and has more extreme temperatures.

The Basque Country has a very good geological, hydrological and biodiversity heritage. The Basque Country is one of the Autonomous Communities with the greatest wealth of species according to the Spanish Inventory of Terrestrial Species, along with La Rioja and Navarre.

Due to its biodiversity, like Navarre, the Basque Country has many natural areas of interest:

- 9 Natural Parks

- 47 Special areas of conservation (ZEC)

- 6 Wetlands

- 51 Natural Enclaves

- 4 Special Protection Areas for Birds, also called ZEPAS

- 16 Wildlife Protection Areas

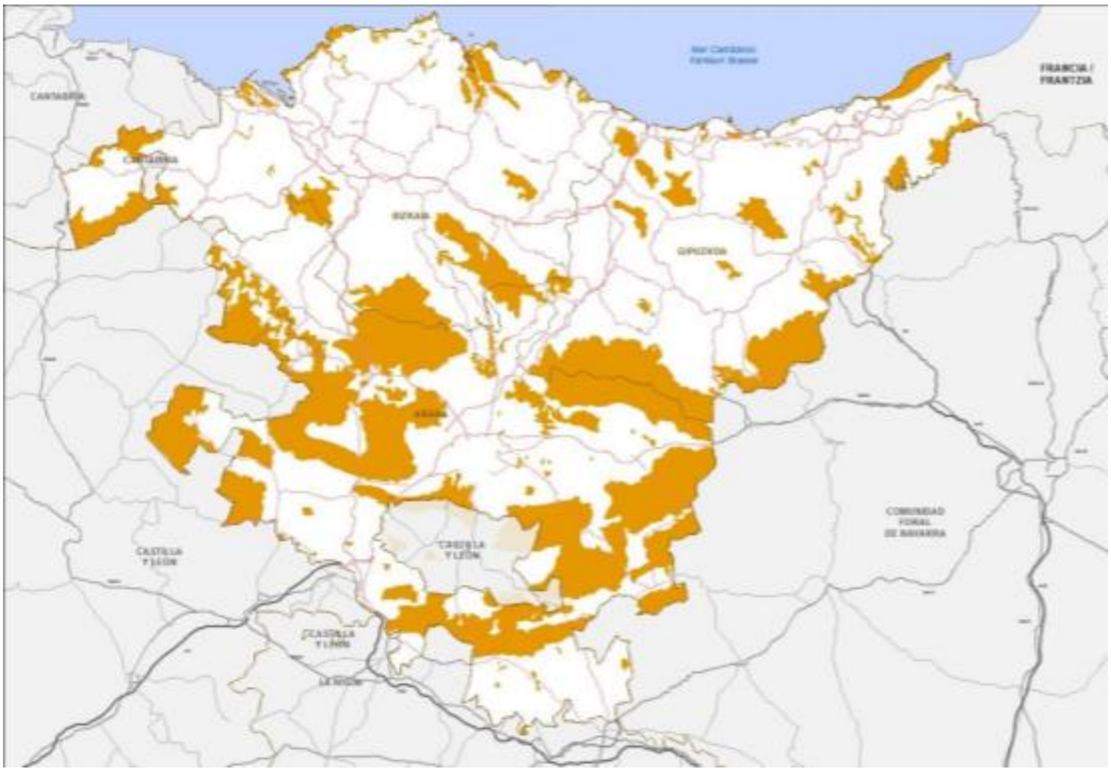


Figure 26: Map of protected natural areas in Gipuzkoa (Source, Reprinted from: III Plan General de Carreteras del Pais Vasco)

These natural areas are protected by various laws, but the most important is Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, known as the Habitats Directive.

The biodiversity of the Basque Country is very rich and has numerous species of flora and fauna, many of which are threatened and endangered due to the increase in urban areas, infrastructures and human activities that affect the habitats of these species.

For this reason there are different laws for the protection and conservation of species such as the la Ley de Conservación de los Espacios Naturales y de la Flora y Fauna Silvestres de marzo de 1989 (Law for the Conservation of Natural Spaces and Wild Flora and Fauna from 03/1989), La ley de Conservación de la Naturaleza (Nature Conservation Act) and the Catálogo Vasco de Especies Amenazadas de junio de 1994 (Basque Catalogue of Threatened Species from 06/1994). Creating management plans for the conservation of different threatened species such as the European mink, the otter, the wolf, the southern frog and many more.

As is the case all over the world, the effects of climate change are reflected in the Basque Country in aspects such as the increase in the average temperature over the last few decades, the rise in sea level, the drop in rainfall and the increase in the concentration of gases in the atmosphere.

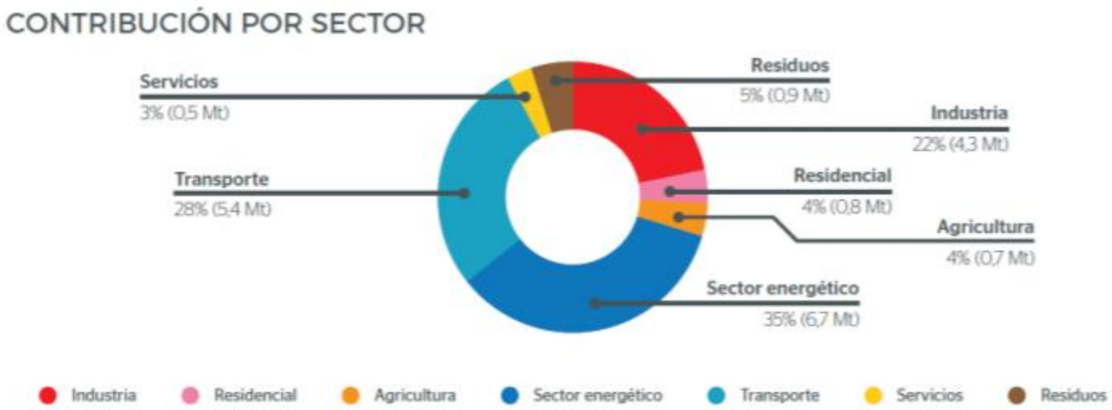


Figure 27: Graph of main sources of GHG in Basque Country (Source, Reprinted from: Estrategia de Cambio Climático Pais Vasco 2050) In Spanish

As we see in Figure 27, the transport sector accounts for 28% of greenhouse gas emissions in the Basque Country. Of these, approximately 96% of emissions from this sector are associated with road transport.

Like Navarre, the Basque Country seeks a sustainable economic model and to help slow down this climate change. To this end, it has developed the Strategy of Climate Change 2050 in the Basque Country.

It has defined in this Strategy the objective of reducing its GHG emissions by at least 40 % by 2030, and by 2050 the objective of reducing them by at least 80 %, all with respect to 2005.

This strategic plan has different goals to achieve, but about transport, two stand out: betting on a low-carbon energy model and moving towards emission-free transport. These goals can be summarized in three guidelines: enhance intermodality and modes of transport with lower GHG emissions, substitute consumption of oil derivatives, and integrate vulnerability and adaptation criteria in transport infrastructures. This is explained in more detail in Table 17:

Línea de actuación 4:
Potenciar la intermodalidad y los modos de transporte con menores emisiones de GEI

12. Desarrollo de la nueva Red Ferroviaria del País Vasco para el transporte de pasajeros y mercancías.
13. Potenciación del corredor atlántico de mercancías (Red Trans-European Transport Networks – TENT-T).
14. Implantación de plataformas logísticas que fomenten el uso del ferrocarril y el transporte marítimo de mercancías (comenzando por Jundiz, Pasaia-Irun y Arasur).
15. Creación y/o ampliación de redes de metro, tren, tranvía y autobús logrando la consecución del billete único para el transporte público municipal e interurbano de toda Euskadi.
16. Fomentar el desarrollo de planes de movilidad sostenible a nivel comarcal, urbano y en los diferentes centros de actividad.

Línea de actuación 5:
Sustituir el consumo de derivados del petróleo

17. Generalización de modos de transporte con menos emisiones de GEI (vehículo eléctrico, vehículos a gas natural, bicicleta, etc.) a través de apoyo económico y de medidas de discriminación positiva como la exención en el pago de OTA a vehículos que no sean de combustión interna, reducción del impuesto sobre vehículos de tracción mecánica, etc.

Línea de actuación 6:
Integrar criterios de vulnerabilidad y de adaptación en infraestructuras de transporte

18. Identificar y monitorizar las infraestructuras de transporte vulnerables para detectar necesidades de redimensionamiento y mantenimiento.
19. Impulsar la innovación en el diseño de soluciones para aumentar la resiliencia de las infraestructuras de transporte.

Table 17: Objectives to be met in order to have a sustainable transport model (Source, Reprinted from: Estrategia de Cambio Climático Pais Vasco 2050) In Spanish

3.4 Geographic Information Systems (GIS)

A geographic information system (GIS) is a set of tools that integrates and relates various components that allow the organization, storage, manipulation, analysis and modeling of large amounts of data from the real world that are linked to a spatial reference, facilitating the incorporation of social-cultural, economic and environmental aspects that lead to decision making more effectively.

In the strictest sense, it is any information system capable of integrating, storing, editing, analyzing, sharing and displaying geographically referenced information. In a more generic sense, GIS are tools that allow users to create interactive queries, analyze spatial information, edit data, maps and present the results of all these operations.

The GIS works as a database with geographic information (alphanumeric data) that is associated by a common identifier to the graphic objects of the digital maps. In this way, by pointing to an object we know its attributes and, inversely, by asking for a record in the database we can know its location in the cartography.

GIS provides, for each type of location-based organization, a platform to update geographic data without wasting time visiting the site and updating the database manually. GIS when interpreted with other integrated solutions such as SAP and Wolfram Language allows you to create powerful decision support systems at the corporate level.

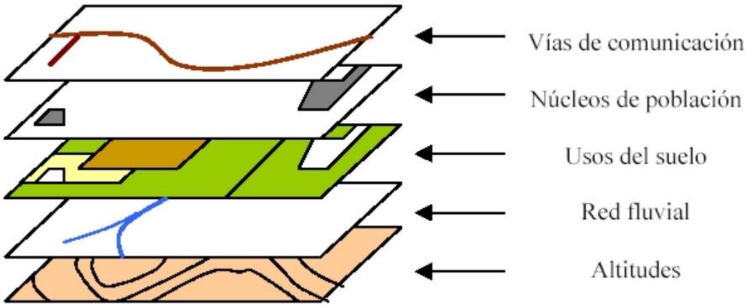


Figure 28: Different layers of a GIS (Source: Wikipedia) In Spanish

The fundamental reason for using a GIS is to manage spatial information. The system allows separating the information into different thematic layers and stores them independently, making it possible to work with them quickly and easily, providing the professional with the possibility of relating the existing information through the geospatial topology of the objects, in order to generate a new one that we could not obtain otherwise.

Because they are so versatile, the field of application of geographic information systems is very broad, and they can be used in most activities with a spatial component. The profound revolution brought about by the new technologies has had a decisive impact on their evolution.

3.4.1 Components

A GIS integrates five main components: hardware, software, data, people and methods.

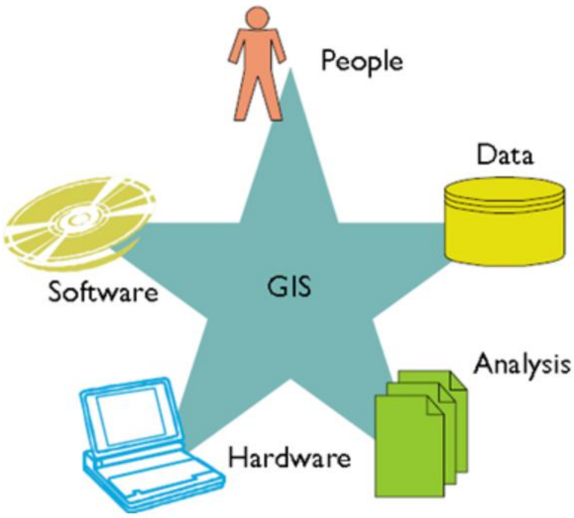


Figure 29: Components of a GIS (Source: Google)

- Hardware

The hardware is the computer where the GIS operates. Today, GIS can be run on a variety of platforms, which can vary from servers (mainframe) to desktop or laptop computers used in network or offline configurations.

- Software

GIS programs provide the functions and tools required to store, analyze and display geographic information. The most important components are:

-Tools for the entry and manipulation of geographic information.

-A database management system (DBMS)

-Tools that allow geographic searches, analysis and visualization.

-Graphical user interface (GUI) for easy access to the tools

- Data

Possibly the most important components of a GIS are the data. The related geographic and tabular data can be collected in the company, in the field or acquired from the person implementing the information system, as well as from third parties who already have them available. The GIS integrates spatial data with other data resources and can even use the most common database managers (DBMS) to organize, maintain and manage spatial data and all geographic information.

- Human resources

GIS technology is limited without the right people to operate, develop and manage the system, and to carry out the development plans to apply them to real-world problems. GIS users include technical specialists, who design and maintain the system for those who use it in their daily work.

- Methodology and Procedures

For a GIS to be successful, it must operate according to a well-designed and structured plan and in accordance with the rules of the company or institution, which are the characteristic operating models and practices of each organization.

3.4.2 Data representation

There are two fundamental forms of data representation in GIS. On the one hand, the vectorial form represents points, lines and polygons according to their topology in space, while the raster representation starts from a previously determined mesh or grid under a specific coordinate system, and each cell or grid has associated alphanumeric information that represents the characteristics of the area or geographical surface it covers.

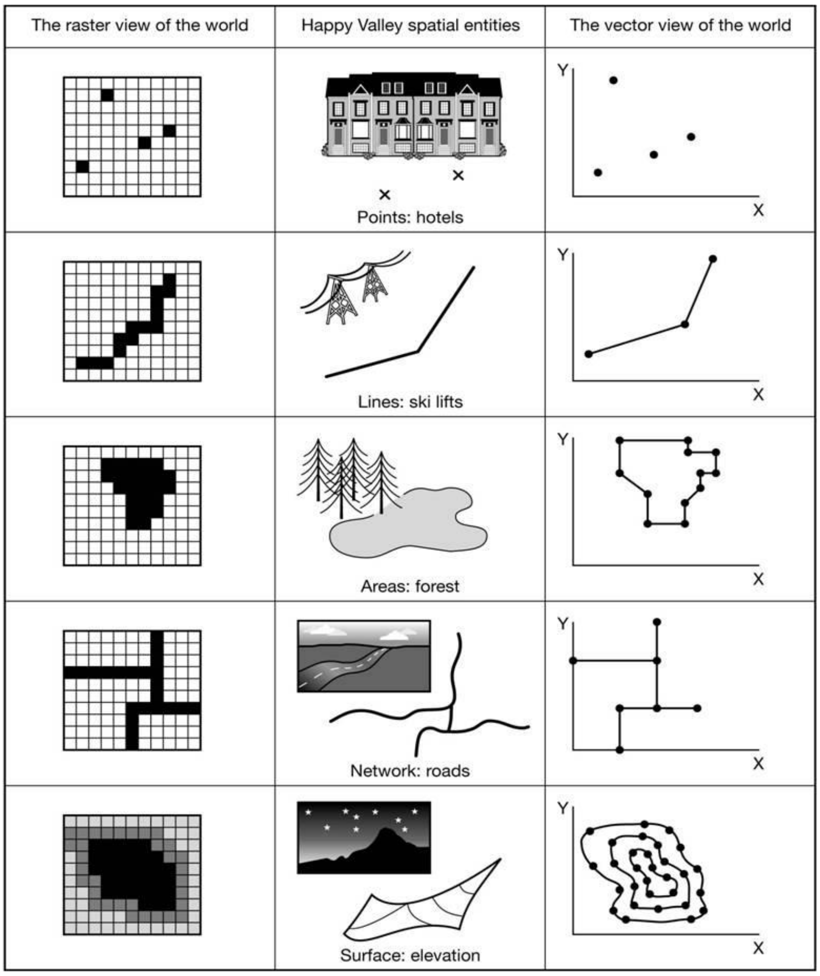


Figure 30: Differences between raster and vector view (Source, Reprinted from: TFG Esteban de Paz Asín)

GIS that focus on handling data in vector format are more popular on the market. However, raster GIS are widely used in studies that require the generation of continuous layers, necessary in non-discrete phenomena; also in environmental studies where excessive spatial accuracy is not required (air pollution, temperature distribution, location of marine species, geological analysis, etc.).

A type of raster data is essentially any type of digital image represented in meshes. The raster GIS model focuses on the properties of space rather than on the accuracy of the location. It divides space into regular cells where each cell represents a single value. It is a data model very suitable for the representation of continuous variables in space.

In the vector data, the interest of the representations is focused on the precision of the location of the geographical elements on the space and where the phenomena to be represented are discrete of defined limits. Each of these geometries is linked to a row in a database that describes its attributes. For example, a database describing lakes may contain data on lake bathymetry, water quality or pollution level. This information can be used to create a map that describes a attribute contained in the database. Lakes can have a range of colors depending on the level of pollution. In addition, the different geometries of the elements can also be compared.

There are advantages and disadvantages to using a raster or vector data model to represent reality.

VECTORIAL	RASTER
ADVANTAGES	DISADVANTAGES
High precision	Low accuracy
High quality maps	Lower quality maps
Small files	Large files
Ability to perform network analysis	Inability to perform network analysis
DISADVANTAGES	ADVANTAGES
Complex data structure	Very simple data structure
Less capacity for the combination of layers	High capacity for overlapping and combination of layers
Inability to image processing	Image Incorporation Capability

Table 18: Advantages and disadvantages between raster and vector view (Source: Self production)

3.4.3 Functions of a GIS

Like any system, a GIS has an initial part that corresponds to data input, a central part where data is processed and analyzed and a part where we receive the information as a result (output). In this way GIS has parts designed for the management of geographic information in:

- Data capture, recording and storage: the passage of analogical information, on paper, to digital format in a computer. This can be done in several ways such as digitalization, vectorization, and import. Likewise, data can be obtained through the collection of digital records from mobile equipment, GPS, satellite images, etc.

- Structuring and manipulation of data: creation of databases, transformation and analysis of the new cartography; here the alphanumeric information is managed through topologies, superposition of layers and creation of metadata.
- Creation of output information: GIS give shape to information products (useful information); these products are used for decision making and can be cartographic (physical) products, graphic reports, 3D representations and digital designs that will be visualized in different media such as an intranet, web page, etc.

