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Sustainability analysis of the ground handling operations using MIVES methodology. Case study: El Prat airport.

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TREBALL FINAL DE MÀSTER

Abstract

The aeronautic sector is a complex system where many stakeholders are involved. In this project is analyzed how are performed the Turnaround Processes (TAP) in El Prat Airport. These processes are the ones needed for attending the aircrafts during their scale, involving the use of fourteen different types of ground handling vehicles, classified as Light Duty Vehicles (LDV) or Heavy Duty Vehicles (HDV). As well, a characterization of the Land and Takeoff cycles (LTO cycles) performed in El Prat Airport is carried.

The main objectives of this project are the quantification of the emissions generated by the ground handling vehicles and the aircrafts during 2017, and their associated environmental impact using the Simapro software. Then an alternative scenario is purposed, where the 19% of the ground handling vehicles are substituted by electric vehicles. A sustainability analysis using MIVES tool is carried, comparing the environmental, social and economic requirements between the actual scenario and the purposed one.

The aircrafts are the main contributors in terms of emissions and environmental impact in comparison with the ground handling vehicles, accumulating a 97% of the total emissions and impacts. The contribution of the aircrafts is higher when the Green House Gases emissions and their associated impacts are analyzed. Oppositely, it decreases when the total polluting gases are compared.

The main aircrafts performing LTO cycles in El Prat airport are the A320, the B738 and the A321. In proportion, this three aircrafts types represents a 70% of the total LTO cycles performed in El Prat airport, thus, they are the main contributors in terms of emissions and environmental impact. There aren't notorious differences between the emission factors of each aircraft, so the total contribution is related to the percentage of aircraft types performing LTO cycles at the airport.

Regarding at the ground handling vehicles, the main emission sources are the follow me vehicles, the refueling trucks, the cargo tapes, the pushback vehicle and the catering vehicle. The Heavy-Duty Vehicles accumulates a 60% of the ground handling emissions and environmental impact, but the contribution per vehicle depends on the analyzed environmental impact category: for the impacts related with the CO_2 emissions, the follow me vehicle (a LDV), is the most contributing vehicle, but for the other impact categories, the HDV are the most contributors.

The sustainability analysis results indicate that, just when the economic requirement is set as the most weighted requirement (between the social and the environmental ones), the actual scenario has an increased sustainability index in comparison with the purposed scenario. For any other weighting configuration, the sustainability index is higher for the purposed scenario, meaning that the substitution of diesel vehicles by electric ones is a viable consideration.

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Special regards to all the PhD students and Doctors working at ICTA (Environmental Science and Technology Institute), who let me be their host, as I could use the Simapro software. Thanks as well to Violeta Vargas, for her collaboration and contacts.

Thanks to my parents and Elena. Their support and recommendations were essential for carrying this project.

ACRONYM LIST

APU – Auxiliary Power Unit

GSE – Ground Support Equipment

GPU – Ground Power Unit

GHG – Green House Gases

HDV – Heavy Duty Vehicles

LDV – Light Duty Vehicles

LEBL – El Prat airport

LTO – Land and Take Off

LH – Long Haul

SH – Short Haul

TAP – Turnaround Process

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1. INTRODUCTION

The aviation is completely different as it was on the beginning, in 110 years the aircrafts passed from flying 100 meters of distance to even reaching the moon, besides transporting more than 1.4 billion passengers per year between 440 airports and performing every day 26000 flights just in Europe (expecting no delays, cancelations, loses or accidents in any of them).

The two key factors impelled the aeronautic sector. At early 50's, the invention of propulsion by turbofans and reactors allowed the aircrafts to fly higher (meaning increased aerodynamically safety) during more time. On the other hand, the formation of the International Civil Aviation Organization (ICAO) from the Chicago convention in 1944, established the basis, rules and regulations about how the activity of aviation should be developed. This is the main regulatory organization in aviation. Then, the aeronautical sector started to grow exponentially in the statistics, becoming a safe, fast and profit-earning transport method.

The aeronautic sector is a complex system where many factors and stakeholders are involved. Specifically, this project is based on the analysis of the ground handling operations in El Prat Airport, Barcelona (ICAO code: LEBL). These operations are required to attend the needs of the aircrafts from their arrival to the next departure in a process named TAP (Turnaround Process), which carries to an environmental burden due the acoustic pollution and the emission of Green House Gases (GHG) and polluting gases by the aircraft and ground handling vehicles engine's.

This project contains a diagnosis about the actual situation of the aviation and the forecasts of the aeronautical sector, regarding the growth of the main indicators and the contribution to the climate change and the deterioration of air quality. Afterwards, the common TAP activities at the airports will be analyzed and particularly the ones at LEBL.

An environmental analysis is carried to quantify the GHG and pollutant emitted by the aircrafts and the ground handling activities, as well as their environmental impact assessed (using the software Simapro). Then, combining this environmental analysis with social and economic parameters, a sustainability analysis is made between the actual scenario (where all the handling vehicles are diesel) and one purposed scenario (where part of the handling vehicles fleet is substituted by electric vehicles).

For this study, the scope has been set on the airside of the airport (where the aircraft and handling activities take place). A wider scope is set for the aircrafts: the LTO Cycles (Land and Take off) performed by the commercial flights. Thus, the characterization and quantification of the emissions and the environmental impacts will be related to the commercial flights and the ground handling activities associated.

OBJECTIVES

Primary Objectives

- Quantify the total emissions of the airside of the airport (aircrafts and handling vehicles).
- Quantify the environmental impact associated to the emissions.
- Evaluate the substitution of the ground handling fleet from diesel engines to electric in sustainability terms.