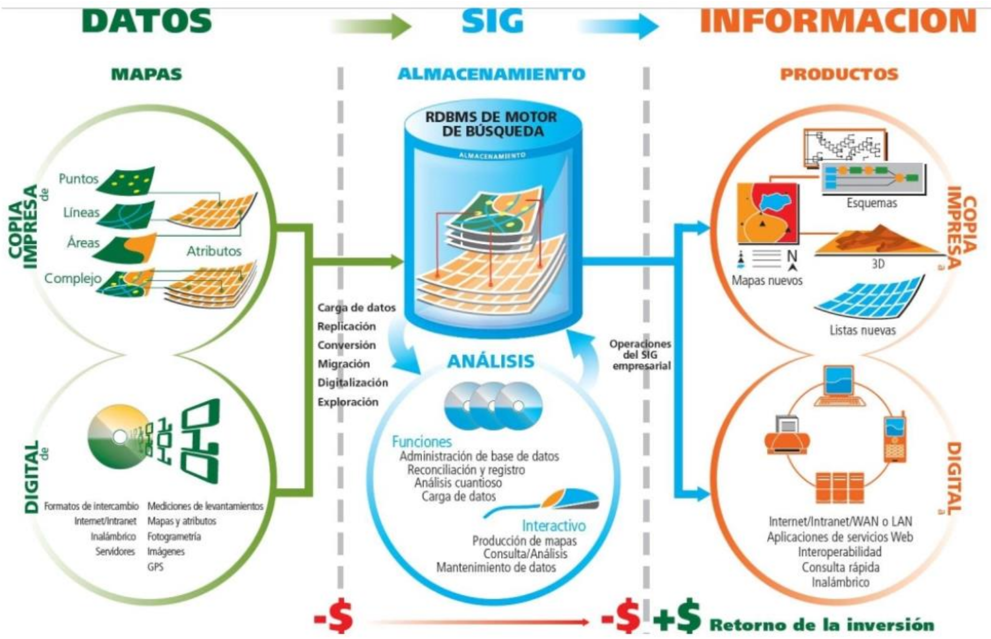


Figure 31: Summary of how a GIS works (Source: Google) In Spanish

The main functions of a GIS are:

- Data Entry Management: that allows to capture and store data in a manual way or in a systemic way by means of data migration; it must also allow the loading of data by means of reading in different formats.
- Data integration: that allows the construction of information that gives a logical sense to the collected data, integrating the different formats and geometries that guarantee the consistency and quality of the data; finally, that can be documented (metadata).
- Data analysis: that allows data analysis through layer manipulation operations and spatial modeling, transforming data into relevant information.

- Information production: that allows consulting and generating data that together form a design that transmits relevant information in a graphic way, where the results are presented to interested users.

- Dissemination of results: that allows the results to be distributed to the final interested parties, in physical or digital formats, in such a way that they are easy to access, read and distribute.

3.4.4 GIS resources used

Within the great variety of existing software in the market, the great boom of free software stands out at present. In the field of GIS, several free open source GIS software projects have also emerged, driven by both public and private interests. Among them are qvGIS of the Conselleria de Infraestructuras y Transporte de la Generalitat Valenciana, and qGIS of A Coruña.

In the present work the online platforms of geographical information of Navarre of SITNA and IDENA have been used, as well as Google Earth, to know the characteristics of the routes of transport studied to its passage by Navarre. As well as the geoEuskadi geographic information system to study the routes on their way through Gipuzkoa.

By drawing the routes section by section every kilometer, it is possible to obtain the information of the altitude of each point, thus being able to calculate the slope of the road in each kilometer.

By importing this file to Google Earth, the profile of the road is obtained and with the StreetView property you can check the speed limitations for these sections by looking at the traffic signs of each section studied.

This has been the working method for obtaining the characteristics of both routes in their Pamplona Irun connection, which will be explained in the following sections.

3.5 Description of the two alternatives

The journey from Pamplona to Irún can be made by different roads but mainly two routes are used, by the N-121A national road, or by the AP15 highway and A15 motorway to Gipuzkoa where Irun is reached by the AP8.

Most of these two routes are in Navarre and the rest in Gipuzkoa, each with different characteristics which are explained in the following sections.

3.5.1 N-121-A route

The Pamplona-Behobia road or N-121-A is a Navarre fast track that connects Pamplona with France, through the Dantxarinea and Behobia border crossings. It is the main communication axis in the north of the region, as well as an alternative to toll roads for journeys between Madrid and Western Europe, and the main communication route between Lapurdi and Navarre.

It is the only high performance road in Navarra. The distance between Pamplona and Irun is approximately 75 km, of which 67 km run through Navarre and the final part through Gipuzkoa. It is one of the main trans-Pyrenean routes, connecting Irun with the French border in one of the busiest passages as seen in the previous sections.

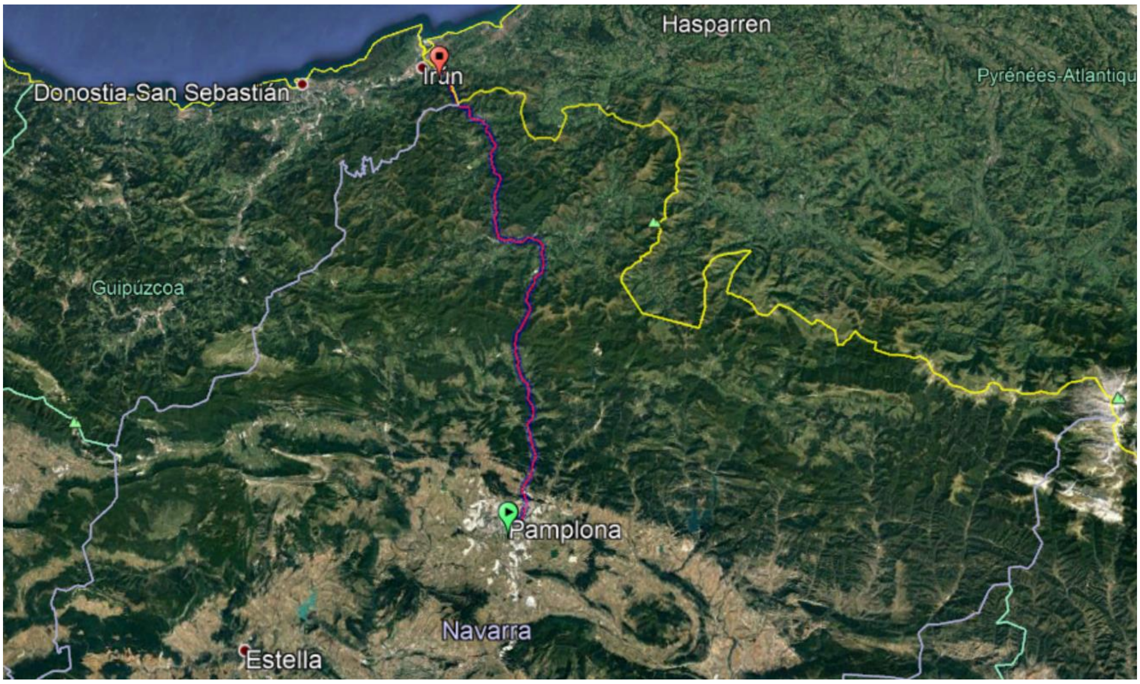


Figure 32: View of the route along the N-121-A in relief (Source: Google Earth)

Its construction dates to ancient times, but the conversion into a fast track is recent, from the decade of the 2000's. For this purpose, numerous viaducts and tunnels were built, including the Belate Tunnel, the seventh longest in the Iberian Peninsula.

Figure 33: Elevation profile of the route on the N-121-A (Source: Google Earth)

In the Figure 33, we can see the elevation profile of this route obtained by Google Earth, but this profile is not valid for our calculations since they do not consider the tunnels and bridges that the road has. This will be explained in more detail in the next sections.

It is frequented by many truck drivers, which makes it a very popular route. The average daily intensity of vehicles in 2018 changes in the different sections of the road, being higher at the beginning near Pamplona, and at the end in the Gipuzkoan section, with an IMD close to 11,000 vehicles of which approximately 25% are heavy vehicles.

In the central section of the route, the average daily intensity of vehicles is lower, around 8,000 vehicles while maintaining practically the same number of heavy vehicles.

The N-121-A begins its route on the Ronda de Pamplona. It heads north through the towns of the valleys of Anue, Ezcabarte and Oláibar. After passing the Belate Pass, it arrives at Oronoz-Mugaire, where it separates from the N-121-B road. Afterwards, the road passes through Cinco Villas de la Montaña and ends its route in Behobia (Guipúzcoa) near the AP-8.

The N-121-A road crosses or passes close to different villages such as:

- Olave
- Ostiz
- Olagüe
- Oronoz-Mugaire
- Doneztebe-Santesteban
- Elgorriaga
- Igantzi
- Arrantza
- Lesaka
- Etxalar
- Bera

In this paper we will focus on the environmental impact of air pollution and greenhouse gas emissions caused by heavy goods vehicles, estimating the monetary cost of these emissions.

However, knowing the potential that geographic information systems have, other calculations of the external impact of freight transport could be made, such as studying the population affected by the passage of this road, in terms of noise, air quality, land use, etc. To do this, vectorial analysis of maps with different software such as Qgis, qvgis mentioned above could be used, drawing the route and creating a buffer of the area affected by the activity of the road.

That is why it is good to take all the external factors of road transport into account when the company makes decisions. For this reason, it is necessary to mention that this road runs through different landscapes and natural parks of interest as we see in Figures 19 and 26, such as:

- Natural Park of Señorio de Bertiz
- Protected landscape of Robledales Ultzama y Barsaburua
- Place of community interest (LIC) of Bidasoa river
- Place of community interest (LIC) of Belate
- Place of community interest (LIC) of Señorio de Bertiz
- Special Conservation Area (ZEC) of Señorio de Bertiz
- Special Conservation Area (ZEC) of Aiako Harria

3.5.2 Highway route

This other route runs along different types of roads. It begins by joining the AP15 motorway in Pamplona until Irurzun, where it passes into the A15 motorway. Once in Gipuzkoa, it continues this road until it joins the A1 and after 2.5 km it passes again onto the A15, until it finally joins the AP8 motorway, which crosses the border at Behobia.

It has approximately 95 km and due to the type of roads, vehicle speeds are higher. Almost half of the route is made in each community, 50 km in Navarra and 45 in Guipuzkoa.

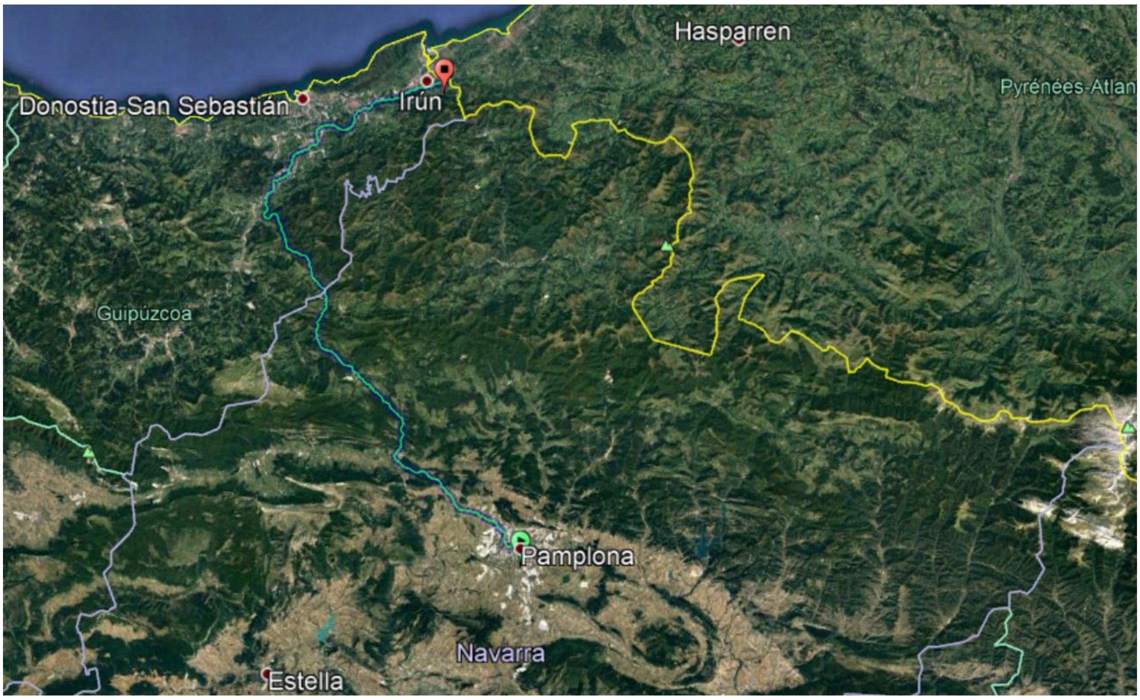


Figure 34: View of the route along the AP15 in relief (Source: Google Earth)

The average daily intensity of vehicles is not the same on all sections. An average of 24,000 vehicles pass daily on the section of the AP15 motorway in Navarre with a percentage of 18% of heavy vehicles.

When changing road to the A15, this intensity drops to around 15,000 vehicles, 18% of which are also heavy vehicles.

Once in Guipuzkoa, as it joins the A1, the number of vehicles increases to 60,000 as it is the main road to San Sebastian, of which approximately 10,000 are heavy vehicles.

Once San Sebastian has been passed and reached Irun, the vehicle density drops to around 25,000, of which around 6,000 are heavy transport vehicles.

Figure 35: Elevation profile of the route on the AP15 (Source: Google Earth)

As with the N-121-A road, the elevation profile in Figure 35 obtained with Google Earth is not precise because it does not consider all types of bridges and tunnels giving an altitude that does not correspond in some points. Despite this, it is possible to get a quick idea of the gradient of the road. Its more precise elevation profile is detailed in the following sections.

In the same way as on the N-121-A, this route crosses or passes near various urban centers such as:

- Erice de Iza
- Irurzun
- Latasa
- Urritza
- Lekunberri
- Gorriti
- Erreka
- Berasategui
- Aduna
- Andoáin
- Urnieta
- Hernani
- Astigarraga
- Rentería
- Arragua
- Irún

Although it is not part of this work, it can be compared between both routes seeing that the latter by motorway, has an impact on a greater number of villages and therefore of people, since those that it crosses in its part of Gipuzkoa are urban centres with greater population as Hernani, Astigarraga, Berasategui, Lekumberri..., that are affected by impacts as the noise, worse quality of the air, occupied ground,... due to transport activity.

Although they pass through the cities, towns or nearby, the highways have protective sound barriers, which results in less noise pollution than the route along the N-121-A. These results can be seen in other works (Sola Freire, 2011) where it is concluded that the route by the motorway is much less contaminating in noise than the route by the N-121-A, since the noises derived from the traffic affect a smaller number of people.

On the other hand, this route has less effect on landscapes or natural parks of interest as can be seen in the maps in Figures 19 and 26. Because on its route through Navarre it does not pass near a protected area and on its way through Giupuzkoa it only passes near the river Leitzaran, which has different protected species.

3.6 Fuel consumption

A vehicle's fuel consumption depends on many factors, such as engine design, bodywork, weight, driving style and environmental conditions.

In all engines, the spent fuel is only partially (about one third) transformed into mechanical energy, through a performance that depends on the compression ratio, the carburetor, the shape of the explosion chamber and the distribution diagram. The rest of the thermal energy developed in the combustion is expelled in the form of heat by the engine, the radiator, and the exhaust gases.

The remaining mechanical energy of the motor is used in turn in:

- reaching a certain speed (power spent on starting);
- maintaining a certain speed (power spent on overcoming air resistance and friction in tires and transmissions);
- going uphill (power spent on overcoming the force of gravity), even on downhill slopes, the low speeds that the load forces to be maintained are not exactly beneficial for vehicle consumption.

On average, the power consumed in starting the car represents about a third of the energy available and depends, above all, on the weight of the car and the load it carries.

On the other hand, the power spent on maintaining speed represents more than 60% of total fuel consumption and depends essentially on the shape of the bodywork and its aerodynamic resistance. For this reason, consumption increases with the square of the speed, since this is how the air resistance varies.

The third type of energy generally represents a very small fraction, less than 10%, and does not depend on the engine or driver, but only on the weight of the car and the slope of the road. As an aside, these three forms of energy are destined, sooner or later, to be transformed into heat and dissipated into the air.

It follows from the above considerations that in order to reduce consumption a car must have: good thermodynamic engine performance (there are no appreciable differences in this respect between factory new cars), a low coefficient of resistance of the bodywork, a small front section and low weight. These are all elements which depend on the car's design; the buyer, however, is free to choose between the different models based on the best characteristics.

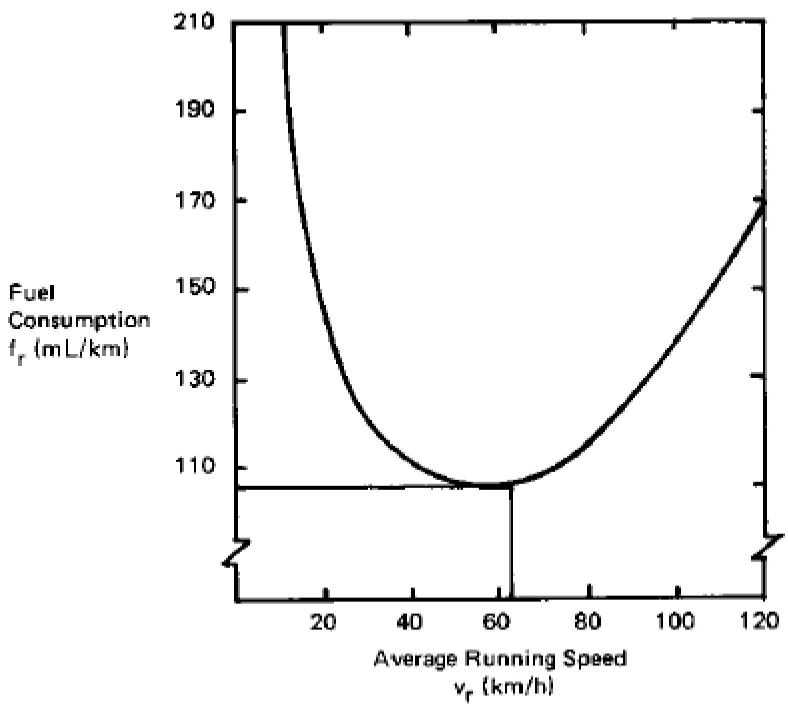


Figure 36: Evolution of fuel consumption versus average speed (Source, Reprinted from: Evolution of fuel consumption versus average speed. Bowyer, Akcelik and Biggs (1985))

As can be seen in Figure 36, fuel consumption increases with speed as the drag to be overcome increases with the square of the speed. The course of the curve is also determined by the fact that the specific consumption is not constant at all rotation speeds and that at low speeds and with partial loads the engine operates with a worse efficiency, consuming even more than at high speeds. Therefore, in big cities there is a higher concentration of pollution because speeds are not very high but fuel consumption is higher. For this work, looking at the Figure 36 it can be predicted that the consumption by the national highway will be more constant since the speeds vary from 40 to 70 km/h remaining in the constant zone of the curve; whereas by the highway where the speed is greater than 80 km/h the consumption will also be higher. Although this will be checked with the estimation methods whose results are explained below.

Specific consumption is a characteristic of the engine and not of the car. It indicates the grams of fuel that need to be spent per hour per developed horsepower. It is measured on the test bench and gives an idea of the thermodynamic performance of the engine at different speeds. In 4-stroke petrol engines it is 190-210 g/hp, at speeds close to maximum torque. For automotive diesel engines it drops to 180-200 g/hp, while for 2-stroke engines it is higher: 330-350 g/hp.

Reduced consumption can also be obtained by keeping the mechanical parts in optimum conditions: efficient electrical installation, precise regulation of the distributor and carburetor, clean air filter, correct tire pressure, perfect wheel camber, etc. It is also essential to drive correctly with moderate maximum speeds, gradual acceleration with slow pedal movements and smooth deceleration. In short, we must get as close as possible to the uniform movement.

As you can see the fuel consumption depends on many factors, aerodynamic body design, weight, engine design, road slope, speed, maintenance, and care of the elements of the vehicle as filters, distance traveled, weather, etc.

Therefore, in order to estimate the fuel consumption of a vehicle, there are numerous approximation methods, two of which will be used in this paper and will be explained in the following sections.