Secondary objectives

- Identification and characterization of the LTO cycles performed at LEBL.
- Identification and characterization of LEBL infrastructures: distances of taxi runways, infrastructural facilities (electrical and air supply), and stand types and location.
- Determine the contribution of the LTO cycles over the emissions and the environmental impacts according the aircraft types.
- Identification and characterization of the Ground handling activities and vehicles.
- Determine the contribution of the ground handling vehicles over the emissions and the environmental impact according to the needs required by the aircrafts.
- Determine the sustainability index of the current scenario (where all the ground handling vehicles are diesel).
- Determine the sustainability index of the purposed scenario (where electric vehicles substitute part of the diesel vehicles fleet).

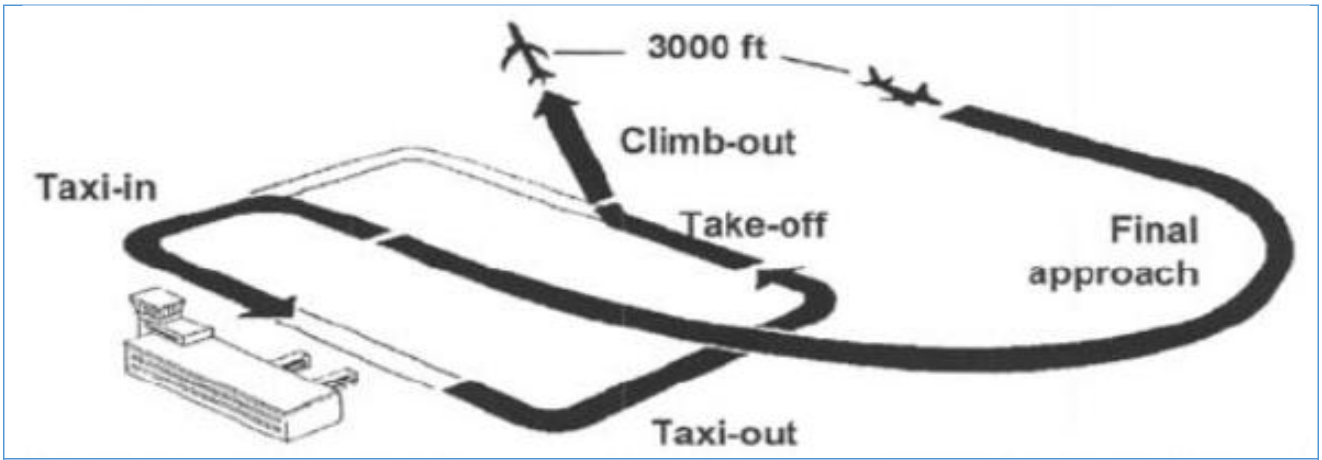
CHAPTER II: STATE OF ART

This chapter presents the current situation of aviation and the legislation that is involved on the ground handling activities and the LTO cycles, describing the international, the European and the Spanish legislations. In addition, a review of all implementations and actions over the environmental protection performed will be regarded.

Afterwards, the environmental impacts and the contribution to climate change due the aviation activities will be analyzed, as well as the trends for the future in terms of emission and fuel consumption.

The second part of this chapter shows how's the management in the Spanish airports and the basic theory about the management of ground handling activities. The director plan of Barcelona's airport will be used to describe how this airport works.

An LTO (Land and Take off) cycle is defined as all the flight phases performed near to the airports, from the final approach (1km of altitude and 25 km away from the airport), the taxi phase (when the engines are in IDLE mode, the takeoff phase (100% of engine thrust used) and the climb out phase (1 km of altitude). Below is presented a schema of the LTO cycle.



Flight Phase	Power setting (% of thrust)	Time (minutes)
Taxi	7	26
Takeoff	100	0.7
Climb out	85	2.2
Approach	30	4

Figure 1: Scheme of the LTO cycles.
Source: ICAO

2.1 THE AERONAUTIC SECTOR: GROWTH AND CONSOLIDATION

The number of transported people has grown exponentially in last years as it's shown in the next graphic, reaching the actual data, where 3.5 billion passengers are registered.

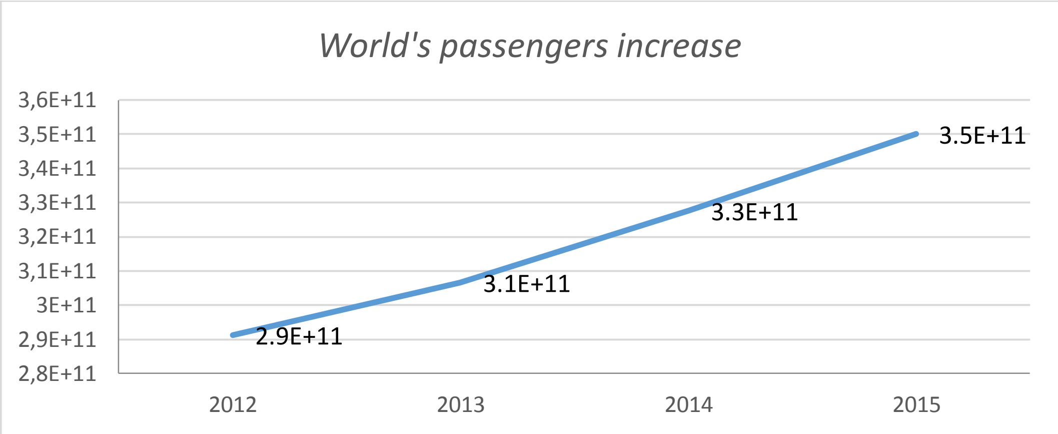


Figure 2: World's passengers increase
Source: ICAO. Global Air Navigation Plan 2016-2030

Another usual indicator for reflecting this growth trend is the RPK (Revenue Passenger Kilometer). This indicator shows the volume of passengers that have paid for a travel in function of the mileage of the travel, measuring the total kilometers traveled by each passenger. The growth of this indicator in the last 5 years is shown in the next graphic.

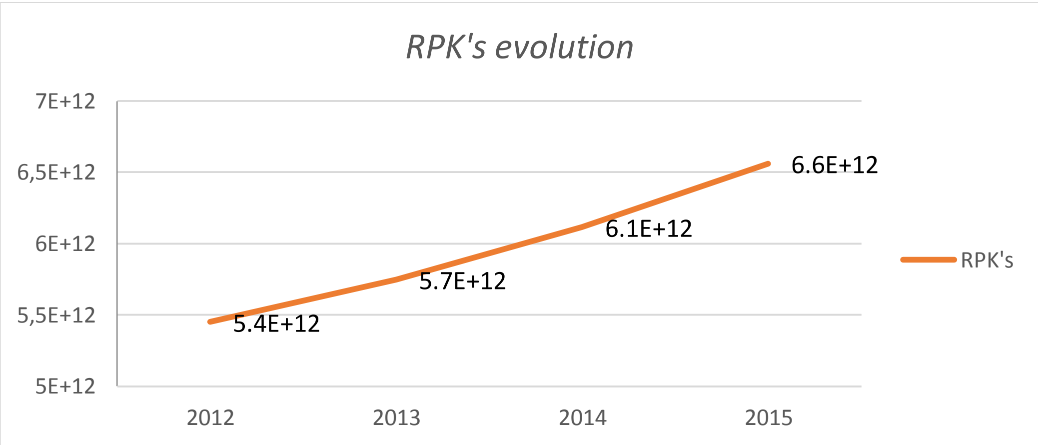


Figure 3: RPK's (Revenue Passenger Kilometer) evolution
Source: ICAO. Global Air Navigation Plan 2016-2030

In the next table is shown the increase (in percentages) of RPK's in 2013 in terms of transit growth and market participation for the domestic and international flights for every continent. The last two columns contain data for the ASK and the LF indicators. The first one (Available Seats per Kilometer) represents the growth of the air routes around the world, and the second one (the Load Factor) represents the average of passenger occupancy per flight.

Aviation industry growth								
	International flights		Regional flights		Total			
	RPK's						ASK	LF
	Transit growth (%)	Market participation (%)	Transit growth (%)	Market participation (%)	Transit growth (%)	Market participation (%)	Capacity increase	Flight occupancy
Africa	7.4	3	4.2	1	7	2	5.2	69.6
Asia/pacific	5.2	28	9.6	37	7.2	31	6.7	77.2
Europe	3.8	38	3.7	8	3.8	27	2.6	79.9
Latin America/Caribbean	8.6	4	4.2	7	6.3	5	5	76.1
Middle East	10.9	13	16.1	1	11.2	9	11.5	76.9
North America	6.2	14	1.9	46	2.2	26	1.9	83
World	5.2	100	5.1	100	5.2	100	4.6	79.1

Table 1: Aviation industry growth
Source: ICAO. Global Air Navigation Plan 2016-2030

It is observed that the growth of the RPK in 2013 was 5.2% (increasing to 6.2 and 6.8 in 2014 and 2015, respectively), and the growth for the ASK's was a 4.6% more than 2012. The load factor was 79.1%, and now it is increased to 80.1% in 2015. North America, Europe and Asia/pacific are the continents where most of the flights are concentrated (reaching an 84% of the total flights).

The trends show a notorious increase on Middle Eastern indicators, supposing a displacement to the East of the average converging point of the global operations (previously this point was the center of Europe).

Regarding the type of flight performed today, it can be seen in the next graphic that an 86% of the flights carries a maximum of 260 passengers per flight. Just a 14% of the global flights carry more than 260 passengers.

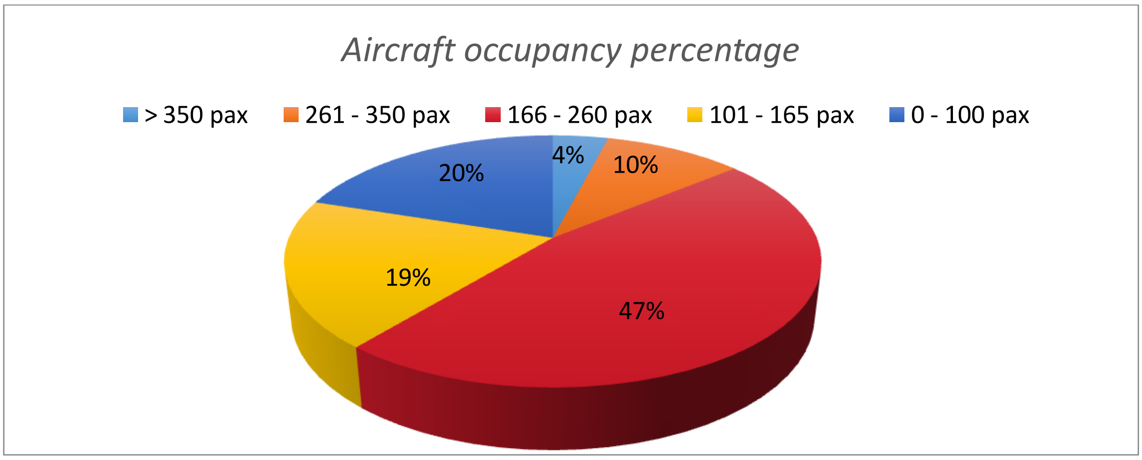


Figure 4: Aircraft occupancy percentage
Source: TITAN project

The trends of growth for the aeronautic sector are clear and evident. This is due the application of new regulations and technologies, as well as the increase of the operational security and the emergence of new routes and airlines (1400 airlines in 2015) and common policies between them.