3.6.1 Engine type

One of the important factors affecting fuel consumption is the type of engine. Depending on the type of engine, the fuel is different, differentiating mainly between petrol and diesel, thus obtaining emissions of different composition. The characteristics of each engine and the composition of its emissions are explained below.

In internal combustion engines, the explosion cycle is caused by the ignition of the air-fuel mixture in the cylinder body which allows a crankshaft to rotate, transforming the chemical energy of the fuel into mechanical energy. In most cases both work with the same four-stroke cycle system, however this does not occur in the same way. Both diesel and gasoline have a temperature from which they ignite, this is known as the auto-ignition temperature, and this is where the operation of both engines differs. This is the big difference between a gasoline engine and a diesel engine.

The combustion cycle normally has 4 steps: Intake-Compression-Expansion-Exhaust. Although the 2-step cycle is also used.

In diesel mechanics this temperature is achieved by air compression. During the admission cycle the air enters the explosion chamber which will be compressed in the next cycle. This compression generates an increase in the temperature of the air until it passes the auto-ignition temperature value. It is at that moment when the injectors put the fuel under pressure, in a pulverized way for a better mixture with the air, and the combustion of the same one takes place.

In this type of engine, the air-fuel mixture is especially heterogeneous. Combustion takes place in those areas where the conditions of the mixture are appropriate and therefore there is no clearly differentiated area where combustion takes place. Instead, many flame fronts are created whose evolution is linked to the jet of fuel injected and the movement of air in the chamber.

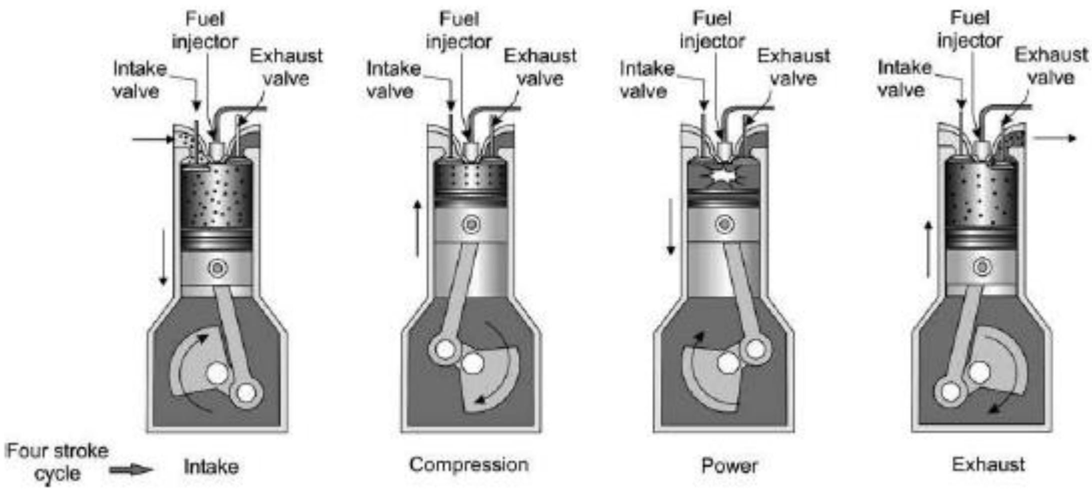


Figure 37: Operation of a four-stroke diesel engine (Source: Google)

In the case of gasoline, the opposite is true: it enters the chamber along with the air (which in this case is below the self-ignition temperature). Therefore, in this case the piston pushes a gasoline air mixture, which increases its pressure, but in no case reaches the auto-ignition temperature of the gasoline. This is where the spark plug comes into play, generating the spark that ignites the gasoline particles that are mixed with the air.

This engine is also called an explosion engine, spark ignition engine or Otto engine, although it is commonly called a gasoline engine.

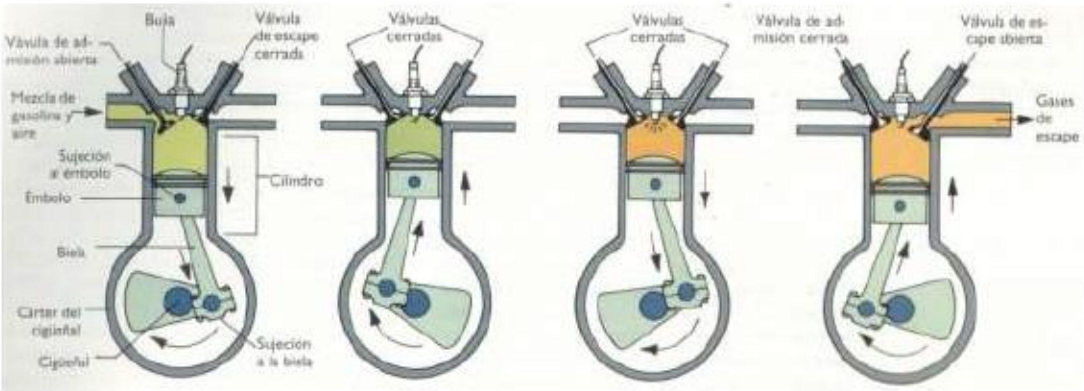


Figure 38: Operation of a four-stroke explosion engine (Source: Google) In Spanish

Diesel engines normally have lower consumption, this is because only air is involved in the compression of the diesel engine, a good compression ratio can be achieved without the risk of the dreaded self-ignition. In a gasoline engine with a mixture, such a high compression ratio is not possible without the risk of premature detonation. The reason why a diesel car offers better economy has to do with the compression ratio. The higher the compression ratio, the better the cycle efficiency. The compression ratio of an engine refers to the degree to which the gases can be compressed in the engine cylinder. A high compression ratio is what engineers are looking for most, because it creates a higher temperature, more evaporation and a more homogeneous air-fuel mixture. An engine with a high compression ratio allows more power and lower fuel consumption. Diesel engines can reach very high compression ratios of between 14:1 and 23:1.

In a gasoline engine, fuel and air are in the engine at the same time and this limits compression partly because gasoline inflates at a lower temperature. Compression ratios in cars usually range from 7:1 to 10:1.

The composition of the fuel also has to do with differences in efficiency. As a fuel, diesel is heavier than gasoline. This is because the hydrogen and carbon chains that make up these fuels are longer and heavier in diesel, which has 17% more of these atoms than gasoline.

This means that the emissions from a gasoline engine are different from those from a diesel engine.

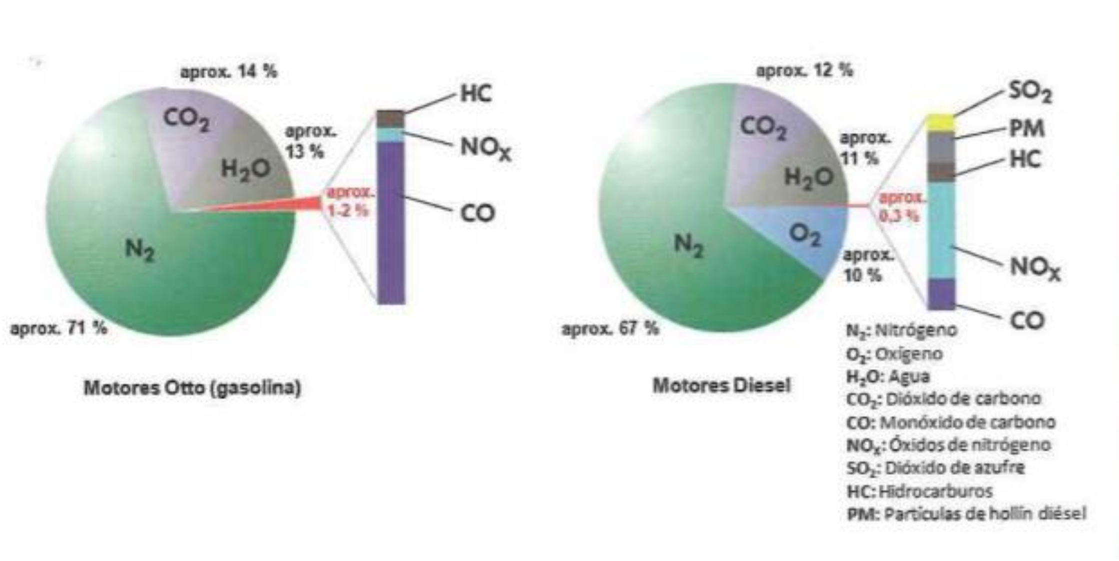


Figure 39: Exhaust gas composition (Source, Reprinted from: Emisión de aerosoles y particulas en motoers diésel) In Spanish

As can be seen in Figure 39, gasoline engines produce 2% more CO_2 than diesel engines. However, diesel engines emit pollutants that gasoline engines do not, such as sulfur dioxides and particulates. Although these emissions are at a lower percentage, as seen in section 2.2 of this paper, the consequences of these can be worse than other types of emissions.

Transport is the main source of NOx emissions, and to a greater extent diesel engine vehicle than petrol engines. As we have seen the consequences of this gas are worse than other emissions, so new European policies and laws are choosing to reduce the use, limit and stop producing vehicles with diesel engines.

On the other hand, CO_2 emissions, which are the main cause of the greenhouse effect, are higher in gasoline engines than in diesel engines, which by prohibiting or limiting the use of diesel vehicles, promotes the use of the gasoline engine and thus increases CO_2 emissions.

This is causing a current debate on the type of engine to be used, in which the common solution seems to be the use of vehicles without fossil fuels, specifically electric vehicles.

The main sources of emission from road vehicles are the exhaust gases and hydrocarbons produced by evaporation of the fuel. When an engine is started below its normal operating temperature, it uses fuel inefficiently, and the amount of pollution produced is higher than when it is hot.

Total emissions are the sum of hot emissions when the engine is hot, cold emissions when the engine has not yet reached its optimum working temperature, and extra emissions from evaporation of substances. Cold emissions occur during the early part of a journey. These emissions need different types of data but is limited, and normally are proposed as constants, and are not the most important. Evaporative emissions occur in different ways, such as fuel vapor is expelled from the tank each time it is refilled, the daily increase in temperature causes fuel vapor to expand and be released from the fuel tank, and vapor is created wherever fuel may be released to the air, especially when the vehicle is hot during or after use. Generally, these factors are a function of the ambient temperature and the fuel volatility, and do not affect all types of emissions in the same way, being mainly responsible for VOC pollutant. Are less important than cold emissions and are not directly related to the journey made, as they can occur with the vehicle stopped on a hot day causing evaporative losses and emissions. Hot emissions are the emissions produced when the engine and the pollution control systems of the vehicle (e.g. catalyst) have reached their normal operating temperature. They can be calculated if the emission per unit of activity and the total activity over the time scale of the calculation are known. These are the most important emissions.

In this study, only hot emissions will be taken into account, since, as will be seen later, the routes of the two routes do not begin in the urban area of Pamplona but the first kilometers are eliminated and they begin on the AP15 highway or the N-121-A national road, where the engine is considered to have already reached its optimum working temperature.

The combustion of a hydrocarbon fuel (such as petrol, diesel, CNG) in air, in ideal conditions follows a simple chemical reaction:

$$C_xH_y + \left(x + \frac{y}{4}\right)O_2 = xCO_2 + \frac{y}{2}H_2O$$

where:

CxHy is the fuel (a compound of carbon and hydrogen)

O_2 is oxygen from the air

CO_2 is carbon dioxide

H_2O is water

Because the masses of reactants and products are related in accordance with their molecular weights, it is possible to determine the amount of CO_2 and water that would be produced from a certain weight of fuel or vice versa. For example, the mass of carbon in the fuel is given by:

$$[C] = [C_xH_y] * \frac{12}{12_x + 1_y}$$

where:

[C] is the mass of carbon

[CxHy] is the mass of fuel

12 and 1 are the approximate atomic weights of carbon and hydrogen respectively

this amount of carbon would combine with oxygen as follows:

$$[C] + \left([C] * \frac{32}{12}\right) O_2 = [CO_2]$$

where:

$[CO_2]$ is the mass of carbon dioxide produced

32 is the approximate molecular weight of oxygen

In practice, the fuel combustion does not proceed according to the ideal equation; some of the carbon is incompletely oxidized and is emitted as CO or carbon particles (PM), some fuel escapes combustion and is emitted as VOC, and NOX are produced because of the oxidation of nitrogen in the air and traces in the fuel itself. Nevertheless, the same principle may be used to calculate the amount of fuel that would produce a certain combination of CO_2, CO, VOC and PM since there must be a balance between the total carbon in the fuel and the total carbon in all of the combustion products. Alternatively, the mass of any one of the carbon containing pollutants may be calculated from the mass of fuel and the amounts of the others. However, this would be imprecise except for CO_2 because the other compounds are produced in relatively small amounts.

Emission tests usually include the measurement of CO_2 as well as the other pollutants, and it is less frequent that fuel consumption is measured directly. For that reason, road transport emission factors are presented for the exhaust components, including CO_2, and fuel consumption may be derived using the 'carbon balance' method outlined above, using the following equation:

$$[FUEL] = (12 + r_1) * \{\frac{[CO_2]}{44} + \frac{[CO]}{28} + \frac{[HC]}{12 + r_2} + \frac{a[PM]}{12}\}$$

Where:

[FUEL] is the mass of fuel

$[CO_2]$, [CO], [HC] and [PM] are the masses of exhaust pollutants

r1 and r2 are the hydrogen to carbon ratios of the fuel and HC emissions respectively, it may be assumed that r1 and r2 are equal with typical values of 1,8 for petrol and 2 for diesel

a is the proportion of carbon in the PM emission, where is not known a value of 1 may be used.

However, some compounds can be retained in the exhaust system, the engine and the lubricating oil, and that is why these balances may not be exact, although is an accuracy approximation.

4. Methodology

At the local and regional levels, a significant portion of freight transportation is carried out by trucks, which emit a large amount of pollutants. While transportation technologies and fuels have improved over the years, most trucks run on diesel engines, which are major sources of emissions of nitrogen oxides (N_2O), particulate matter (PM) and carbon dioxide (CO_2). Repeated exposure to N_2O-based smog and PM has been linked to a wide range of health problems. At the global level, greenhouse gases (GHGs) significantly contribute to global warming. In the transportation sector, GHG emissions are dominated by CO_2 emissions from burning fossil fuels. As we see, these cause atmospheric changes and climate disruptions which are harmful to the natural and built environments and pose health risks.

Freight transportation planning has many facets, particularly when viewed from the multiple levels of decision making. Arguably the most famous problem at this level is the well-known Vehicle Routing Problem (VRP), which consists of determining least cost routes for a fleet of vehicles to satisfy the demands of a set of customers, subject to side constraints. The traditional objective in the standard VRP is to minimize the total distance traveled by all vehicles, but this objective can be enriched through the inclusion of terms related to fuel consumption.

The factors that influence fuel consumption are many such as weight, shape, speed, slope, distance, driver behavior, climate, engine, etc. But these factors con be divided into five categories: vehicle, environment, traffic, driver and operations, which are summarized in the next Figure:

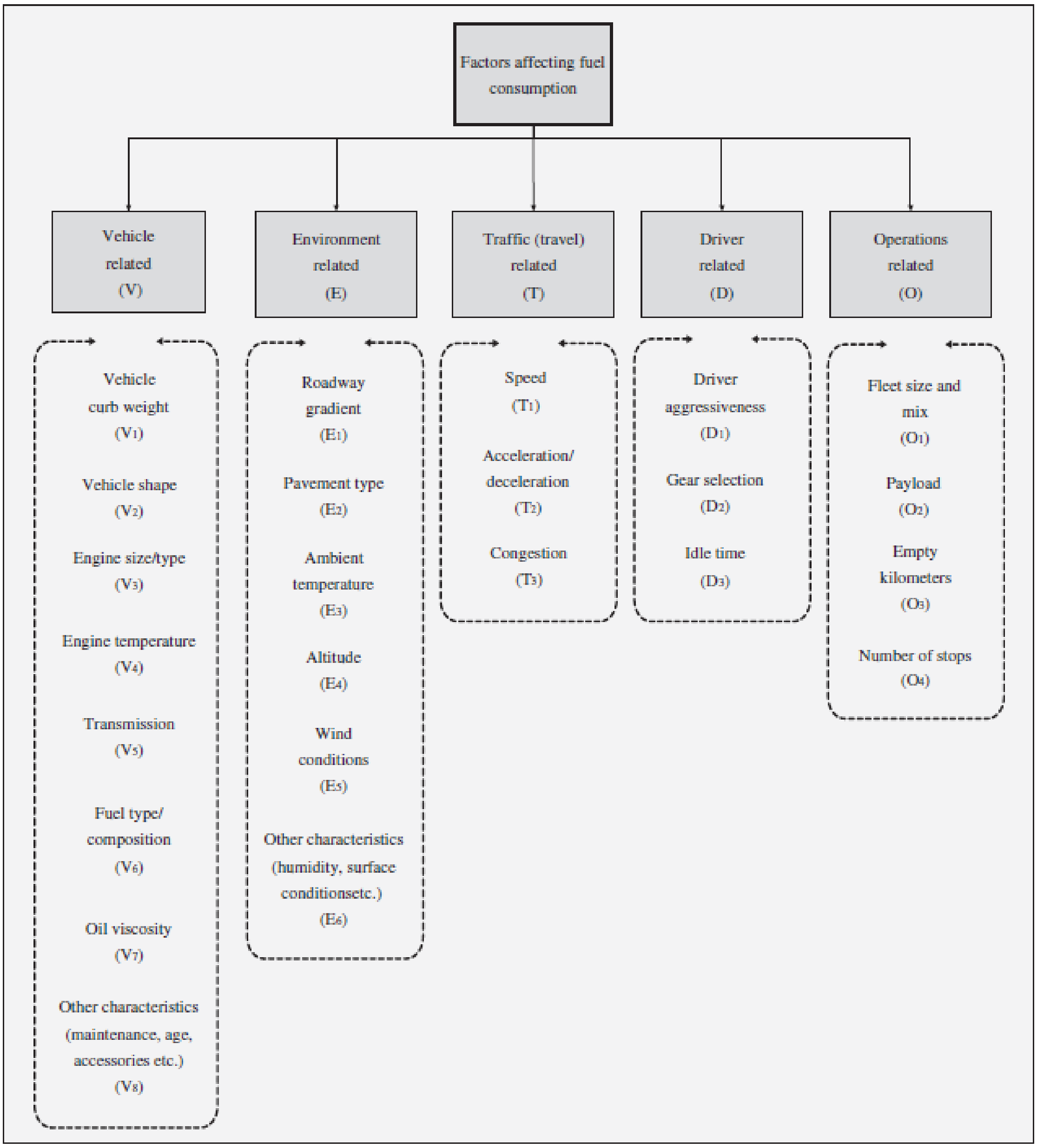


Figure 40: Factor affecting fuel consumption (Source, Reprinted from: A review of recent research on green road freight transportation. Demir)

- Speed: is the most important factor because it affects inertia, rolling resistance, air resistance and load slope.
- Road gradient: on a slope, wheel horsepower demand increases significantly with vehicle weight because road slope force.
- Congestion: driving in congested areas increases fuel consumption because of lower than optimal speeds.

- Driver: one of the most significant factors because controls vehicle speed, acceleration rate, brake usage, shifting technique, idle time, tire pressure, and more.
- Fleet size and mix: selecting the right type of vehicle has a significant impact on fuel consumption, small ones have less fuel consumption than larger vehicles.
- Payload: increasing the payload increases the engine demand horsepower, which leads to a higher fuel consumption.
- Empty kilometers: are kilometers driven by empty vehicles and should be avoided as much as possible as these are kilometers that don't add any value.
- Green freight corridors: this can be part of the future, they are roads that minimize environmental impact and therefore lower fuel consumption by studying the different factors that affect them.