A remarkable milestone in the sector was the apparition of Low-Cost Carriers (LCC's). These airlines gave the chance to travel for cheaper prices than the traditional airlines. In 2015, the LCC's carried a 28% of the global passengers (950 million), and in Europe LCC's represents the 30% of total airlines.

Another remarkable milestone was the decreasing trend for the fuel prizes, which represent almost a 33% of the total operational costs. The next graphic synthesizes the growth of the sector in terms of fuel consumption and RPK.

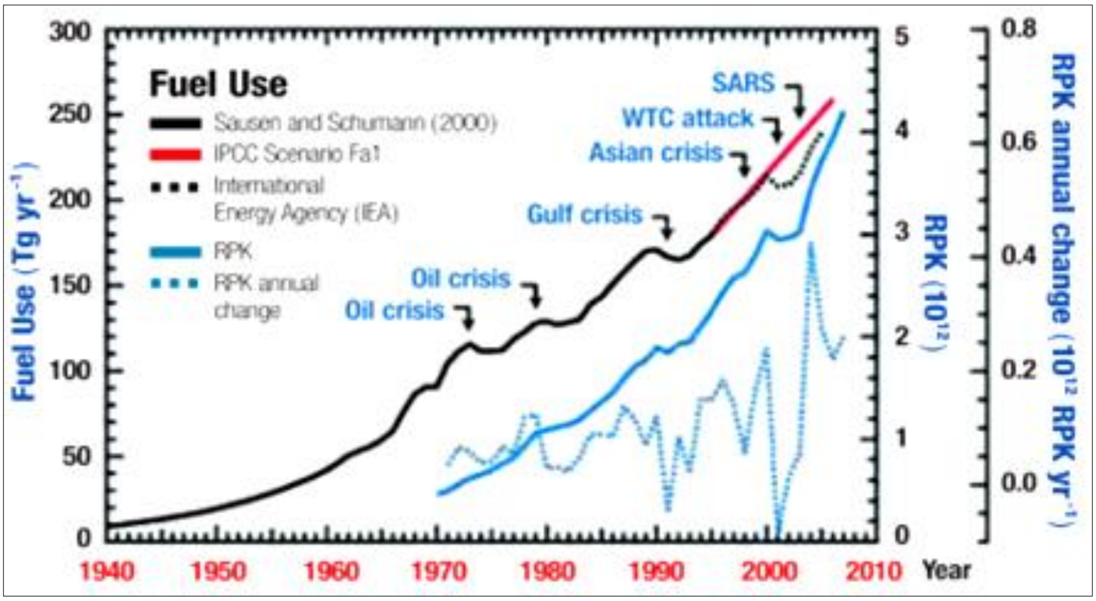


Figure 5: Fuel consumption evolution
Source: ICAO environmental report. 2016

Because of this growth on the aeronautic sector, the industry closed with benefit records of over 60 and 40 billion dollars, with an operative margin of 7.6% and 5.5% in 2015 and 2014, respectively.

In Spain, the trends are expected to be the same than the global ones. According to AENA (Spanish Agency of Air Navigation), 2016 registered a passenger's increase of 11% respect 2015. The same data are registered in LEBL, with an increase of 11.2%.

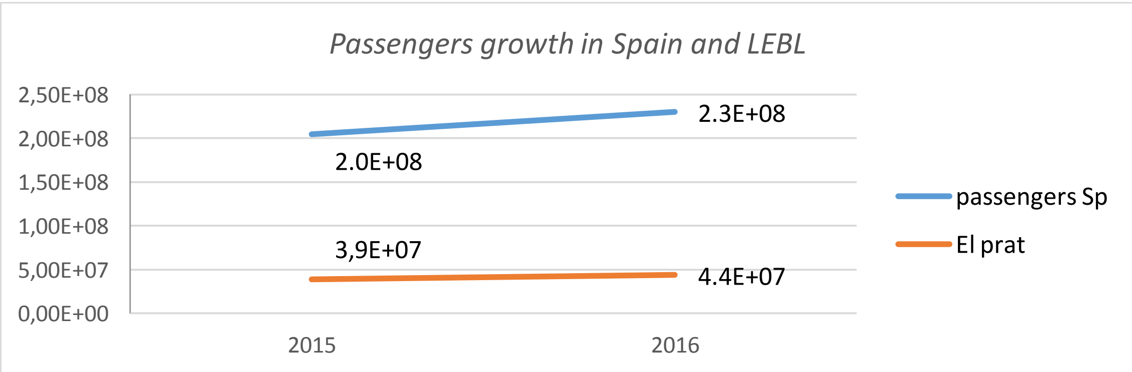


Figure 6: Passengers growth in Spain and LEBL.
Source: AENA report. 2015

2.2 INTERNATIONAL ORGANIZATIONS

This section describes the main rules and regulations with direct or indirect affection on ground handling activities and the LTO cycle. There are more regulations and laws evolving the aeronautical sector operations in the European and Spanish legislations, but they're not mentioned because these don't have an influence over the ground handling activities.

The aeronautic sector was finally established when ICAO (International civil Aviation council) appeared in 1944, the first main international organization that regulates the entire sector. Currently, 191 states are members of the organization, working together to reach a consensus about the recommended rules and the methods for the international civil aviation. These methods are based in policies that surround the operational safety, efficiency and the sustainable economy.

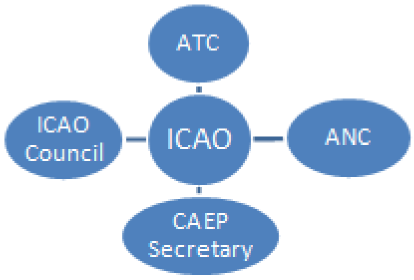


Figure 7: ICAO branches.
Source: Own source.

ICAO has three sections that work together but in different areas, with the aim of purposing and improving the current operational policies and methods. These sections are the ATC (Air Transport Committee), ANC (Air Navigation Commission) and CAEP (Committee on Aviation Environmental Protection).

Thus, ICAO created the SARP's (Standards And Recommendations Practices), which are mandatory to apply in every member state. These are contained in 19 different annexes, presented below (the highlighted annexes are the ones that have influence over the LTO cycle and the ground handling operations).

1) Personnel licensing (aircraft maintenance, ATC and aircrew)
2) **Rules of the air (flying rules, commandant's authority, operations, signals, lights…)**
3) Meteorological service for international air navigation (forecasts and communication)
4) Aeronautical charts (Hazard, parking and topographic maps, Visual Flights Rules)
5) Units of measurement to be used in air and ground conditions
6) **Operation of aircraft (international standardization of the operations to ensure security and efficiency)**
7) Aircraft nationality and registration marks
8) Airworthiness of aircraft (aircraft's inspections and certifications)
9) Facilitation of passengers, cargo across state borders.
10) Aeronautical telecommunications
11) Air traffic services
12) Search and rescue
13) Aircraft accident and incident investigation
14) Aerodromes (planning, equipment, installations, collision prevention measures)
15) Aeronautical information services (NOTAM)
16) **Environmental protection (noise and emission certifications)**
17) Security, Safeguarding international civil aviation (AVSEC Program)
18) The safe transport of dangerous goods by air
19) Operational security management

Another international organization is IATA (Air Transport Association). This is the tool for the cooperation between the airlines to promote de safety, reliability and confidence in air transport.

This association doesn't have any legislative or regulative power. Any airline can join IATA if operates a regular international air service and if the airline belongs to a state member of ICAO. Currently 265 airlines of 117 states are members of the IATA, representing the 83% of the global air traffic.

2.3 EUROPEAN AND SPANISH LEGISLATION

2.3.1 European legislation

The European Union converted into laws the recommendations developed by ICAO, granting to the state members the liability to accomplish the objectives. The recommendations created doesn't contain specific acting measures, trusting in the law transpositions of each state government and in the aeronautical state managers to apply specific measures that allow the fulfillment of the law.

Directive 2002/49, relative to acoustic pollution

This directive imposes that acoustic indicators, as well as methods for the evaluation of acoustic levels, must be set at the influence area of an airport. Over more, the airports with more than 50000 operations per year must perform a strategic sonority map.

CAFE Program (Clean Air For Europe), 2001

This program is a long-term strategy implanted in 2001 as a complementary program to directive 2001/81 (relative to GHG emissions and not polluting gases). Thus, this program pretends to set guidelines for the prevention of atmospheric pollution, as the fuel desulfurization.

In 2012 a study was carried out to know how successfully the implementation of the plan was. The results showed in the next graphic indicate that almost all the UE members achieved the objectives for all pollutants excepting for the NOx.

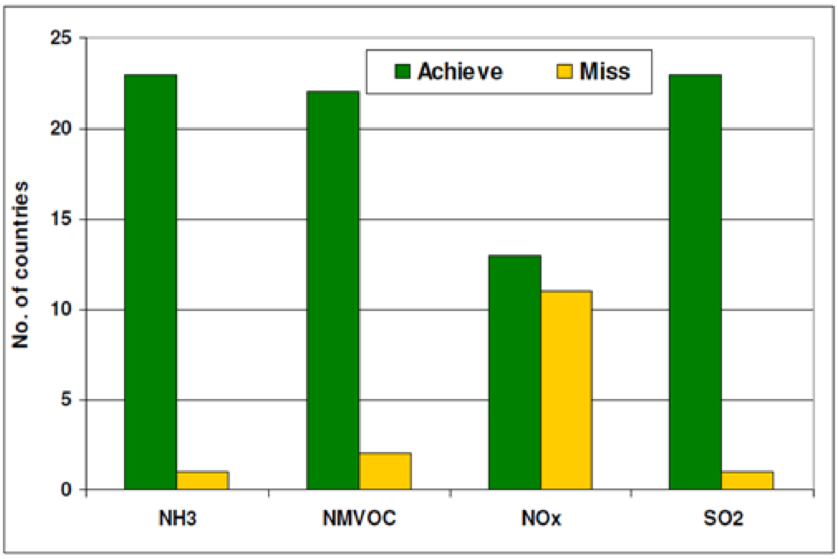


Figure 8: Number of countries that have achieved the CAFE program goals.
Source: CAFE report results

2.3.2 Spanish legislation

In Spain, the transposition of the directive 49/2002 was realized through the law 37/2003, relative to the elaboration of strategic sonority maps to make accurate actuation plans. To achieve that, a data base of the acoustic emission sources at airports was created, known as SICA (Acoustic Pollution System Information). The methodology followed to establish the sonority levels is the detailed on the ISO 9613-2.

Due the implementation of the plans to reduce the acoustic pollution, the airlines must respect several operative restrictions like the limitation on the power applied to the engines during the landing or the prohibition of APU's (Auxiliary Power Units) use during the parking.

To achieve the objectives established by CAFE program, the Spanish government has legislated national regulations, forcing the creation of control and vigilance plans trough the installation of monitoring networks in specific places of the airport and the cities near to it.