There are many studies and emission model that differ in their modeling approaches, modeling structures and data requirements. The two main groups of models are the macroscopic models and the microscopic models.

Macroscopic models use average aggregate network parameters to estimate network-wide emission rates. Emission rates are measured for a variety of trips, each with different average speed. These emissions of CO2 are directly related to fuel consumption and therefore can be easily calculated if the amount of fuel consumptions is known. The main macroscopic models are:

- Methodology for calculating transportation emissions and energy consumption (MEET)
- Network for transport and environment (NTM)
- Computer programmer to calculate emissions from load transportation (COPERT)
- Ecological transport information tool (ECOTRANSIT)
- National atmospheric emission inventory (NAEI)

Microscopic models estimate the instantaneous vehicle fuel consumption and emission rates at a more detailed level. These models are necessary to predict traffic emissions more accurately. Are based on instantaneous vehicle kinematic variables, such as speed and acceleration, or on more aggregated modal variables, such as spent in each traffic mode, cruise and acceleration. The main microscopic models are:

- An instantaneous fuel consumption model (IFCM)

- A four-mode elemental fuel consumption model (FMEFCM)
- A running speed fuel consumption model (RSFCM)
- Average speed fuel consumption model (ASFCM)
- Vehicle specific power (VSP)
- Emissions from traffic mode (EMIT)
- Virginia tech microscopic (VT-Micro)
- The Oguchi, Katakura and Taniguchi (2002) fuel consumption model (OFCM)
- Physical emission rate estimator model (PERE)
- Comprehensive power-based fuel consumption models (CPFMs)
- Passenger car and heavy-duty emission model (PHEM)
- A comprehensive modal emission model (CMEM)

Microscopic models are similar in that they can reflect a certain level of detail to consider technical and vehicle-specific parameters such as vehicle shape (frontal area), and road conditions (e.g., gradient, surface resistance). This is not the case for macroscopic models which mostly present simpler ways of regression-based estimations through a predefined set of parameters for a given vehicle class.

The most used models, both microscopic and macroscopic, are described in articles such as Demir et al (2011). Here 6 models are described:

- An instantaneous fuel consumption model
- A four-mode elemental fuel consumption model
- A running speed fuel consumption model
- A comprehensive modal emission model
- Methodology for calculating transportation emissions and energy consumption (MEET)
- Computer programme to calculate emissions from road transportation model (COPERT)

The first four models are microscopic models, while the last two are macroscopic. Each has its advantages and disadvantages. Most of the models consider vehicle load and speed, although the way in which they incorporate these factors into the approximations, for load, varies highly. Only a few of the models consider driver-related factor and none of the models considers congestion. Microscopic model seems more robust, reliable and more applicable in the area of optimization.

Data requirement is also more important for microscopic models. On the other hand, macroscopic models have more technical support and provide continuous improvement, also are more capable of estimating other air pollutants.

The instantaneous fuel consumption model operates at microscale level and is better suited for short trip emission estimations. It uses vehicle characteristics such as mass, energy, efficiency parameters, drags force and fuel consumption components associated with aerodynamic drag and rolling resistance, and approximates the fuel consumption per second. Is able to take into account acceleration, deceleration, cruise and idle phases. The main disadvantage is the age of the parameters used as they have not been updated since 1985.

A four-mode elemental fuel consumption model is similar to instantaneous model, using the same parameters but including new considerations and requiring more data. This model consists of four functions corresponding to fuel consumption estimations for acceleration, deceleration, cruise and idle modes, which needs more calculations but obtaining more accuracy in the results.

The running speed fuel consumption model is an aggregated form of the elemental fuel consumption model and as an extension of the instantaneous model. Acceleration, deceleration and cruise modes are considered together within a single function. It does not take into account the idle mode of a vehicle.

The comprehensive modal emission model is quite different from the other three microscopic methods discussed in the previous paragraphs. Is a model user for heavy-good vehicles consisting in three modules: engine power, engine speed, and fuel rate. It requires detailed vehicle-specific parameters to estimation such as the engine friction coefficient, and the vehicle engine speed, but having a higher accuracy.

The methodology called MEET is used for calculating transportation emissions and energy consumption for heavy-goods vehicles. This methodology includes a variety of estimating functions, which are primarily dependent on speed and a number of fixed and predefined parameters for vehicles of weights ranging from 3.5 to 32 tons. MEET is based on on-road measurements and parameters are extracted from real-life experiments. The main deficiency of the model is its use of fixed vehicle-specific parameter settings for any vehicle in a given weight class.

The COPERT model is similar to MEET, it uses a number of functions which are specific to vehicles of different weights and is also based on on-road measurements but does not take road gradient and acceleration into account. In addition, it is necessary to know how to use the computer program well in order to calculate the emissions.

Looking over these six models and knowing that the route is considered interurban or long, the four microscopic models are discarded because they have better results in short or urban routes.

So in this work we will study the emissions and fuel consumption by the two routes, using the mathematical models of Methodology for calculating transportation emissions and energy consumption (MEET), since it includes the characteristics of the slope on the road and it is not necessary to control any type of computer program which facilitates the calculations, unlike the COPERT model.

4.1 Methodology for calculating transportation emissions and energy consumption (MEET)

A publication of the European Commission (Hickman et al, 1999) on emission factors for road transportation (INFRAS, 1995) describes a methodology called MEET, used for calculating transportation emissions and energy consumption for heavy goods vehicles. MEET is based on on-road measurements and all its parameters are extracted from real-life experiments.

This method calculates de among in kg of different types of pollutant emissions, such as CO2, CO, NOx, VOC, and PM.

It covers several vehicle technologies for different classes of vehicles, such as light vehicles weighing less than 3.5 tons, vehicles weighing between 3.5 and 7.5 tons, vehicles weighing between 7.5 and 16 tons, vehicles weighing between 16 and 32 tons and vehicles weighing more than 32 tons.

For the light vehicles with less weigh than 3,5 tons MEET provides different speed dependency formulas according to the type of vehicle and the type of fuel for each type of emission.

Pollutant	Vehicle class	Speed range	Emission factor (g/km)	R^2
CO	Uncontrolled	10-110	$0.00020V^2 - 0.0256V + 1.8281$	0.136
	EURO I	10-110	$0.000223V^2 - 0.026V + 1.076$	0.301
NO_X	Uncontrolled	10-110	$0.000816V^2 - 0.1189V + 5.1234$	0.402
	EURO I	10-110	$0.000241V^2 - 0.03181V + 2.0247$	0.072
VOC	Uncontrolled	10-110	$0.000066V^2 - 0.0113V + 0.6024$	0.141
	EURO I	10-110	$0.0000175V^2 - 0.00284V + 0.2162$	0.037
PM	Uncontrolled	10-110	$0.0000125V^2 - 0.000577V + 0.2880$	0.023
	EURO I	10-110	$0.000045V^2 - 0.004885V + 0.1932$	0.224
CO_2	Uncontrolled	10-110	$0.066V^2 - 8.2756V + 464.4$	0.486
	EURO I	10-110	$0.0617V^2 - 7.8227V + 429.51$	0.422

Table 19: Speed dependency formulas for each type of emission in light vehicles with less weigh than 3,5 tons (Source, Reprinted from: Methodology for calculating transport emissions and energy consumption. Hickman (1999))

For the rest of heavy-duty vehicles, MEET suggest the use a function form depending on the average speed:

$$\varepsilon = K + av + bv^2 + cv^3 + \frac{d}{v} + \frac{e}{v^2} + \frac{f}{v^3}$$

Where:

ε is the rate of emission in g/km for an unloaded goods vehicle, or for a bus or coach carrying a mean load, on a road with a gradient of 0%

K is a constant

a - f are coefficients

v is the mean velocity of the vehicle in km/h

Depending on the vehicle weight, these coefficients are different for each type of emission:

weights from 16 to 32 tonnes

	K	a	b	c	d	e	f
CO	1.53	0	0	0	60.6	117	0
CO_2	765	-7.04	0	0.000632	8334	0	0
VOC	0.207	0	0	0	58.3	0	0
NO_X	9.45	-0.107	0	7.55E-6	132	0	0
PM	0.184	0	0	1.72E-7	15.2	0	0

Table 20: Coefficients for vehicle weight between 16 and 32 tons (Source, Reprinted from: Methodology for calculating transport emissions and energy consumption. Hickman (1999))

The emission factors and functions of MEET refer to standard testing conditions (i.e., zero road gradient, empty vehicle, etc.) and are typically calculated as a function of the average vehicle speed. Depending on the vehicle type, several corrections may be needed to account for the effects of road gradient and vehicle load on the emissions once a rough estimate has been produced.

The gradient of a road has the effect of increasing or decreasing the resistance of a vehicle to traction. Increases or decreases in the load on the engine have a corresponding effect on rates of emission and fuel consumption, but even in the case of large-scale applications, it cannot be assumed that the extra emission when travelling uphill is fully compensated by the reduced emission when travelling downhill because when the slope is downhill the low speeds that the load forces to maintain are not beneficial for consumption, in this case it's best to have a zero road gradient.

Because of their higher masses, the gradient influence is much more significant in the case of heavy-duty vehicles. Special gradient factors have been introduced, considered to be a function of:

-The technology (for light duty vehicles) or the mass (for heavy duty vehicles)

-The road gradient

-The pollutant

-The mean speed of the vehicle

For each vehicle category, gradient and pollutant, the gradient factor can be calculated as a polynomial function of the vehicle's mean speed:

$$as_{i,j,k} = A6_{i,j,k} * V^6 + A5_{i,j,k} * V^5 + A4_{i,j,k} * V^4 + A3_{i,j,k} * V^3 + A2_{i,j,k} * V^2 + A1_{i,j,k} * V + A0$$

where:

asi,j,k is the correction factor

V is the mean speed

A0i,j,k... A6i,j,k are constants for each pollutant, vehicle and gradient class

An example for these constants is seen in the Table 21:

A6	A5	A4	A3	A2	A1	A0	Pollutant	Slope (%)	Vmin (km/h)	Vmax (km/h)
0.00E+00	1.28E-07	-1.65E-05	7.96E-04	-1.82E-02	2.04E-01	3.24E-01	VOC	4… 6	13.1	39.5
0.00E+00	-4.01E-08	8.12E-06	-6.01E-04	2.01E-02	-3.01E-01	2.76E+00		-6… -4	13.5	49.9
0.00E+00	-1.82E-08	3.70E-06	-2.78E-04	9.60E-03	-1.51E-01	1.94E+00		0… 4	15.1	70.3
0.00E+00	1.10E-09	-3.38E-07	3.94E-05	-2.13E-03	5.25E-02	6.52E-01		-4… 0	15.1	86.4
0.00E+00	3.28E-07	-4.35E-05	2.21E-03	-5.46E-02	6.73E-01	-1.88E+00	CO	4… 6	13.1	39.5
0.00E+00	-6.79E-08	1.21E-05	-8.24E-04	2.58E-02	-3.67E-01	2.89E+00		-6… -4	13.5	49.9
0.00E+00	-1.09E-08	2.16E-06	-1.56E-04	4.85E-03	-5.79E-02	1.34E+00		0… 4	15.1	70.3
0.00E+00	-1.11E-10	-3.21E-08	1.19E-05	-1.09E-03	3.34E-02	6.97E-01		-4… 0	15.1	86.4
0.00E+00	-2.42E-07	3.49E-05	-1.96E-03	5.28E-02	-6.52E-01	4.60E+00	NO_x	4… 6	13.1	39.5
0.00E+00	-9.71E-08	1.70E-05	-1.14E-03	3.57E-02	-5.30E-01	3.81E+00		-6… -4	13.5	49.9
0.00E+00	-1.21E-08	2.39E-06	-1.77E-04	6.00E-03	-8.29E-02	1.56E+00		0… 4	15.1	70.3
0.00E+00	-8.49E-11	1.17E-08	3.94E-07	-1.38E-04	2.18E-03	9.09E-01		-4… 0	15.1	86.4
0.00E+00	3.21E-07	-4.29E-05	2.23E-03	-5.75E-02	7.62E-01	-1.98E+00	CO_2	4… 6	13.1	39.5
0.00E+00	-1.24E-07	2.08E-05	-1.33E-03	4.00E-02	-5.65E-01	3.57E+00		-6… -4	13.5	49.9
0.00E+00	-9.78E-10	-2.01E-09	1.91E-05	-1.63E-03	5.91E-02	7.70E-01		0… 4	15.1	70.3
0.00E+00	-6.04E-11	-2.36E-08	7.76E-06	-6.83E-04	1.79E-02	6.12E-01		-4… 0	15.1	86.4
0.00E+00	8.06E-09	3.61E-07	-1.27E-04	5.99E-03	-8.25E-02	1.76E+00	PM	4… 6	13.1	39.5
0.00E+00	-5.44E-08	1.01E-05	-7.06E-04	2.28E-02	-3.38E-01	2.86E+00		-6… -4	13.5	49.9
0.00E+00	-1.61E-08	3.27E-06	-2.45E-04	8.30E-03	-1.18E-01	1.72E+00		0… 4	15.1	70.3
0.00E+00	-7.69E-10	1.50E-07	-7.72E-06	-8.94E-05	1.04E-02	8.95E-01		-4… 0	15.1	86.4

Table 21: Constants for vehicle with total weight between 7,5 and 16 tons (Source, Reprinted from: Methodology for calculating transport emissions and energy consumption. Hickman (1999))

The driving resistance of a vehicle is influenced by vehicle mass, i.e. higher vehicle mass requires higher power from the engine during driving, especially in acceleration modes. Because of the well-known fact that emissions and fuel consumption are proportional to the engine power, the calculations must take into account, in principle, vehicle load.

In the case of heavy duty vehicles the vehicle load has an important influence on emissions and fuel consumption as the load can contribute significantly to the total weight of the vehicle.

Functions to correct for load have been determined for goods vehicles with a load correction factor:

$$\Phi(\Upsilon, v) = k + n\Upsilon + p\Upsilon^2 + q\Upsilon^3 + rv + sv^2 + tv^3 + \frac{u}{v}$$

where:

k is a constant

n - u are coefficients

$\Phi(\gamma, v)$ is the load correction factor function

These coefficients depend on the weight of the load and type of emission, and are expressed in tables like this:

	K	n	p	q	r	s	t	u
CO	1.03	0.0345	0	-7.55E-4	9.77E-4	0	0	0
CO_2	1.26	0.0790	0	-0.00109	0	0	-2.03E-7	-1.14
VOC	0.985	0.00367	0	0	0.00135	0	0	0.201
NO_X	1.19	0.0594	0	-9.69E-4	0	0	0	-0.977
PM	1.02	0.0437	0	-9.16E-4	0.00234	0	0	0

Table 22: Coefficients for weight of load between 7,5 and 16 tons (Source, Reprinted from: Methodology for calculating transport emissions and energy consumption. Hickman (1999))

The MEET model, in addition to these corrections, considers other more complex factors and parameters to be applied according to the type of vehicle in order to make a more precise estimate of emissions, such as mileage factor and temperature factor.

The degradation of pollution controls, in the case of conventional spark-ignition and diesel vehicles, the emission behavior generally deteriorates within a service interval. The emission level can, however, be restored to approximately that of a new vehicle by adjustment and maintenance or by the correction of defects, whatever the mileage. Because of this, no deterioration of the emission figures as a function of vehicle mileage is quoted in the case of conventional spark-ignition and diesel vehicles. The generally poorer maintenance condition of older vehicles does have the effect of increasing emissions, but this is ignored. Therefore a correction is made according to the mileage of the vehicles:

$$MC_v = a + bv + cm + dvm$$

where:

m is the mileage of the vehicle

a, b, c & d are coefficients

The coefficients for these equations are also included in some table:

	Capacity class (l)	Average mileage (km)	a	b	c	d	Value at 120000 km
Urban correction function (v ≤ 19 km/h)							
CO	< 1.4	29057	0.557	0	1.523E-05	0	2.39
	1.4 - 2.0	39837	0.543	0	1.148E-05	0	1.92
	>2.0	47028	0.565	0	9.243E-06	0	1.67
NO_X	< 1.4	29057	0.478	0	1.798E-05	0	2.64
	1.4 - 2.0	39837	0.207	0	1.990E-05	0	2.59
	>2.0	47028	0.839	0	3.416E-06	0	1.25
HC	< 1.4	29057	0.647	0	1.215E-05	0	2.10
	1.4 - 2.0	39837	0.509	0	1.232E-05	0	1.99
	>2.0	47028	0.432	0	1.208E-05	0	1.88
Intermediate correction function (v between 19 and 63 km/h)							
CO	< 1.4	29057	0.578	-1.091E-03	1.451E-05	3.773E-08	
	1.4 - 2.0	39837	0.511	1.682E-03	1.229E-05	-4.257E-08	n/a
	>2.0	47028	0.432	7.000E-03	1.207E-05	-1.486E-07	
NO_X	< 1.4	29057	0.551	-3.841E-03	1.548E-05	1.318E-07	
	1.4 - 2.0	39837	0.116	4.795E-03	2.219E-05	-1.205E-07	n/a
	>2.0	47028	0.941	-5.364E-03	1.246E-06	1.142E-07	
HC	< 1.4	29057	0.577	3.682E-03	1.456E-05	-1.268E-07	
	1.4 - 2.0	39837	0.466	2.273E-03	1.340E-05	-5.693E-08	n/a
	>2.0	47028	0.313	6.250E-03	1.461E-05	-1.331E-07	
Extraurban correction function (v ≥ 63 km/h)							
CO	< 1.4	29057	0.509	0	1.689E-05	0	2.54
	1.4 - 2.0	39837	0.617	0	9.607E-06	0	1.77
	>2.0	47028	0.873	0	2.704E-06	0	1.20
NO_X	< 1.4	29057	0.309	0	2.378E-05	0	3.16
	1.4 - 2.0	39837	0.418	0	1.460E-05	0	2.17
	>2.0	47028	0.603	0	8.442E-06	0	1.62
HC	< 1.4	29057	0.809	0	6.570E-06	0	1.60
	1.4 - 2.0	39837	0.609	0	9.815E-06	0	1.79
	>2.0	47028	0.707	0	6.224E-06	0	1.45

Table 23: Mileage correction functions (Source, Reprinted from: Methodology for calculating transport emissions and energy consumption. Hickman (1999))

Hot emissions are influenced much less by the ambient temperature than start emissions, but because of the wide range of ambient temperatures found in Europe, from north to south and winter to summer, attention should also be given to this effect. Measurements are available covering the temperature range -20 to +25 ºC. The effect of the temperature may be expressed as the ratio of emissions at any particular temperature with those at a reference temperature, and in this analysis, the reference temperature was taken to be 20 ºC, which is typical for the measurements used to generate the basic emission functions. Then temperature correction functions valid from – 20 to 22,5ºC are expressed in the Table 24:

Pollutant	FTP75 phase	A	B	Value at -20°C
CO	s ht average	-0.0249 -0.0155 -0.0202	1.58 1.37 1.48	2.08 1.68 1.88
NO_X	s ht average	-0.0101 -0.0143 -0.0122	1.26 1.28 1.27	1.46 1.57 1.51
HC	s ht average	-0.0201 -0.0126 -0.0164	1.47 1.31 1.39	1.87 1.56 1.72
Temperature correction TC = A × temperature (°C) + B				

Table 24: Temperature correction functions (Source, Reprinted from: Methodology for calculating transport emissions and energy consumption. Hickman (1999))

Other factors such as air conditioning or altitude are not taken into account with this model. So Hot emission factors are calculated firstly as a function of the average vehicle speed. Depending on the vehicle type, a number of corrections may be made to allow for the effects of road gradient, vehicle load, vehicle mileage and ambient temperature. Thus, for one vehicle type and pollutant:

$$e_{hot} = f(v) * GC * LC * MC * TC$$

where:

e_{hot} is the corrected hot emission factor

f(v) is the average speed (v) dependent emission rate for standard conditions

GC, LC, MC & TC are correction factors for gradient, load, mileage and temperature respectively

All these correction factors are not apply for all vehicle classes, only those which the information is available and is demonstrated that have a significant effect. In the next table is summarized the parameters included in the calculation of hot emissions for each type of vehicle:

Vehicle type	Average speed	Gradient	Load	Mileage	Temperature
Car - conventional	✓	✓			
- catalyst	✓	✓		✓	✓
- diesel	✓	✓			
LDV - conventional	✓	✓			
- catalyst	✓	✓		(✓)[31]	(✓)
- diesel	✓	✓			
HGV	✓	✓	✓		
Bus and coach	✓	✓			
Motorcycle	✓				

Table 25: Parameters included for each type of vehicle (Source, Reprinted from: Methodology for calculating transport emissions and energy consumption. Hickman (1999))

This is the reason why in the MEET model used in this work, only load and gradient correction factors are applied in the average speed estimation of emissions, as the work deals with pollution from road freight transport. The calculations made are explained in more detail in the following sections.