AENA traces the operation carried by the contractors. Moreover, AENA publishes a report about social responsibility and a manual of good practices where the use of APU's electric systems and the usage of alternative fuels in ground handling are promoted. Catalonia created his own program in 2008 relative to the reduction of GHG emissions.

In conclusion, there are many international regulations that control the aeronautic sector, but the way of applying these regulations on the states depends on their will to make it much or less exigent.

2.4 PERFORMED ACTIONS

This section contains the description of the international and national measures performed until today with the aim to reduce the environmental impact during the LTO cycles. Although the ground handling operations may not be directly mentioned in these documents below, there are indirect references due the use of combustion engines.

ICAO's annex 16, environmental protection, 1971

This document is divided into two volumes, and deals with the environmental protection against the affection of the noise and pollutants emission. Within other factors, aircraft's noise depends on the power supplied to the engines (how less the power is less is the noise, having in mind that the reduction of power during landings can affect the aircraft's security parameters).

This annex written in 1971, deals with the problematic evolved with the noise and the emissions. In this document was incorporated a procedure to describe and measure the aircraft's noise and determinates the human tolerance to that noise levels. Over more, an acoustic homologation for the aircrafts was performed as well as the formulation of criteria for the attenuation of aircraft's noise.

Likewise, this annex prepared directives for acoustic homologation of the future supersonic aircrafts, STOL aircrafts (Short takeoff and landing) propelled by helix, the auxiliary power units (APU's) and for the auxiliary systems used during the TAP operations.

On the same way, aircraft's engines are homologated and certificated for controlling their emissions, trending to use more efficient engines. According to ICAO's document 9889, the new engines design allows to reduce the emissions in a 50 – 80% during a LTO cycle.

Guidance on the balanced approach, reduction of aircraft noise. ICAO's document 9829, 2007.

This ICAO's document pretends to give solutions to the acoustic and fuel consumption impacts generated by the aircrafts on the final approach phase in an environmental and economically sustainable way, detailing how the approach should be performed for an impact minimization if the meteorological conditions allow this kind of approaches.

These approaches are known as CDA (Continuous Decent Approach).

Airport's air quality manual. ICAO's document 9889, 2011

The air quality issues related with the aircrafts emissions were analyzed in this ICAO document, bearing in mind the actual technology and the actual airport operations.

In this manual are identified which are the emission sources at the airports and it establishes methodologies to quantify them, with the aim of limiting or minimizing the local air pollution near the airport.

In 2013, ICAO redacted an environmental report where it was highlighted how dangerous the PM_{10} and the NOx are for the human health and the environment and the need of using pollution dispersion models to anticipate the possible different meteorological scenarios.

Ultimately, this document contains the methodology to assess the air quality in the airport using air quality maps. This is the same methodology explained for the ACI before.

ACI (Airport Carbon Accreditation), 2015

In 2015 a procedure was performed with the aim of certificating that all the airports are accomplishing the emission limits established. This procedure is managed through an international organization, the Airport Council International, which manages the interests between the airport stakeholders and the governments in addition of developing new rules and policies to increase the environmental quality of the airports.

Through the ACI, an airport emission ceiling is established as well as evaluation procedures that recognizes the effort made (or not) by the airports managers to reduce their emissions.

This certification is based on a voluntary presentation of the carbon footprint (ISO 14064 methodology) and a report of the gases emission sources and their management. Thus, airports can be classified in 4 management levels:

- Mapping: Identification and characterization of the emission sources
- Optimization: Optimization of the activities
- Reduction: Showing of emission reduction evidences and establishment of goals
- Neutrality: Neutralization of non-eliminable emission (just 16 airports have this certification level).

Most of the airports have one of the three fist certification level, representing a 22% of global air traffic.

CAEP (committee on Aviation Environmental Protection)

CAEP is an ICAO's extension with a technical view instead of political, which gives support to the adoption of new policies through the recommendation of new SARP's for noise and emission reduction. These recommendations are developed according to 4 criteria: technical feasibility, economic viability, environmental benefits and the consideration of the interdependence between the mitigation measures.

CAEP has 3 different working groups: aircraft noise (with the aim to keep the international engine certifications), operations (decrease the problematic of airport's emissions) and engine emissions (decrease of emissions due the increase of engines efficiency). Over more, CAEP has a modeling work group and another for prediction and economic analysis.

Below are presented all the technical documentation developed and published by CAEP:

- Annex 16, Volume I Amendment 10
- Annex 16, Volume II Amendment 7
- Noise report
- Fuel burn report
- NOx report
- Operational goals report
- CDA (Collaborative Decision making) guidance
- Guidance for the balanced approach (to aircrafts noise management)
- Environmental technical manuals, Volumes I and II
- Collaboration on the Global Air Navigation Plan
- Draft guidance on the use of emissions trading for aviation
- Local air quality and climate change mitigation effects
- Measures for fuel minimization
- Update of the Airport Air quality guidance Manual.

For the next 40 years, ICAO established along his members several regional goals that every national aviation organization must to accomplish (AENA in case of Spain). These goals appear in a priority order in the ICAO's Air Navigation report (2016), which are:

- PNB implementation (performance-based Navigational international aerodromes)
- Use of ATFM (Air Traffic Flow Management)
- AIM implementation (Aeronautical Information Management)
- GGDCT implementation (Ground-Ground digital coordination/Transfer)
- CCO/CDO operations implementation (Continuous Climb/Descent Operations)
- ABSU Implementation (Aviation system Block Update for the reduction in fuel use and emissions). Below is presented an example of the measures established in the module 0 of the ABSU.