4.2 Analysis of road gradients

When a freight vehicle is preparing to drive up a slope, it is impossible for it to maintain a gear ratio and engine speed that will allow efficient driving. What is important in such cases is that the engine power is sufficient to keep the vehicle going uphill even at fairly low speeds.

Although uphill slopes require higher fuel consumption, it is best for these vehicles to drive on slopes close to zero, since even on downhill slopes the low speeds that the load forces to be maintained are not exactly beneficial for vehicle consumption.

To obtain the slopes of these two roads, different geographical information systems have been used, such as SITNA for the sections of road in Navarre, and geoEuskadi for the sections in Gipuzkoa.

To calculate the gradient, values have been taken every kilometer coinciding with the kilometer points (PK) marked on the road, noting the altitude of each point with the help of Google Earth, so that the errors that this system makes by omitting tunnels, bridges or footbridges are corrected, taking more real values of the altitude of these points on the road.

Once the altitude of each point is obtained and knowing that the horizontal distance between two points is one kilometer, the angle of inclination of the road can be obtained by applying trigonometry:

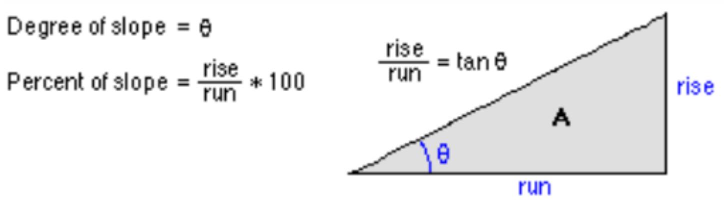


Figure 41: Road gradient (Source: Google)

In these cases where the tilt angle is so small, the horizontal distance is practically equal to the hypotenuse, so this angle can also be calculated with the mathematical function arcsine of the ratio between the height and the horizontal distance.

Another more widely used way of calculating the gradient is as a percentage. This operation is much simpler, since the percentage of a gradient indicates the meters you climb for every 100 you go horizontally. For example, if you go up 10 meters while advancing 100, the gradient is 10%.

In the case of a downward gradient the calculations are made in the same way, obtaining a gradient with a negative value.

All these calculations of the gradients for both routes can be seen in the attached Excel files.

Finally, the following elevation profiles are obtained for both routes:

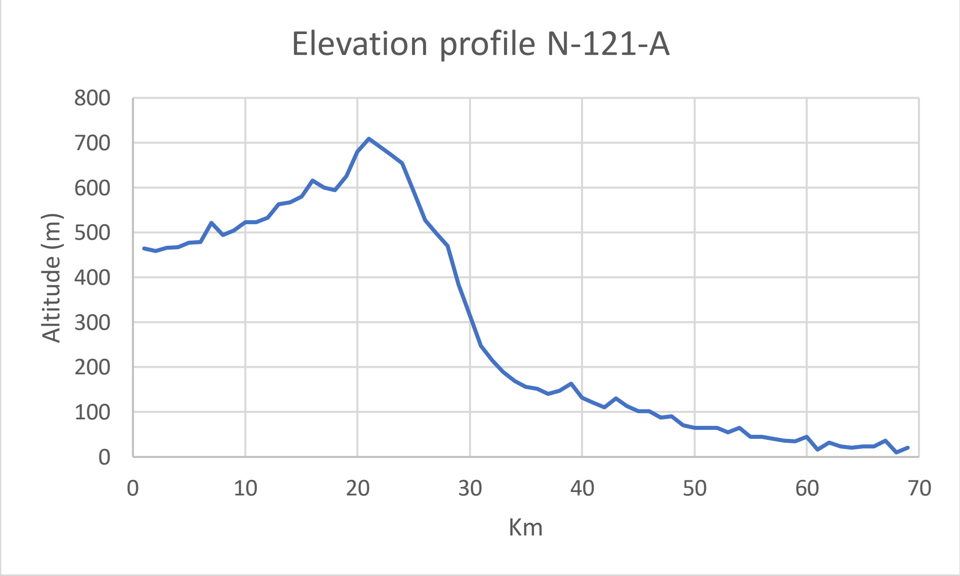


Figure 42: Elevation profile of the route on the N-121-A (Source: Self production)

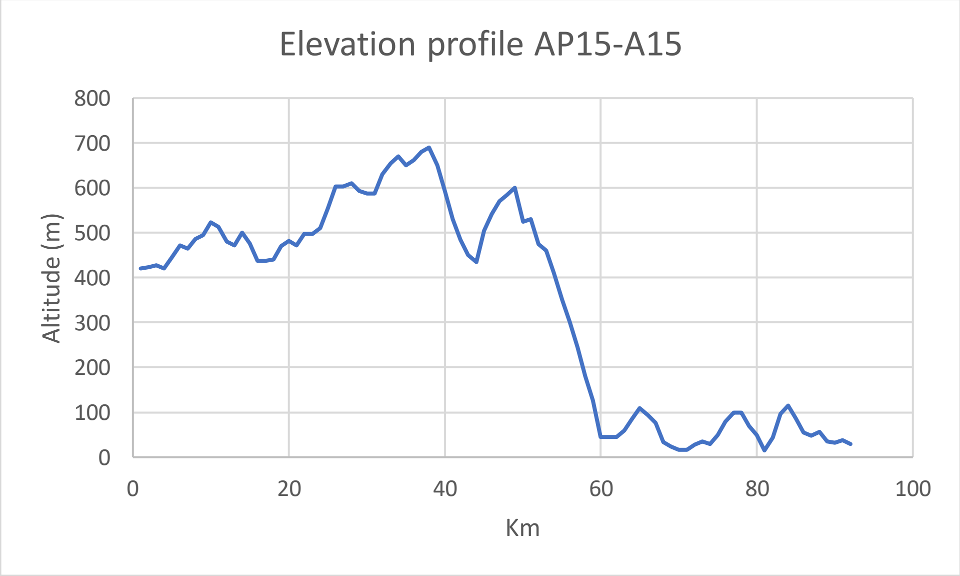


Figure 43: Elevation profile of the route on the AP15 (Source: Self production)

Looking at Figures 42 and 43, it can be seen that the elevation profile of the route through the highway has larger sections with ascending road slopes, and a priori, without making any calculations, it is expected to have higher fuel consumption than the route through the N-121-A, in addition to being a route with greater distance travelled.

Taking into account the sections with positive slope, the average slope obtained in each of the routes is:

	ROUTE 1	ROUTE 2
AVERAGE SLOPE + (%)	1,62	2,17

Table 26: Average slopes for both routes (Source: Self production)

The route 2 (AP 15) having a higher average slope seems to predict higher fuel consumption, it has 41 km with positive gradient against 25 of the route 1.

However, this will be checked with the final results obtained by both estimation methods in the next sections.

4.3 Analysis of road speeds

Many factors influence a vehicle's fuel economy, one of the most important being speed. The relationship between fuel consumption and speed is exponential from certain values that depend on the type of vehicle. In any case, what happens is that from a certain speed (about 100 km/h in passenger cars, for example) consumption increases much faster than speed. For this reason, it would be logical to think that the higher the average speed of a road, the more consumption it will require when travelling.

The case of goods vehicles is special, because the speed for them is limited and so they should not enter the exponential curve zone. In addition to this, at moderate speeds (no more than 90 km/h for these vehicles) an important aspect of efficient driving is to try to select a gear that allows the engine to operate in the lower part of the maximum torque range.

As is known, heavy goods vehicles have greater speed restrictions, on motorways and highways their maximum speed is 90 km/, and on conventional roads it is 80 km/h.

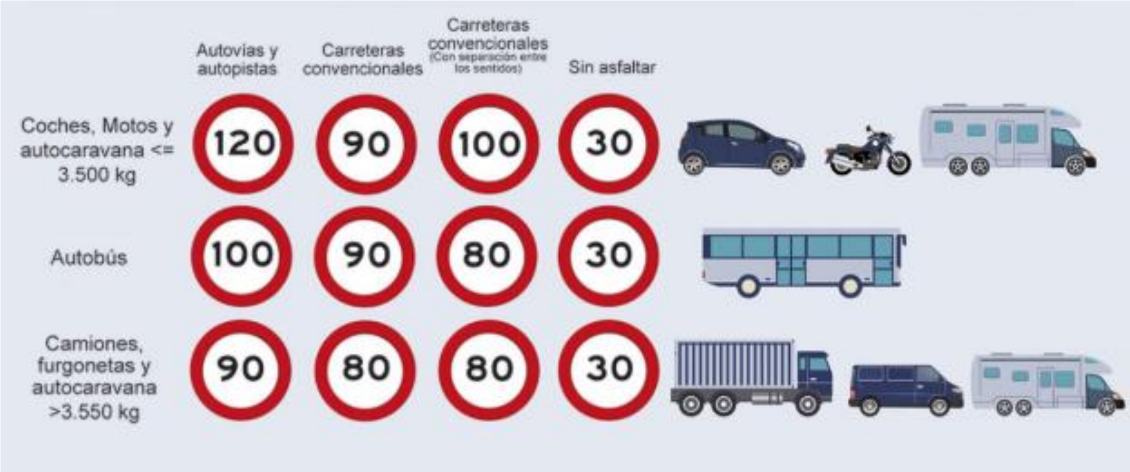


Figure 44: Speed restrictions for each vehicle type and road (Source, Reprinted from: DGT)

In addition, on these sections the traffic signs indicating the maximum permitted speed change due to tunnels, intersections, town crossings, bridges, etc. With speed limitations in this work of 50 km/h when crossing urban areas, 70 km/h in sections with intersections, crossings and additions to other roads, and 80 km/h in tunnels; both for cars and heavy vehicles.

Therefore, in order to know the maximum permitted speed in each kilometer of each route, the Google Street View has been used, covering the routes by road and noting the permitted speed values of the road signs. And then applying the speed restrictions for heavy vehicles in Figure 44.

Figure 45: Actual image of a road section with a speed limit signal (Source: Google Street View)

As will be seen later, in order to apply the fuel consumption estimation models it will be necessary to modify the speed limits and gradients in some sections of the road, since these models work with parameters that can only be used within speed and gradient limits.

In this work, the heavy goods vehicle will not travel at the maximum permitted speed, since to maintain that speed with the load and on sections with an upward slope, the engine needs more power by taking it out of its optimum speed range for lower fuel consumption, as explained in the section on efficient driving.

Opting for a driving speed equal to the average speed of heavy vehicles in Spain on motorways and highways, and on conventional roads, data obtained from the Ministry of Development of the Spanish government, with an average speed of 86 km/h on motorways, and 72 km/h on conventional roads, with their respective estimation model restrictions depending on the characteristics of the sections.

By applying speed restrictions to both traffic signs and estimation models, an average speed is obtained for each route:

	ROUTE 1	ROUTE 2
AVERAGE SPEED (km/h)	67,40	71,60

Table 27: Average speed for both routes (Source: Self production)

As expected, speeds on Route 2, which is the highway, are higher, although the difference is not very large, but it has sections where speeds are higher, which seems to indicate that consumption will be higher, which will be checked in the following sections.

Knowing the average speed at which the heavy vehicle circulates, and the kilometers to be covered, we can calculate the average time of the journey.

	ROUTE 1	ROUTE 2
TIME	1 h	1h 17min

Table 28: Time spend in each route (Source: Self production)

As you can see, under normal conditions, it takes 17 minutes longer on route 2 than on route 1. However, it is important to know that on the N-121-A conditions are not always normal, as there are many heavy vehicles that on stretches that cannot be passed, work in the tunnels, or accidents, can increase this time considerably.

4.4 Initial data

Before performing the calculations, it is necessary to establish the starting data, which in this case will be the same for both routes in order to compare them correctly.

This is one of the most important parts of the work and is known as the field work, which consists of obtaining the initial data needed to perform the calculations.

The first thing will be to define the most suitable type of vehicle for the transport of goods, which will carry out both routes. The truck covers the need to be able to transport a large amount of cargo with the capacity of maneuver that any car has. The transport of goods is carried out with two types of trucks: rigid (full truck) and articulated.

Although when carrying out international operations the most important means of transport is by sea, since it handles the majority of freight forwarding, trucks are the most common means of transporting goods due to their visible advantages, such as accessibility, proper preservation of products, cost reduction and security of delivery of products, among other benefits.

Rigid trucks perform ground transportation generally in the city, due to their smaller size (normally 2 axles, although there are rigid trucks with more axles with larger sizes than if they can be used for international transport). Its structure is in one piece, the driver's cabin and the trailer are indivisible parts of the same structure. Due to their smaller size, they are usually used for urban transportation. Then this type of truck is discarded.

Mega trucks are special vehicles designed to transport a greater volume of goods and much larger, can transport heavy goods and can reach a length of about 25 meters and move about 60 tons, but this type of vehicle is not the most used so it is also discarded, as well as road trains that are trucks with more than one semi-trailer whose lengths are very large and have difficulty driving on certain roads.

Then the vehicle to be used must be an articulated truck, the most used for international transport. These transport vehicles have two different rigid structures that are joined by an articulated point. The trailers are made up of a part called a tractor truck and another part called a semi-trailer. The first one corresponds to the head (cabin, which is not used for loading, but for towing and is where the driver is) and the second one is the one that contains the trailer with the load, also called platform.

Within the trailers, there are different types of trucks depending on the type of goods: canvas trucks, refrigerated trucks, tank trucks, closed trucks, open platform trucks, car carriers, etc.

They can also be differentiated according to the maximum authorized mass they can carry, which includes the weight of the empty truck and the load it is carrying. This is differentiated according to the number of axles the truck has, 4, 5 or 6.

Therefore, before choosing the type of truck, it is necessary to know the average merchandise that crosses the border through the Pyrenees. According to the Spanish-French Observatory of Traffic in the Pyrenees, the average tonnage per heavy vehicle is 14, which can be seen in the following Table:

Estimación del tonelaje de los intercambios de mercancías por carretera en 2016						
Pasos	Tonelaje medio t / V.P.	Tráfico V.P. / día	Tráfico autocares por día	Tráfico VP mercancías por día	Tonelaje por día en kt / día	Tonelaje anual en Mt/año
Autopista A8 - A63 Norte-Sur	14,1	4.500	80	4.420	62,4	22,9
Autopista A8 - A63 Sur-Norte	15,1	4.460	80	4.380	66,0	24,2
Autopista A7 - A9 Norte-Sur	12,3	4.880	140	4.740	58,4	21,4
Autopista A7 - A9 Sur-Norte	15,5	4.910	140	4.770	74,0	27,1
Puentes vascos - VP cruces reales	9,3	1.040	60	980	9,1	3,3
Otras R.N.*	14,2	1.165	135	1.030	14,6	5,4
Total	**14,0**	**20.955**	**635**	**20.320**	**284,6**	**104,1**

Table 29: Estimated tonnage crossing the border through the Pyrenees (Source, Reprinted from: Observatorio Hispano-Frances de tráfico en los Pirineos)

There is a higher percentage of trucks with canvas on the road, and a 5-axle articulated truck, whose empty weight is 15 tons, is sufficient to carry 14 tons.

These five-axle trucks have a maximum mass authorized by law of 40 tons, then the 14 of the load and the 15 that the truck weighs do not exceed them and therefore it is a correct transport.

Therefore, the transport vehicle is finally defined as a five-axle articulated tractor with closed semitrailer with a total mass (including load) of 29 tons. Like almost 90 % of heavy trucks, it will use as diesel fuel. The rest of the characteristics are defined in the following Table:

TRUCK CHARACTERISTICS	
EMPTY WEIGHT (ton)	15
TYPE OF FUEL	Diesel
ENGINE POWER (kW)	330
LOADED MASS (ton)	14
Nº AXES	5
Nº WHEELS	18
TIRE DIAMETER (m)	1
COST OF TIRE (€)	562
AVERAGE DURATION OF A TIRE (km)	150.000
FRONTAL AREA (m^2)	7,8
LARGE (m)	16,5
AVERAGE COST MAINTENANACE AND REPAIRS (€/km)	0,055
MILEAGE (km)	200.000

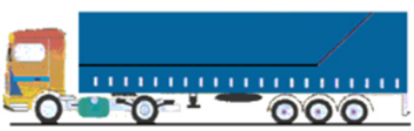


Table 30: General truck characteristics (Source: Self production)

Once the characteristics of the vehicle have been defined, emissions can be calculated using the estimation model explained above, but not without first commenting on certain details.

In order to make a more accurate final comparison between the two routes, equal aspects will be considered for both routes, such as weather and temperature, traffic, fuel price, starting characteristics of the trailer such as tires, maintenance, mileage, etc., (the same for both routes), the same driver with the same efficient driving for both routes, and fixed costs (not kilometer costs) such as insurance, driving salary, financing and taxes, etc., will not be included as they are considered equal regardless of the route.

The starting point could have been chosen the same for both routes, but due to the traffic, study of speeds and gradients in urban areas of the center of Pamplona, a previous warm-up to reach the optimum working temperatures of the engine, it is considered correct to compare both routes starting from different points practically equidistant from the center such as the incorporation into the AP15 in Berriozar (PK 97), and in the incorporation into the N-121-A (PK 6) at the exit of the Ezcaba tunnels, for each route respectively.

The route is considered one-way from Pamplona to Irún and ends at the Biratou toll booth on the Behobia Bridge to France over the Bidasoa River.

5. Results

In this section, the method seen in the previous section will be applied in order to arrive at a result that will allow both routes to be compared and will allow conclusions to be drawn.

All the calculations explained below can be seen in the Excel sheets attached to the CD.

Before starting to apply the model, the gradient is calculated every kilometer and the speed allowed on both routes, as seen in the sections on gradient and speed analysis, saving this data in the Excel in the columns of Slope %, and Permissible speed on each section (km/h)

Once the permitted speed has been obtained on each section, the maximum permitted speed restrictions for heavy vehicles apply as shown in Figure 44, by entering these values in the Excel column of Permissible speed truck (km/h)

Normally, heavy goods vehicles do not run at the maximum speed allowed due to their heavy weight, the care of the load, maintaining a more efficient driving, slopes, traffic, climate, etc., but usually circulate below this speed.

In this work, the truck will circulate at the average speed that trucks circulate on highways and conventional roads in Spain according to the Ministerio de Fomento as can be seen in the following tables:

TIPO	Nº Esta	Nº HORAS (miles)	T	Nº VEH. (miles)	VEL. MEDIA	% Velocidad KM/h <20	20 30	30 40	40 50	50 65	65 80	80 90	90 100	100 110	110 120	120 130	130 140	140 150	150 160	160 200	%Vel > 110	%Vel > 120
ENERO																						
Resumen	359	230	L	321555	101,28	0,3	0,4	0,5	0,7	2,1	9,0	13,7	19,5	19,1	17,0	10,7	4,5	1,6	0,5	0,3	34,6	17,7
			P	41598	88,63	0,7	0,4	0,6	0,8	2,4	10,9	38,5	32,2	6,3	2,7	4,4	0,0	0,0	0,0	0,0	7,1	4,4
FEBRERO																						
Resumen	361	219	L	328613	102,44	0,3	0,4	0,5	0,7	2,2	8,9	13,7	18,6	18,5	16,4	10,4	4,4	1,9	1,7	1,3	36,1	19,7
			P	55033	88,30	0,9	0,4	0,5	8,1	2,0	8,8	29,4	31,7	4,9	2,0	11,3	0,0	0,0	0,0	0,0	13,3	11,3
MARZO																						
Resumen	362	237	L	350905	102,41	0,3	0,4	0,5	0,7	2,1	8,9	12,8	18,6	18,7	17,4	11,3	4,9	1,7	1,6	0,3	37,1	19,7
			P	43423	85,56	1,3	0,4	3,5	0,8	2,4	10,8	38,0	31,8	6,8	2,7	1,4	0,0	0,0	0,0	0,0	4,1	1,4
ABRIL																						
Resumen	368	229	L	552899	97,51	3,1	2,8	2,7	2,8	3,7	8,2	10,6	14,1	14,6	13,7	9,7	5,4	3,4	2,8	2,4	37,5	23,8
			P	214127	76,71	6,1	6,0	6,0	6,1	8,3	11,6	15,6	14,5	9,3	8,4	8,1	0,0	0,0	0,0	0,0	16,5	8,1
MAYO																						
Resumen	366	244	L	380956	101,77	0,3	0,4	0,5	0,7	2,2	9,4	12,8	18,5	18,9	17,5	11,4	4,9	1,7	0,6	0,3	36,3	18,9
			P	57328	86,58	1,1	0,3	0,6	7,2	2,1	11,7	33,9	27,2	5,8	2,4	7,8	0,0	0,0	0,0	0,0	10,2	7,8
JUNIO																						
Resumen	364	240	L	385854	102,02	0,3	0,4	0,6	1,1	2,3	8,4	12,6	18,2	18,9	17,6	11,7	5,1	1,8	0,6	0,3	37,2	19,6
			P	46508	84,69	4,5	0,4	0,6	1,0	2,6	10,7	36,9	31,9	7,1	2,9	1,5	0,0	0,0	0,0	0,0	4,4	1,5
JULIO																						
Resumen	363	246	L	425951	103,41	0,2	0,6	0,4	0,6	1,9	7,5	12,1	17,8	19,0	18,5	12,7	5,6	2,0	0,6	0,3	39,8	21,2
			P	47143	87,60	1,2	0,3	0,6	0,8	2,5	10,8	38,7	33,0	7,4	3,1	1,6	0,0	0,0	0,0	0,0	4,7	1,6
AGOSTO																						
Resumen	355	247	L	414409	106,17	0,1	0,2	0,2	0,3	1,2	6,0	11,1	17,5	19,5	20,0	14,2	6,3	2,3	0,8	0,3	43,9	23,9
			P	41875	88,44	1,2	0,2	0,4	0,6	2,0	10,2	38,9	33,6	7,8	3,4	1,8	0,0	0,0	0,0	0,0	5,2	1,8
SEPTIEMBRE																						
Resumen	366	244	L	407389	102,30	0,3	0,4	0,6	0,8	2,4	8,1	12,5	18,3	18,9	17,8	11,8	5,4	1,8	0,6	0,3	37,7	19,9
			P	44218	87,46	1,1	0,5	0,7	0,9	2,6	10,8	38,7	32,8	7,4	3,1	1,6	0,0	0,0	0,0	0,0	4,7	1,6
OCTUBRE																						
Resumen	376	250	L	401195	100,29	0,4	0,6	0,8	1,1	3,0	9,1	13,1	18,6	18,6	16,8	10,8	4,6	1,6	0,5	0,3	34,6	17,8
			P	50367	86,15	1,3	0,4	0,7	1,0	5,3	10,9	37,6	31,7	6,9	2,8	1,4	0,0	0,0	0,0	0,0	4,3	1,4
NOVIEMBRE																						
Resumen	379	246	L	380745	100,10	0,4	0,6	0,8	1,0	2,9	9,4	13,5	18,9	18,7	16,5	10,5	4,4	1,6	0,5	0,3	33,8	17,2
			P	47623	87,73	0,5	0,4	0,6	0,9	2,8	11,3	39,0	33,2	6,9	2,9	1,5	0,0	0,0	0,0	0,0	4,4	1,5
DICIEMBRE																						
Resumen	376	255	L	385554	101,69	0,3	0,4	0,6	0,7	2,4	9,0	13,0	18,8	18,5	17,1	11,4	5,0	1,8	0,6	0,3	36,2	19,1
			P	40738	88,27	0,4	0,3	0,4	0,8	2,7	11,2	38,5	33,5	7,3	3,1	1,7	0,0	0,0	0,0	0,0	4,8	1,7

Table 31: Average speeds on Spanish highways (Source, Reprinted from: Ministerio de Fomento) In Spanish

TIPO	Nº Esta	Nº HORAS (miles)	T	Nº VEH. (miles)	VEL. MEDIA	% Velocidad KM/h <20	20 30	30 40	40 50	50 65	65 80	80 90	90 100	100 110	110 120	120 130	130 140	140 150	150 160	160 200	%Vel > 90	> 100
ENERO																						
Resumen	159	111	L	26783	72,29	0,3	0,8	2,7	10,3	23,0	28,0	16,0	10,4	4,9	2,3	0,9	0,3	0,1	0,0	0,0	19,0	8,6
			P	2662	73,03	0,9	0,6	2,1	6,8	17,6	32,1	26,3	11,2	1,7	0,5	0,2	0,0	0,0	0,0	0,0	13,6	2,4
FEBRERO																						
Resumen	160	106	L	26939	72,07	0,4	1,0	2,7	10,4	23,1	27,4	16,1	10,4	4,9	2,3	0,8	0,3	0,1	0,0	0,0	18,8	8,4
			P	2755	73,34	0,5	0,7	2,3	7,0	16,9	31,3	27,5	11,4	1,7	0,5	0,2	0,0	0,0	0,0	0,0	13,7	2,3
MARZO																						
Resumen	161	118	L	30580	72,28	0,4	1,0	2,8	10,3	23,1	26,8	16,3	10,7	5,1	2,3	0,8	0,3	0,1	0,0	0,0	19,4	8,7
			P	3015	73,23	0,9	1,0	2,2	6,7	16,5	31,3	27,5	11,5	1,8	0,5	0,2	0,0	0,0	0,0	0,0	13,9	2,4
ABRIL																						
Resumen	174	116	L	31069	72,81	0,4	1,0	2,7	9,9	22,6	26,6	16,4	11,1	5,3	2,5	0,9	0,3	0,1	0,0	0,0	20,3	9,2
			P	3158	74,00	0,5	0,8	2,4	6,8	16,1	29,7	28,4	12,6	1,9	0,6	0,2	0,0	0,0	0,0	0,0	15,3	2,7
MAYO																						
Resumen	163	124	L	33464	72,34	0,4	1,0	2,9	10,6	22,8	26,5	16,1	10,8	5,2	2,5	0,9	0,3	0,1	0,0	0,0	19,8	9,0
			P	3568	74,48	0,3	0,7	2,4	6,5	15,6	29,8	29,1	12,8	1,9	0,6	0,2	0,0	0,0	0,0	0,0	15,6	2,7
JUNIO																						
Resumen	164	122	L	33476	72,08	0,4	1,1	2,9	10,8	22,9	26,5	15,8	10,6	5,1	2,4	0,9	0,3	0,1	0,0	0,0	19,5	8,9
			P	3431	74,08	0,4	0,8	2,4	6,7	15,8	30,0	29,0	12,6	1,7	0,5	0,2	0,0	0,0	0,0	0,0	14,9	2,4
JULIO																						
Resumen	166	126	L	35248	72,52	0,4	1,0	2,7	10,0	22,6	27,2	16,4	10,9	5,1	2,4	0,9	0,3	0,1	0,0	0,0	19,7	8,8
			P	3399	72,87	1,3	0,8	2,4	6,7	16,4	31,6	27,7	11,0	1,5	0,5	0,2	0,0	0,0	0,0	0,0	13,2	2,2
AGOSTO																						
Resumen	162	124	L	36217	72,41	0,5	1,1	3,0	10,0	22,3	26,8	16,2	10,9	5,2	2,4	0,9	0,3	0,1	0,0	0,0	19,9	9,0
			P	3082	71,65	2,2	0,9	2,5	7,0	17,2	31,5	26,1	10,5	1,5	0,5	0,2	0,0	0,0	0,0	0,0	12,6	2,2
SEPTIEMBRE																						
Resumen	160	120	L	32475	71,85	0,6	1,2	3,0	10,6	22,8	26,9	15,7	10,4	5,0	2,4	0,9	0,3	0,1	0,0	0,0	19,1	8,7
			P	2839	71,12	2,0	1,0	2,8	7,5	17,9	31,9	24,5	10,2	1,6	0,4	0,1	0,0	0,0	0,0	0,0	12,4	2,2
OCTUBRE																						
Resumen	161	119	L	30743	71,23	0,7	1,4	3,2	11,0	23,1	26,6	15,5	10,2	4,8	2,2	0,8	0,3	0,1	0,0	0,0	18,5	8,3
			P	3001	71,68	1,7	1,0	2,8	7,2	17,4	31,6	25,1	11,2	1,4	0,4	0,1	0,0	0,0	0,0	0,0	13,1	1,9
NOVIEMBRE																						
Resumen	164	120	L	29511	71,35	0,6	1,3	3,2	11,0	22,7	27,1	15,7	10,2	4,8	2,2	0,8	0,3	0,1	0,0	0,0	18,4	8,2
			P	3040	72,19	1,3	0,8	2,5	6,8	18,1	32,1	25,1	11,5	1,4	0,3	0,1	0,0	0,0	0,0	0,0	13,4	1,9
DICIEMBRE																						
Resumen	161	123	L	30565	71,04	0,6	1,3	3,3	11,7	23,1	26,3	15,3	10,1	4,8	2,2	0,8	0,3	0,1	0,0	0,0	18,4	8,3
			P	2542	71,58	2,1	1,0	2,9	7,7	17,7	30,7	23,3	11,3	2,1	0,8	0,4	0,0	0,0	0,0	0,0	14,7	3,3

Table 32: Average speeds on Spanish conventional roads (Source, Reprinted from: Ministerio de Fomento) In Spanish

By averaging the average speed of heavy vehicles (P) each month seen in the Tables 31 and 32, we get a speed of 86 km/h for motorways, and 72 km/h for conventional roads.

These speeds will be the maximum speeds at which the truck will circulate on motorway-highways and high-performance roads (N-121-A) respectively, as the N-121-A is considered to be similar to a conventional road as its maximum permitted speed is the same.

On stretches of road where it is necessary to reduce speed, such as crossings, intersections, junctions, tunnels, village crossings, etc., the speed of the truck will also be reduced, going from

64 km/h on stretches with a permitted speed of 70 km/h, to 47 on stretches of 50, maintaining the speed of 72 on stretches of 80 km/h.

5.1 MEET method applied to the route on the N-121-A

Once the road gradient and speed are known for all the route, it can be applied this MEET method.

As we see before, the MEET method is a macroscopic model where the emissions rates are estimated depending on the average speed, using different parameters in function of the vehicle characteristics. With this method we can estimate the kg of different pollutants such as CO_2, CO, VOC, NOx and PM, changing the value of several parameters.

Firstly, the emission rate in g/km for an empty vehicle with zero gradient can be calculated. Knowing that a heavy vehicle is chosen, the following formula explained before must be used:

$$\varepsilon = \mathrm{K} + \mathrm{av} + \mathrm{b}v^2 + cv^3 + \frac{d}{v} + \frac{e}{v^2} + \frac{f}{v^3}$$

The different parameters used depend on the weight of the empty vehicle, as there are different tables for different vehicle weights, and the values change from one type of pollutant to another. These tables can be seen in the ANNEX 1.

In this case, the table from 7,5 to 16 tons will be used due to the weight of the empty heavy vehicle used in this work is 15 tons. The result can be seen in the column with the title CO_2 empty in the attached Excel called N121A_meet_f. This is done for each pollutant (CO_2, CO, VOC, NOx and PM) with its values respectively.

Once we have calculated the emissions of each pollutant in grams per kilometer for the empty vehicle, we need to calculate the correction factors due to the load on the vehicle and due to the gradient of the road.

For the load factor is known that the load has a weight of 14 tons, so the table used to select the correct parameter in the next formula is the table from 7,5 to 16 tons seen in the ANNEX 2, this formula depends on the speed average and the gradient in %.

$$\Phi(\Upsilon, v) = k + n\Upsilon + p\Upsilon^2 + q\Upsilon^3 + rv + sv^2 + tv^3 + \frac{u}{v}$$

The load factor results can be seen in the column named Load factor of the attached Excel.

To apply the gradient factor there are different tables with different values for the parameters of the equation for each type of pollutant:

$$as_{i,j,k} = A6_{i,j,k} * V^6 + A5_{i,j,k} * V^5 + A4_{i,j,k} * V^4 + A3_{i,j,k} * V^3 + A2_{i,j,k} * V^2 + A1_{i,j,k} * V + A0$$

The tables are differentiated according to the weight of the vehicle, which in this case the vehicle weighs 15 tons in empty, then the table is chosen for a weight of 7.5 to 16 tons from the tables included in the ANNEX 3.

This gradient factor as it can be seen in the tables has ranges of percentage gradient, from -6 to -4 %, from -4 to 0 %, from 0 to 4 % and from 4 to 6 %, changing the coefficients from one range to another. Then before applying the formula, it is necessary to check that all the slopes obtained in this route are between -6 and 6% of slope.

As this is not the case, it is necessary to make a correction, smoothing the slopes by taking altitudes of separate points 2, 3 or 4 kilometers, calculating a new slope for these sections that falls within the ranges of the tables. If even so, the slope is still outside the range of application of slopes, the value of this slope will be changed by the maximum value admitted in the tables (-6 or 6 % in each case).

The results obtain from using the above formula are noted in the column of the attached Excel named Slope factor.

These values should be greater than 1 for upward slopes (positive) and less than 1 for downward slopes (negative), although as is explained above downward slopes do not always imply lower fuel consumption but reducing the speed too much to go downhill does reduce fuel consumption considerably.

In addition, these tables have a range of maximum and minimum speeds (Vmax and Vmin) where these correction factors can be applied. Then the speed should be checked on each section and make sure it is inside the speed ranges of the tables, if not, the speed must be changed by a value within the ranges (in this case it is considered 49.9 km/h equal to 50 km/h, and 39.5 equal to 40).

The sections that need to be modified, either because their speed is outside the limits allowed in the tables for a gradient, or the slopes that are outside the ranges allowed by the tables, are indicated in the attached Excel. This can be seen by marking in orange those kilometers where it has been necessary to adapt the speed, and in red those where it has been necessary to adapt the gradient of the road. These changes correspond to the columns called Modified slope % and Modified speed (km/h)

You could take the values of the table from 16 to 32 tons including the load but in this case the load factor should be the unit. This will be done at the end of this section to compare the results and see if they are very important.

Once the grams per kilometer of each pollutant in the empty heavy vehicle is calculated, it is multiplied by the load correction factor and by the gradient correction factor. Obtaining the grams of each type of pollutant in each kilometer, multiplying by one kilometer, you have the grams for each kilometer, and doing the sum of all these you have the total grams of each pollutant.

Obtaining the results for each contaminant summarized in the following Table:

CO2 TOTAL (kg):	**38,53**
CO TOTAL (kg):	**0,1334**
VOC TOTAL (kg):	**0,1013**
NOx TOTAL (kg):	**0,3585**
PM TOTAL (kg):	**0,0530**

Table 33: Emissions obtained through the MEET model for Route 1 (Source: Self production)

As expected, CO_2 emissions are the highest at 38,53 kg, the rest of the emissions are very small but must be considered because their consequences are worse than those of CO_2.

This practically meets the emissions of a diesel combustion engine, where 12% is CO_2 and the rest approximately 0.3% as shown in Figure 39.

As mentioned above, these calculations can be made without applying the load factor, assuming that the weight of the truck is the sum of its weight and the load. To do so, it is necessary to change the parameters used and choose them from another table, keeping the load factor equals to 1.

In this case the results obtained are expressed in the following Table:

CO2 TOTAL (kg):	**45,20**
CO TOTAL (kg):	**0,1734**
VOC TOTAL (kg):	**0,0839**
NOx TOTAL (kg):	**0,4692**
PM TOTAL (kg):	**0,0343**

Table 34: Emissions obtained through the MEET model for Route 1 with load factor equal to 1(Source: Self production)

CO_2 emissions are higher than in the previous case with a total of 45,2 kg, as well as CO and NO_x emissions which increase with respect to the previous case. However, VOC and PM emissions are lower. Even so, the results are very similar between both cases.

Another comparison that can be tested with this method is to see the emissions that would be caused by two smaller trucks each carrying half of the load. To do this, it is necessary to change the coefficients used, and use those shown in the tables for vehicles under 7.5 tons, and for the load factor the table whose weight is also under 7.5 tons.

The result obtained will have to be multiplied by the two trucks, obtaining the results that can be seen in the following Table:

CO2 TOTAL (kg):	**52,63**
CO TOTAL (kg):	**0,2653**
VOC TOTAL (kg):	**0,1854**
NOx TOTAL (kg):	**0,4893**
PM TOTAL (kg):	**0,0448**

Table 35: Emissions obtained through the MEET model for Route 1 with two trucks (Source: Self production)

In this case the emissions are higher, reaching 14 kg more CO2 than using a single heavier truck.

Emissions of all other pollutants are also higher, except PM, so it can be concluded that according to this model, two smaller trucks carrying half the load pollute more than one heavier truck with the whole load.

All these calculations can be seen in the attached Excel.

5.2 MEET method applied to the highway route

As seen in the previous section, the calculations made for this route on the AP15 and A15 motorways are the same as for the N-121-A road, only the gradient and speed characteristics of the road have changed.