2.5 ACTUAL IMPACT OF THE AVIATION

Globally, 2010 registered a total of 49Gt of gas emissions (CO_2 eq) to the atmosphere, which a 65% belongs to carbon dioxide coming from combustion/industrial processes and an 11% corresponds to deforestation and land use. Methane represents a 16% of total emissions and, with a reduced percentage, the N20 and the fluorinated gases represents a 6.2 and 2% respectively. This data is shown in the next graphic.

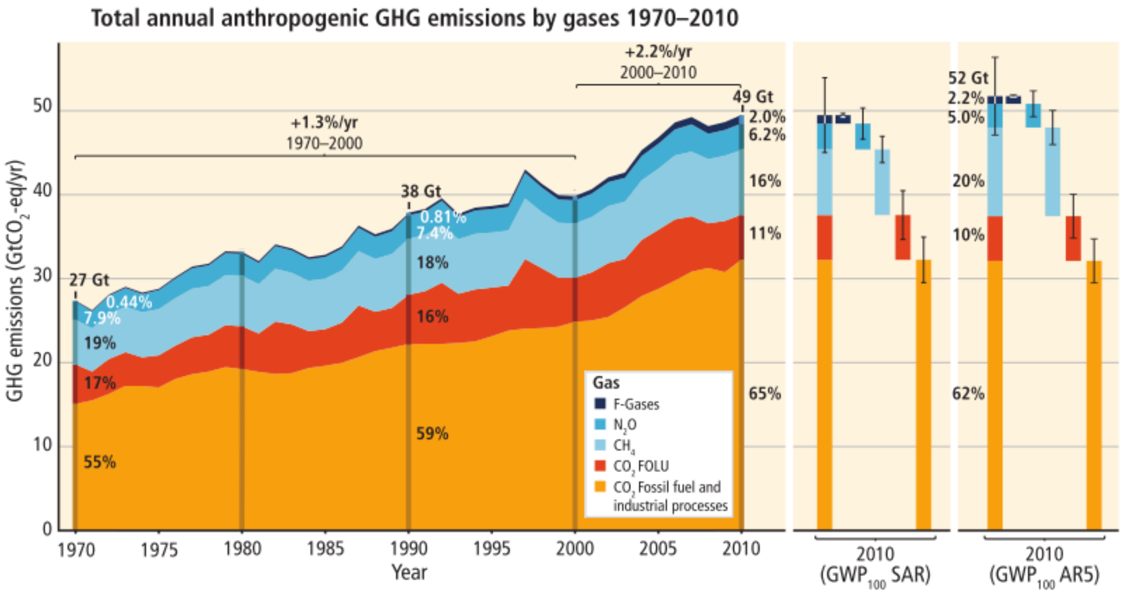


Figure 9: Total annual anthropogenic GHG emissions.
Source: ICAO environmental report 2010. The two last columns belong to the IPCC prediction modeling.

An economic approach can be analyzed from this data, showing that the production of electricity and heat, agriculture/deforestation/land use; and the industrial uses are the main contributors of GHG emissions in a 24, 24 and 21% respectively. Regarding at the transport sector, his contribution represents a 14% of the total emissions, mostly coming from road transports. The aviation industry is responsible from an 11% of transport emissions, meaning that the global contribution to climate change from the aviation rises to 2% in 2010. In quantitative terms, the aeronautic sector emits 600 million tons of CO_2 eq. The next graphics show the sectorial emission contribution and specifically for the transport sector.