In this case the number of kilograms obtained from each contaminant is:

CO2 TOTAL (kg):	**59,485**
CO TOTAL (kg):	**0,1763**
VOC TOTAL (kg):	**0,1325**
NOx TOTAL (kg):	**0,5255**
PM TOTAL (kg):	**0,0886**

Table 36: Emissions obtained through the MEET model for Route 2 (Source: Self production)

As on the other route, CO2 emissions are the highest, totaling 59,485 kg. Here again, the study will be carried out without applying the load factor. Achieving very similar results, with an approximate difference of 8 kg of CO2. This is shown in the following Table:

CO2 TOTAL (kg):	**67,992**
CO TOTAL (kg):	**0,2414**
VOC TOTAL (kg):	**0,1150**
NOx TOTAL (kg):	**0,6725**
PM TOTAL (kg):	**0,0495**

Table 37: Emissions obtained through the MEET model for Route 2 with load factor equal to 1(Source: Self production)

However, on this route if it is decided to use two lighter vehicles each with half the load, the difference in emissions is much greater.

CO2 TOTAL (kg):	**81,043**
CO TOTAL (kg):	**0,3847**
VOC TOTAL (kg):	**0,2955**
NOx TOTAL (kg):	**0,7596**
PM TOTAL (kg):	**0,0646**

Table 38: Emissions obtained through the MEET model for Route 2 with two trucks (Source: Self production)

As can be seen in the table above, the emissions of each pollutant are higher using two lighter vehicles. The biggest difference can be seen in the amount of CO2 emitted, with a total of 21 kg more than the initial case.

All these calculations are made in the attached Excel named A15_meet_f.

5.3 Comparison of routes using the MEET method

In order to compare both routes, the route along the N-121-A will first be called route 1, while the route along the AP15 highway, A15 motorway, and the AP8 highway in Gipuzkoa, will be called route 2.

The following Table shows the comparison between the two routes using the MEET method:

	ROUTE 1	ROUTE 2	VARIATION %
CO2 TOTAL (kg):	**38,53**	**59,485**	54%
CO TOTAL (kg):	**0,1334**	**0,1763**	32%
VOC TOTAL (kg):	**0,1013**	**0,1325**	31%
NOx TOTAL (kg):	**0,3585**	**0,5255**	47%
PM TOTAL (kg):	**0,0530**	**0,0886**	67%

Table 39: Comparison of both routes with the MEET method (Source: Self production)

As can be seen, pollution is greater on Route 2, specifically emitting 20,955 kg more CO2, with a 54% increase in CO2 emissions compared to Route 1. The rest of the pollutants are also greater in route 2, but the difference is smaller, although some of these pollutants have worse consequences on the environment.

These results can be considered correct, since without any calculation or methodology, by observing both routes it can be expected that route 2 will cause more pollution.

Mainly for two reasons, the first is that Route 2 has a greater distance, specifically 92 km against 68 (eliminating the first kilometers in Pamplona as explained in previous sections), which means that heavy goods vehicles must travel an extra 24 km.

The second reason can be extracted by looking at the elevation profiles of both routes (Figures 42 and 43). Here we can see that the profile of the N-121-A road has a positive slope until it reaches the Belate and Almandoz tunnels, from which the rest of the route is practically downhill. While the profile of the route 2 is much more abrupt, having two important climbs near Azpiroz and Berastegui, in addition to small slopes in the vicinity of Hernani, Astigarraga and Oyarzun.

This can be checked using the MEET method, and as you have seen the results agree with the first impression by comparing both routes.

Having used this method alone, it seems that transporters should choose the route along the N-121-A to have a lesser environmental impact. Furthermore, as will be seen in the following sections, it may have a lower cost, as there are no tolls on this road, and it seems that petrol consumption is lower. All this will be calculated in more detail below.

These calculations have been made for a 5-axle heavy vehicle; whose load is 14 tons. Taking into account that the maximum authorized mass (MMA) for this type of vehicle is 40 tons, and that the empty vehicle weighs 15, it can be said that it has a maximum load capacity of 25 tons.

14 tons over the maximum capacity of 25, equivalent to carrying the load at 56%. For this reason, emissions are made in different cases according to the load the truck is carrying, allowing another comparison between the two routes. It will be done for a percentage of load of 100, 75, 25 % and empty, which is equivalent to carrying a load of 25, 18.75, 6.25 and 0 tons respectively.

These calculations can be seen in the attached Excel sheets, and the results obtained are shown in Table 40:

		ROUTE 1	ROUTE 2	VARIATION
EMPTY	CO2 TOTAL (kg):	**31,50**	**48,008**	52%
	CO TOTAL (kg):	**0,1215**	**0,1583**	30%
	VOC TOTAL (kg):	**0,0942**	**0,1227**	30%
	NOx TOTAL (kg):	**0,2973**	**0,4243**	43%
	PM TOTAL (kg):	**0,0454**	**0,0748**	64%
PARTIALLY	CO2 TOTAL (kg):	**35,49**	**54,70**	54%
	CO TOTAL (kg):	**0,1266**	**0,1655**	31%
	VOC TOTAL (kg):	**0,0964**	**0,1259**	31%
	NOx TOTAL (kg):	**0,3523**	**0,5139**	46%
	PM TOTAL (kg):	**0,0502**	**0,0823**	64%
PARTIALLY	CO2 TOTAL (kg):	**38,53**	**59,48**	54%
	CO TOTAL (kg):	**0,1334**	**0,1763**	32%
	VOC TOTAL (kg):	**0,1013**	**0,1325**	31%
	NOx TOTAL (kg):	**0,3585**	**0,5255**	47%
	PM TOTAL (kg):	**0,0530**	**0,0886**	67%
FULL	CO2 TOTAL (kg):	**41,21**	**64,31**	56%
	CO TOTAL (kg):	**0,1408**	**0,1869**	33%
	VOC TOTAL (kg):	**0,0931**	**0,1196**	28%
	NOx TOTAL (kg):	**0,3878**	**0,5711**	47%
	PM TOTAL (kg):	**0,0545**	**0,0898**	65%

Table 40: Comparison of both routes for different load levels with the MEET method (Source: Self production)

For the calculation of emissions of each type of pollutant, the MEET method uses different tables depending on the type of pollutant, the load of the vehicle, its empty weight, the speed and the slope of the road. When calculating and applying the load correction factor, the method differentiates the coefficients to be used in different weight ranges of these loads, separating these coefficients in tables.

There are tables for heavy vehicles with loads between 3.5 and 7.5 tons, loads between 7.5 and 16 tons, from 16 to 32, and from 32 to 40 tons. Therefore, the results obtained for a 50% and 56% load, partially full, are the same since they fall within the same range of tons of load (12.5 and 14 tons respectively) using the table with coefficients for load weights between 7.5 and 16. The same happens with a 75 and 100% load, full load, (18.75 and 25 tons) where the table from 16 to 32 tons is used.

Increasing the load has a greater effect on route 2, because as the load increases the difference in fuel consumption between route 1 and 2 increases. Having a variation of 52% with the empty vehicle, and a variation of 56% with the maximum load. This is why these differences in emissions according to the percentage of load are not very precise, since the same coefficients are considered and therefore the same correction factor for very different loads as long as they are in the same ranges discussed in previous paragraphs. Even so, the results shown in Table 40 obtained using the MEET method confirm that pollutant emissions are lower on the N-121-A than on the motorway. Even varying the percentage of load, it continues to pollute more on route 2, to the point that it pollutes more a 15-tonne empty weight heavy vehicle on route 2 than the same vehicle carrying 25 tons (reaching its maximum authorized weight of 40 tons).

It should also be noted that two lighter vehicles of 7 tons carrying another 7 tons of load each circulating on Route 1, emit 6.85 kg less CO2 than a heavier vehicle of 14 tons empty weight carrying the sum of the load of the two lighter vehicles (7+7=14 tons of load), circulating on Route 2.

The difference between the other pollutants is very small depending on the load that the truck is carrying, normally increasing a little as the load increases, except for the VOC pollutants where they pollute less with the maximum load than with 56% of the load. But when comparing one route with another, route 2 pollution is still higher for all types of pollutants. This is one of the reasons for the increase in heavy vehicle traffic on the N-121-A, and one which should be studied in order to find solutions.

With this method it is possible to apply other correction factors such as vehicle mileage, or the difference in ambient and engine temperature. But as explained in previous sections, these factors have not been applied.

The mileage factor is not applied because even though the vehicle has 200,000 km, it is considered to be well maintained which is equivalent to a semi-new vehicle where it is not necessary to apply this factor.

The temperature factor is also not applied because only hot emissions have been considered, which are hardly influenced by this temperature. This factor gains importance in cold emissions when starting the engine where temperature differences are greater and fuel consumption increases. But in this work, the first kilometers of roads have been eliminated to avoid counting these emissions and starting the engine at its optimal working temperature.

One of the comparisons that was made was to see the effect that distance alone has on fuel consumption assuming a flat road with a zero-tilt angle. With this method the result is:

		ROUTE 1	ROUTE 2	VARIATION %
NO GRADIENT	CO2 TOTAL (kg):	**36,80**	**52,659**	43%
	CO TOTAL (kg):	**0,1449**	**0,1915**	32%
	VOC TOTAL (kg):	**0,0872**	**0,1118**	28%
	NOx TOTAL (kg):	**0,3494**	**0,4972**	42%
	PM TOTAL (kg):	**0,0332**	**0,0450**	36%
WITH GRA-DIENT	CO2 TOTAL (kg):	**38,53**	**59,485**	54%
	CO TOTAL (kg):	**0,1334**	**0,1763**	32%
	VOC TOTAL (kg):	**0,1013**	**0,1325**	31%
	NOx TOTAL (kg):	**0,3585**	**0,5255**	47%
	PM TOTAL (kg):	**0,0530**	**0,0886**	67%
	VARIATION CO2 %	-5%	-11%	

Table 41: Slope effect in both routes with MEET (Sources: Self production)

As can be seen in the Table above, removing the slopes from the road reduces fuel consumption. As Pamplona is at a higher altitude than Irún, the route has a negative average gradient. It might be thought that by eliminating the slopes, consumption would increase because more downhill sections are eliminated where consumption is lower than on the flat, but as can be seen this is not the case, so according to this method, the increase in consumption due to the uphill slopes is greater than the saving in consumption on the downhill ones, since on the downhill ones consumption is also higher than it should be (idling fuel).

Comparing one route with another, it can be seen that the decrease in consumption is greater in route 2 (11% compared to 5%).

This means that the slopes of route 2 have a greater importance on fuel consumption than in route 1. This is because it has a steeper profile where the uphill sections are more, as can be seen in the average positive slope of both routes, so 11% of consumption is due to the elevation profile of this route along the AP15, the rest is mainly due to distance and higher speed.

In the column on the right you can see how the difference in CO2 emissions between one route and another is less when the slopes are not taken into account, going from a variation in CO2 emissions of 54% to 43%, reducing a 11% due to the road gradient.

Although not all emissions are reduced, maintaining the same variation between the two routes for CO, having higher emissions of CO for both routes with no road gradient.

However, the emissions are still higher in route 2 than route 1. This is because the estimated emissions do not vary only with the slope of the road, since in this model the controllable factors of speed and distance have been included, which causes fuel consumption and therefore emissions to be higher on route 2 than on route 1, since on this route through motorways, the speed at which the vehicle travels are higher, and the total distance travelled is also greater.

Another comparison that has been made is to see the influence of speed on emissions, maintaining an equal and constant speed for both routes, also eliminating road slopes:

		ROUTE 1	ROUTE 2	VARIATION %
NO GRADIENT and SPEED 70km/h	CO2 TOTAL (kg):	**36,58**	**49,497**	35%
	CO TOTAL (kg):	**0,1418**	**0,1918**	35%
	VOC TOTAL (kg):	**0,0840**	**0,1136**	35%
	NOx TOTAL (kg):	**0,3413**	**0,4617**	35%
	PM TOTAL (kg):	**0,0325**	**0,0440**	35%

Table 42: Slope and speed effect on both routes (Source: Self production

Obtaining as a result the expected values, having the same variation for all emissions (35%), which coincides with the difference in distance traveled between route 1 (68 km) and 2 (92 km) whose variation is also 35%.

It can therefore be concluded that a 54% variation in CO2 emissions between the two routes is due to the difference in distance travelled (35%), the slope of the road (11%) and therefore the difference in speed at which one can travel along one route or the other (8%).

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ANNEXES

ANNEX 1: Coefficients of emissions functions for heavy goods vehicles for different weights with MEET method.

ANNEX 2: Coefficients of gradient factor functions for heavy goods vehicles for different weights with MEET method.

ANNEX 3: Coefficients of the load correction functions for heavy goods vehicles for different weights with MEET method.

ANNEX 4: Excel attached in the CD.

ANNEX 1: Coefficients of emissions functions for heavy goods vehicles for different weights with MEET method.

Coefficients of emissions functions for heavy goods vehicles with gross vehicle weights from 3.5 to 7.5 tones:

	K	*a*	*b*	*c*	*d*	*e*	*f*
CO	1.50	-0.0595	0.00119	-6.16E-6	58.8	0	0
CO_2	110	0	0	0.000375	8702	0	0
VOC	0.186	0	0	-2.97E-7	61.5	0	0
NO_X	0.508	0	0	3.87E-6	92.5	-77.3	0
PM	0.0506	0	0	1.22E-7	12.5	0	-21.1

Coefficients of emissions functions for heavy goods vehicles with gross vehicle weights from 7.5 to 16 tones:

	K	*a*	*b*	*c*	*d*	*e*	*f*
CO	3.08	-0.0135	0	0	-37.7	1560	-5736
CO_2	871	-16.0	0.143	0	0	32031	0
VOC	1.37	0	-8.10E-5	0	0	870	-3282
NO_X	2.59	0	-0.000665	8.56E-6	140	0	0
PM	0.0541	0.00151	0	0	17.1	0	0

Coefficients of emissions functions for heavy goods vehicles with gross vehicle weights from 16 to 32 tones:

	K	*a*	*b*	*c*	*d*	*e*	*f*
CO	1.53	0	0	0	60.6	117	0
CO_2	765	-7.04	0	0.000632	8334	0	0
VOC	0.207	0	0	0	58.3	0	0
NO_X	9.45	-0.107	0	7.55E-6	132	0	0
PM	0.184	0	0	1.72E-7	15.2	0	0

Coefficients of emissions functions for heavy goods vehicles with gross vehicle weights from 32 to 40 tones:

	K	**a**	**b**	**c**	**d**	**e**	**f**
CO	0.349	0.0101	0	0	79.6	0	0
CO_2	1576	-17.6	0	0.00117	0	36067	0
VOC	0.254	0	0	0	53.9	0	0
NO_X	5.27	0	0	0	343	-552	0
PM	0.246	0	0	0	18.2	0	0

Coefficients of emission functions for urban buses:

	K	*a*	*b*	*c*	*d*	*e*	*f*
CO	1.64	0	0	0	132	0	0
CO_2	679	0	0	-0.00268	9635	0	0
VOC	0.0778	0	0	0	41.2	0	184
NO_X	16.3	-0.173	0	0	111	0	0
PM	0.0694	0	0.000366	-8.71E-6	13.9	0	0

Coefficients of emission functions for coaches:

	K	*a*	*b*	*c*	*d*	*e*	*f*
CO	0.930	0	-4.00E-5	0	99.2	0	0
CO_2	523	0	-0.0487	0.000527	12501	0	0
VOC	0.632	-0.00402	0	0	59.3	0	254
NO_X	6.12	0	-0.000651	7.23E-6	181	0	0
PM	0.193	0	0	0	15.6	0	29.6

Weight correction factors for goods vehicles over 40 tons gross weight:

Weight class	**Weight correction factor (applicable to functions for HGVs 32 - 40 t)**		
	NO_X	**PM**	**CO_2**
40 - 50 t	1.18	1.12	1.17
50 - 60 t	1.41	1.24	1.35

ANNEX 2: Coefficients of gradient factor functions for heavy goods vehicles for different weights with MEET method.

Coefficients of gradient factor functions for heavy duty vehicles <7.5 tons:

A6	A5	A4	A3	A2	A1	A0	Pollutant	Slope (%)	Vmin (km/h)	Vmax (km/h)
0.00E+00	-4.33E-09	1.40E-06	-1.53E-04	6.22E-03	-1.01E-01	1.63E+00	VOC	4… 6	13.0	39.3
0.00E+00	-5.14E-08	9.90E-06	-7.17E-04	2.39E-02	-3.57E-01	2.95E+00		-6… -4	13.5	49.9
0.00E+00	-2.05E-08	4.25E-06	-3.30E-04	1.18E-02	-1.92E-01	2.16E+00		0… 4	15.1	69.9
0.00E+00	4.02E-09	-9.36E-07	8.39E-05	-3.66E-03	7.99E-02	3.98E-01		-4… 0	15.1	86.2
0.00E+00	1.51E-07	-1.93E-05	9.26E-04	-2.11E-02	2.57E-01	6.58E-02	CO	4… 6	13.0	39.3
0.00E+00	-7.00E-08	1.25E-05	-8.51E-04	2.71E-02	-3.96E-01	2.86E+00		-6… -4	13.5	49.9
0.00E+00	-1.18E-08	2.49E-06	-1.95E-04	6.78E-03	-9.28E-02	1.52E+00		0… 4	15.1	69.9
0.00E+00	-5.54E-10	1.80E-07	-1.82E-05	6.42E-04	-5.54E-03	8.14E-01		-4… 0	15.1	86.2
0.00E+00	1.82E-08	-1.85E-06	3.32E-05	1.28E-03	-4.14E-03	1.43E+00	NO_X	4… 6	13.0	39.3
0.00E+00	-7.94E-08	1.37E-05	-9.08E-04	2.83E-02	-4.13E-01	2.78E+00		-6… -4	13.5	49.9
0.00E+00	-6.87E-09	1.37E-06	-1.06E-04	3.74E-03	-4.19E-02	1.23E+00		0… 4	15.1	69.9
0.00E+00	-3.00E-10	8.69E-08	-7.87E-06	2.26E-04	-2.07E-03	7.03E-01		-4… 0	15.1	86.2
0.00E+00	4.27E-07	-5.74E-05	2.97E-03	-7.43E-02	9.35E-01	-3.03E+00	CO_2	4… 6	13.0	39.3
0.00E+00	-7.74E-08	1.33E-05	-8.78E-04	2.72E-02	-3.93E-01	2.65E+00		-6… -4	13.5	49.9
0.00E+00	-3.01E-09	5.73E-07	-4.13E-05	1.13E-03	8.13E-03	9.14E-01		0… 4	15.1	69.9
0.00E+00	-1.39E-10	5.03E-08	-4.18E-06	1.95E-05	3.68E-03	6.69E-01		-4… 0	15.1	86.2
0.00E+00	-2.54E-07	3.58E-05	-1.99E-03	5.42E-02	-6.89E-01	4.54E+00	PM	4… 6	13.0	39.3
0.00E+00	-5.34E-08	9.97E-06	-7.05E-04	2.32E-02	-3.48E-01	2.71E+00		-6… -4	13.5	49.9
0.00E+00	-1.96E-08	4.11E-06	-3.22E-04	1.16E-02	-1.83E-01	2.08E+00		0… 4	15.1	69.9
0.00E+00	-1.89E-10	8.23E-08	-9.49E-06	3.25E-04	-2.54E-04	8.21E-01		-4… 0	15.1	86.2

Coefficients of gradient factor functions for heavy duty vehicles 7.5 – 16 tons:

A6	A5	A4	A3	A2	A1	A0	Pollutant	Slope (%)	Vmin (km/h)	Vmax (km/h)
0.00E+00	1.28E-07	-1.65E-05	7.96E-04	-1.82E-02	2.04E-01	3.24E-01	VOC	4… 6	13.1	39.5
0.00E+00	-4.01E-08	8.12E-06	-6.01E-04	2.01E-02	-3.01E-01	2.76E+00		-6… -4	13.5	49.9
0.00E+00	-1.82E-08	3.70E-06	-2.78E-04	9.60E-03	-1.51E-01	1.94E+00		0… 4	15.1	70.3
0.00E+00	1.10E-09	-3.38E-07	3.94E-05	-2.13E-03	5.25E-02	6.52E-01		-4… 0	15.1	86.4
0.00E+00	3.28E-07	-4.35E-05	2.21E-03	-5.46E-02	6.73E-01	-1.88E+00	CO	4… 6	13.1	39.5
0.00E+00	-6.79E-08	1.21E-05	-8.24E-04	2.58E-02	-3.67E-01	2.89E+00		-6… -4	13.5	49.9
0.00E+00	-1.09E-08	2.16E-06	-1.56E-04	4.85E-03	-5.79E-02	1.34E+00		0… 4	15.1	70.3
0.00E+00	-1.11E-10	-3.21E-08	1.19E-05	-1.09E-03	3.34E-02	6.97E-01		-4… 0	15.1	86.4
0.00E+00	-2.42E-07	3.49E-05	-1.96E-03	5.28E-02	-6.52E-01	4.60E+00	NO_X	4… 6	13.1	39.5
0.00E+00	-9.71E-08	1.70E-05	-1.14E-03	3.57E-02	-5.30E-01	3.81E+00		-6… -4	13.5	49.9
0.00E+00	-1.21E-08	2.39E-06	-1.77E-04	6.00E-03	-8.29E-02	1.56E+00		0… 4	15.1	70.3
0.00E+00	-8.49E-11	1.17E-08	3.94E-07	-1.38E-04	2.18E-03	9.09E-01		-4… 0	15.1	86.4
0.00E+00	3.21E-07	-4.29E-05	2.23E-03	-5.75E-02	7.62E-01	-1.98E+00	CO_2	4… 6	13.1	39.5
0.00E+00	-1.24E-07	2.08E-05	-1.33E-03	4.00E-02	-5.65E-01	3.57E+00		-6… -4	13.5	49.9
0.00E+00	-9.78E-10	-2.01E-09	1.91E-05	-1.63E-03	5.91E-02	7.70E-01		0… 4	15.1	70.3
0.00E+00	-6.04E-11	-2.36E-08	7.76E-06	-6.83E-04	1.79E-02	6.12E-01		-4… 0	15.1	86.4
0.00E+00	8.06E-09	3.61E-07	-1.27E-04	5.99E-03	-8.25E-02	1.76E+00	PM	4… 6	13.1	39.5
0.00E+00	-5.44E-08	1.01E-05	-7.06E-04	2.28E-02	-3.38E-01	2.86E+00		-6… -4	13.5	49.9
0.00E+00	-1.61E-08	3.27E-06	-2.45E-04	8.30E-03	-1.18E-01	1.72E+00		0… 4	15.1	70.3
0.00E+00	-7.69E-10	1.50E-07	-7.72E-06	-8.94E-05	1.04E-02	8.95E-01		-4… 0	15.1	86.4

Coefficients of gradient factor functions for heavy duty vehicles 16 – 32 tons:

A6	A5	A4	A3	A2	A1	A0	Pollutant	Slope (%)	Vmin (km/h)	Vmax (km/h)
0.00E+00	0.00E+00	6.18E-06	-6.51E-04	2.39E-02	-3.66E-01	3.24E+00	VOC	4… 6	12.5	36.5
0.00E+00	-4.96E-08	9.03E-06	-6.37E-04	2.11E-02	-3.22E-01	3.08E+00		-6… -4	13.5	49.9
0.00E+00	-2.11E-08	4.32E-06	-3.30E-04	1.17E-02	-1.91E-01	2.25E+00		0… 4	14.9	64.7
0.00E+00	3.21E-09	-7.41E-07	6.58E-05	-2.82E-03	5.69E-02	7.55E-01		-4… 0	15.1	86.1
0.00E+00	0.00E+00	-1.50E-05	1.43E-03	-4.92E-02	7.32E-01	-2.31E+00	CO	4… 6	12.5	36.5
0.00E+00	-7.70E-08	1.30E-05	-8.51E-04	2.62E-02	-3.80E-01	3.15E+00		-6… -4	13.5	49.9
0.00E+00	-2.46E-08	4.79E-06	-3.44E-04	1.13E-02	-1.66E-01	2.12E+00		0… 4	14.9	64.7
0.00E+00	1.44E-09	-3.32E-07	3.06E-05	-1.45E-03	2.91E-02	8.76E-01		-4… 0	15.1	86.1
0.00E+00	0.00E+00	2.30E-06	-2.49E-04	9.39E-03	-1.26E-01	2.51E+00	NO_X	4… 6	12.5	36.5
0.00E+00	-1.09E-07	1.84E-05	-1.20E-03	3.70E-02	-5.49E-01	3.83E+00		-6… -4	13.5	49.9
0.00E+00	-2.00E-08	3.87E-06	-2.81E-04	9.57E-03	-1.43E-01	2.08E+00		0… 4	14.9	64.7
0.00E+00	5.72E-11	1.59E-08	-4.09E-06	2.73E-04	-1.18E-02	9.79E-01		-4… 0	15.1	86.1
0.00E+00	0.00E+00	-6.69E-06	6.55E-04	-2.31E-02	3.69E-01	1.07E-01	CO_2	4… 6	12.5	36.5
0.00E+00	-1.22E-07	2.03E-05	-1.30E-03	3.94E-02	-5.70E-01	3.75E+00		-6… -4	13.5	49.9
0.00E+00	-5.25E-09	9.93E-07	-6.74E-05	2.06E-03	-1.96E-02	1.45E+00		0… 4	14.9	64.7
0.00E+00	-8.24E-11	2.91E-08	-2.58E-06	5.76E-05	-4.74E-03	8.55E-01		-4… 0	15.1	86.1
0.00E+00	0.00E+00	-1.05E-05	9.88E-04	-3.35E-02	5.10E-01	-1.09E+00	PM	4… 6	12.5	36.5
0.00E+00	-6.72E-08	1.16E-05	-7.82E-04	2.50E-02	-3.79E-01	3.23E+00		-6… -4	13.5	49.9
0.00E+00	-3.60E-08	7.00E-06	-5.07E-04	1.69E-02	-2.49E-01	2.59E+00		0… 4	14.9	64.7
0.00E+00	2.40E-11	3.95E-08	-6.78E-06	3.25E-04	-9.46E-03	1.12E+00		-4… 0	15.1	86.1

Coefficients of gradient factor functions for heavy duty vehicles >32 tons:

A6	A5	A4	A3	A2	A1	A0	Pollutant	Slope (%)	Vmin (km/h)	Vmax (km/h)
0.00E+00	5.68E-08	-5.40E-06	1.24E-04	1.11E-03	-6.09E-02	1.80E+00	VOC	4… 6	12.4	35.0
0.00E+00	-2.50E-08	5.91E-06	-4.88E-04	1.79E-02	-2.98E-01	3.08E+00		-6… -4	13.5	49.9
0.00E+00	-2.02E-08	4.10E-06	-3.11E-04	1.09E-02	-1.76E-01	2.18E+00		0… 4	14.8	66.3
0.00E+00	1.95E-09	-4.68E-07	4.26E-05	-1.84E-03	3.52E-02	9.32E-01		-4… 0	15.1	86.3
0.00E+00	1.43E-06	-1.75E-04	8.27E-03	-1.89E-01	2.09E+00	-7.12E+00	CO	4… 6	12.4	35.0
0.00E+00	-6.48E-08	1.17E-05	-7.95E-04	2.51E-02	-3.71E-01	3.10E+00		-6… -4	13.5	49.9
0.00E+00	-8.63E-09	1.50E-06	-9.50E-05	2.65E-03	-2.44E-02	1.35E+00		0… 4	14.8	66.3
0.00E+00	1.28E-09	-3.07E-07	2.99E-05	-1.48E-03	3.00E-02	8.54E-01		-4… 0	15.1	86.3
0.00E+00	2.42E-08	3.11E-06	-4.50E-04	1.79E-02	-2.70E-01	3.56E+00	NO_X	4… 6	12.4	35.0
0.00E+00	-9.96E-08	1.73E-05	-1.15E-03	3.63E-02	-5.48E-01	3.85E+00		-6… -4	13.5	49.9
0.00E+00	-1.31E-08	2.49E-06	-1.82E-04	6.46E-03	-1.01E-01	1.94E+00		0… 4	14.8	66.3
0.00E+00	-7.69E-10	2.13E-07	-2.19E-05	1.06E-03	-2.84E-02	1.08E+00		-4… 0	15.1	86.3
0.00E+00	5.88E-07	-7.24E-05	3.45E-03	-7.86E-02	8.63E-01	-9.76E-01	CO_2	4… 6	12.4	35.0
0.00E+00	-1.18E-07	2.00E-05	-1.29E-03	3.96E-02	-5.78E-01	3.72E+00		-6… -4	13.5	49.9
0.00E+00	-2.04E-09	4.35E-07	-3.69E-05	1.69E-03	-3.16E-02	1.77E+00		0… 4	14.8	66.3
0.00E+00	-1.10E-09	2.69E-07	-2.38E-05	9.51E-04	-2.24E-02	9.16E-01		-4… 0	15.1	86.3
0.00E+00	-3.23E-07	3.70E-05	-1.70E-03	3.89E-02	-4.15E-01	3.36E+00	PM	4… 6	12.4	35.0
0.00E+00	-4.37E-08	8.63E-06	-6.36E-04	2.17E-02	-3.46E-01	3.17E+00		-6… -4	13.5	49.9
0.00E+00	-1.83E-08	3.60E-06	-2.65E-04	8.95E-03	-1.30E-01	1.92E+00		0… 4	14.8	66.3
0.00E+00	4.10E-10	-7.06E-08	4.33E-06	-1.28E-04	-1.87E-03	1.11E+00		-4… 0	15.1	86.3

Coefficients of gradient factor functions for urban buses:

A6	A5	A4	A3	A2	A1	A0	Pollutant	Slope (%)	Vmin (km/h)	Vmax (km/h)
0.00E+00	-2.12E-06	2.15E-04	-8.50E-03	1.62E-01	-1.49E+00	6.19E+00	VOC	4… 6	11.4	31.2
0.00E+00	-3.13E-07	3.32E-05	-1.37E-03	2.70E-02	-2.45E-01	1.72E+00		-6… -4	11.7	35.3
0.00E+00	1.75E-08	-4.51E-06	3.08E-04	-8.79E-03	1.11E-01	5.33E-01		0… 4	13.1	37.5
0.00E+00	4.15E-07	-5.26E-05	2.59E-03	-6.16E-02	7.06E-01	-2.13E+00		-4… 0	13.2	39.5
0.00E+00	-1.59E-06	1.57E-04	-6.04E-03	1.14E-01	-1.03E+00	4.91E+00	CO	4… 6	11.4	31.2
0.00E+00	-3.26E-07	3.80E-05	-1.71E-03	3.64E-02	-3.61E-01	2.05E+00		-6… -4	11.7	35.3
0.00E+00	-3.21E-07	3.94E-05	-1.92E-03	4.65E-02	-5.57E-01	3.78E+00		0… 4	13.1	37.5
0.00E+00	2.75E-07	-3.56E-05	1.79E-03	-4.36E-02	5.09E-01	-1.46E+00		-4… 0	13.2	39.5
0.00E+00	7.96E-07	-9.09E-05	3.83E-03	-7.42E-02	6.63E-01	-2.96E-01	NO_X	4… 6	11.4	31.2
0.00E+00	-3.27E-07	4.10E-05	-2.00E-03	4.65E-02	-5.18E-01	2.99E+00		-6… -4	11.7	35.3
0.00E+00	1.85E-07	-2.28E-05	1.08E-03	-2.47E-02	2.79E-01	9.98E-02		0… 4	13.1	37.5
0.00E+00	4.52E-08	-5.67E-06	2.75E-04	-6.43E-03	6.72E-02	5.15E-01		-4… 0	13.2	39.5
0.00E+00	1.25E-07	-1.82E-05	7.87E-04	-1.32E-02	7.18E-02	2.07E+00	CO_2	4… 6	11.4	31.2
0.00E+00	-3.77E-07	4.59E-05	-2.16E-03	4.83E-02	-5.14E-01	2.76E+00		-6… -4	11.7	35.3
0.00E+00	8.21E-08	-9.61E-06	4.20E-04	-8.55E-03	8.22E-02	1.05E+00		0… 4	13.1	37.5
0.00E+00	2.13E-07	-2.78E-05	1.41E-03	-3.45E-02	4.00E-01	-1.06E+00		-4… 0	13.2	39.5
0.00E+00	-7.39E-07	5.92E-05	-1.83E-03	2.80E-02	-2.18E-01	1.78E+00	PM	4… 6	11.4	31.2
0.00E+00	2.54E-07	-2.61E-05	1.01E-03	-1.81E-02	1.54E-01	3.83E-01		-6… -4	11.7	35.3
0.00E+00	1.39E-07	-1.87E-05	9.46E-04	-2.26E-02	2.60E-01	-1.14E-01		0… 4	13.1	37.5
0.00E+00	2.02E-07	-2.43E-05	1.14E-03	-2.60E-02	2.86E-01	-3.34E-01		-4… 0	13.2	39.5

Coefficients of gradient factor functions for coaches:

A6	A5	A4	A3	A2	A1	A0	Pollutant	Slope (%)	Vmin (km/h)	Vmax (km/h)
0.00E+00	0.00E+00	4.15E-06	-5.14E-04	2.17E-02	-3.76E-01	3.43E+00	VOC	4… 6	9.7	34.8
0.00E+00	0.00E+00	3.03E-06	-4.09E-04	1.94E-02	-3.75E-01	3.98E+00		-6… -4	11.7	49.9
2.49E-10	-8.50E-08	1.14E-05	-7.66E-04	2.65E-02	-4.41E-01	3.80E+00		0… 4	13.1	95.3
1.42E-10	-5.47E-08	8.20E-06	-6.05E-04	2.27E-02	-4.01E-01	3.89E+00		-4… 0	13.1	102.9
0.00E+00	0.00E+00	5.20E-06	-6.07E-04	2.51E-02	-4.28E-01	3.56E+00	CO	4… 6	9.7	34.8
0.00E+00	0.00E+00	2.24E-06	-3.21E-04	1.61E-02	-3.30E-01	3.25E+00		-6… -4	11.7	49.9
2.22E-10	-7.88E-08	1.10E-05	-7.63E-04	2.73E-02	-4.69E-01	3.99E+00		0… 4	13.1	95.3
1.09E-10	-4.42E-08	6.93E-06	-5.33E-04	2.09E-02	-3.87E-01	3.60E+00		-4… 0	13.1	102.9
0.00E+00	0.00E+00	-1.15E-05	9.84E-04	-3.02E-02	3.89E-01	7.29E-01	NO_X	4… 6	9.7	34.8
1.65E-08	-3.13E-06	2.39E-04	-9.44E-03	2.02E-01	-2.22E+00	1.04E+01		-6… -4	11.7	49.9
2.97E-10	-9.51E-08	1.18E-05	-7.16E-04	2.18E-02	-3.07E-01	3.21E+00		0… 4	13.1	95.3
1.27E-10	-4.61E-08	6.56E-06	-4.66E-04	1.71E-02	-3.00E-01	2.75E+00		-4… 0	13.1	102.9
0.00E+00	0.00E+00	-1.34E-05	1.12E-03	-3.31E-02	4.00E-01	9.84E-01	CO_2	4… 6	9.7	34.8
1.61E-08	-3.07E-06	2.37E-04	-9.43E-03	2.04E-01	-2.25E+00	1.04E+01		-6… -4	11.7	49.9
1.99E-10	-6.52E-08	8.32E-06	-5.20E-04	1.65E-02	-2.43E-01	3.02E+00		0… 4	13.1	95.3
1.15E-10	-4.23E-08	6.16E-06	-4.48E-04	1.69E-02	-3.05E-01	2.70E+00		-4… 0	13.1	102.9
0.00E+00	0.00E+00	4.91E-07	-1.88E-04	1.17E-02	-2.47E-01	3.11E+00	PM	4… 6	9.7	34.8
-3.03E-09	4.76E-07	-2.59E-05	4.46E-04	6.68E-03	-2.90E-01	3.25E+00		-6… -4	11.7	49.9
2.83E-10	-9.69E-08	1.30E-05	-8.68E-04	2.97E-02	-4.88E-01	4.21E+00		0… 4	13.1	95.3
1.40E-10	-5.29E-08	7.85E-06	-5.78E-04	2.18E-02	-3.91E-01	3.54E+00		-4… 0	13.1	102.9

ANNEX 3: Coefficients of the load correction functions for heavy goods vehicles for different weights with MEET method.

Coefficients of load correction functions for heavy goods vehicles from 3.5 to 7.5 tons:

	K	n	p	q	r	s	t	u
CO	1.09	0.0370	0	-5.29E-4	0	0	-1.52E-7	0
CO_2	1.27	0.0614	0	-0.00110	-0.00235	0	0	-1.33
VOC	0.990	-0.0141	0	4.04E-4	0	0	1.16E-7	0
NO_X	1.26	0.0672	0	-0.00117	0	-1.90E-5	0	-1.60
PM	1.14	0.0306	-0.00278	-9.14E-4	0	0	0	-0.988

Coefficients of load correction functions for heavy goods vehicles from 7.5 to 16 tons:

	K	n	p	q	r	s	t	u
CO	1.03	0.0345	0	-7.55E-4	9.77E-4	0	0	0
CO_2	1.26	0.0790	0	-0.00109	0	0	-2.03E-7	-1.14
VOC	0.985	0.00367	0	0	0.00135	0	0	0.201
NO_X	1.19	0.0594	0	-9.69E-4	0	0	0	-0.977
PM	1.02	0.0437	0	-9.16E-4	0.00234	0	0	0

Coefficients of load correction functions for heavy goods vehicles from 16 to 32 tons:

	K	n	p	q	r	s	t	u
CO	1.17	0.0563	0	-8.19E-4	0	0	0	-0.755
CO_2	1.27	0.0882	0	-0.00101	0	0	0	-0.483
VOC	1.01	-0.00660	0	2.09E-4	8.89E-4	0	-2.54E-7	0
NO_X	1.28	0.0795	-0.00105	-0.00117	0	0	0	-0.874
PM	1.24	0.0727	0	-0.00113	0	0	0	-1.06

Coefficients of load correction functions for heavy goods vehicles from 32 to 40 tons:

	K	n	p	q	r	s	t	u
CO	1.20	0.0849	0	-0.00184	0	0	0	-1.19
CO_2	1.43	0.121	0	-0.00125	0	0	0	-0.916
VOC	1.07	0.0150	0	-1.70E-4	0	0	-9.49E-8	-0.220
NO_X	1.42	0.116	0	-0.00160	0	0	0	-1.62
PM	1.22	0.0709	0	-0.00119	0	0	0	-0.968

ANNEX 4: Excel attached in the CD.

Excel named: “N121A_meet_f”. In this file are the calculations made on route 1 by the N-121-A with the MEET estimation model.

Excel named: “A15_meet_f”. In this file are the calculations made on route 2 by AP15 motorway with the MEET estimation model.