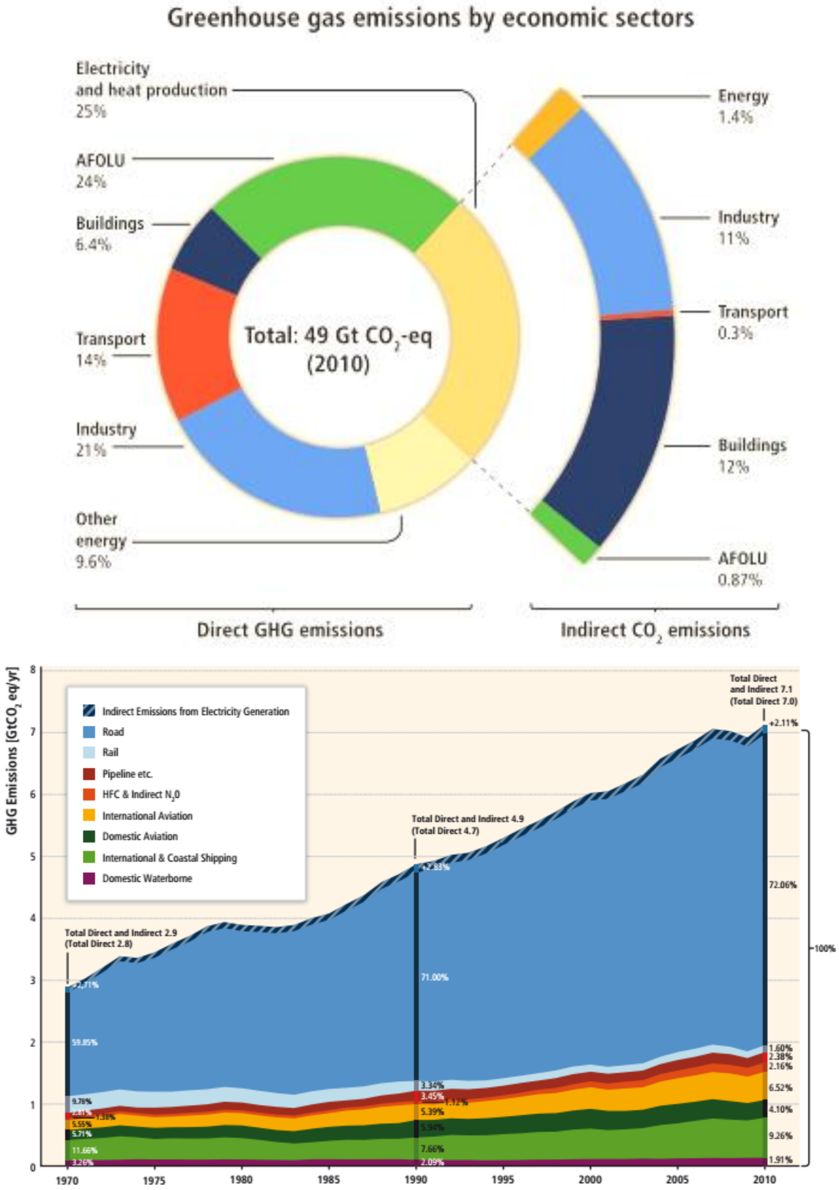


Figure 8.1 | Direct GHG emissions of the transport sector (shown here by transport mode) rose 250% from 2.8 Gt CO_2eq worldwide in 1970 to 7.0 Gt CO_2eq in 2010 (IEA, 2012a; JRC/PBL, 2013; see Annex II.8).

Figure 10: GHG emissions per sector and GHG per transport sector
Source: IPCC report. 2004

Respecting the NOx, a 46% of this gas emissions is due the transport activities and particularly a 6% is coming from the aviation.

Jet engines are combustion chambers; thus, the exhaust gases are the ones well known: CO_2, NOx, H_20, SOx, HC and soot. These gasses have a directly affection (CO_2 and water by increasing the normal atmospheric concentrations) or indirectly like the NOx (which trough chemical reactions it forms methane and ozone) or the SOx, HC and soot (which suffers microphysical processes that increases the concentration of particulate matter and clouds and contributes to the formation of contrails).

Because of the concentration increase of these gasses, the atmospheric radiative force is as well increased, making stronger the natural greenhouse effect and contributing to the enhancement of climate change. On the other hand, is needed to take in account the contribution on air quality deterioration and their affectation to human health when the aircrafts fly at low altitudes.

The following scheme shows the exhaust gases previously mentioned and their interactions with the environment. The second graphic shows the radiative force increase due the aviation's emissions. Carbon dioxide is the gas that contributes more to the radiative force followed by the ozone (produced from NOx) and water vapor.

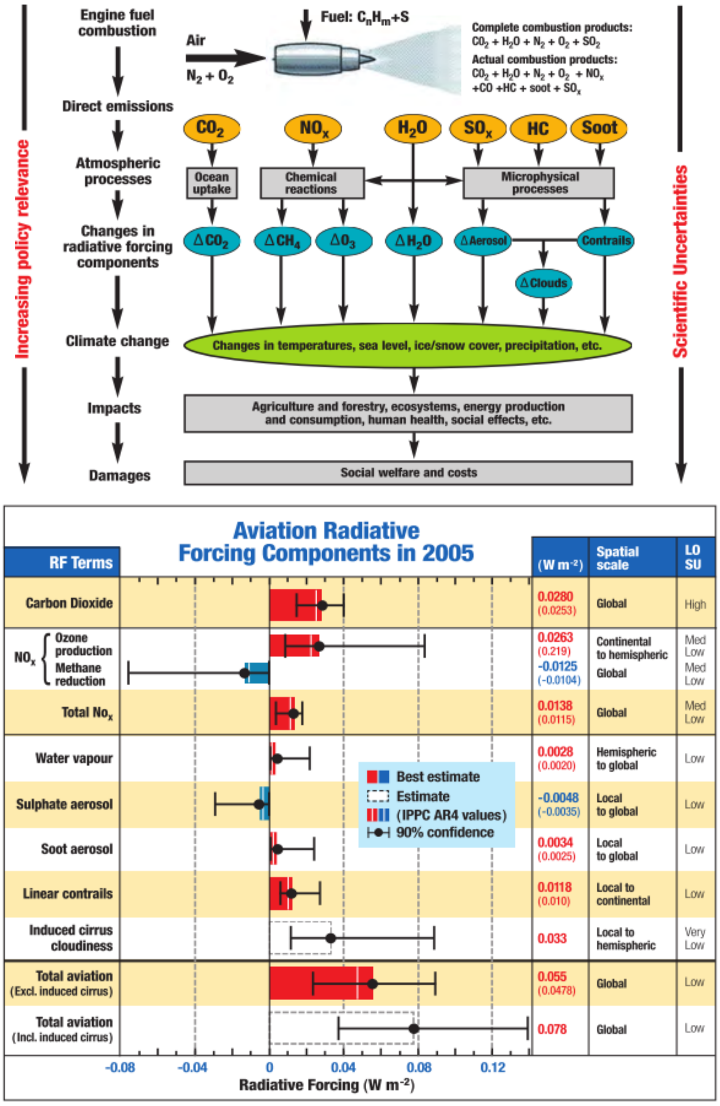


Figure 11: Combustion's primary and secondary pollutants. The second image shows the radiative force of each pollutant and their contribution to the global warming.
Source: IPCC environmental report 2004

Globally, aviation contribution to radiative force is 0.08W/m^2 and the forecasts made by IPCC indicate that following the actual trend, the aviation contribution to the global temperature increase in 2100 would be 0.4mK (millikelvin).

In terms of air quality, according to ICAO's 2014 environmental report, the emission contribution of NOx, PM_{10}, VOC's and SO_2 during the LTO cycles (where the aircrafts fly below the mixing layer thus the emissions have more influence over the air quality) represents a 3% for NOx and 1% for the rest of pollutants. This data is variable in function of airport's capacity and their surrounding topography.

It's needed to take in account that there are more emissions in the airport area that affects the air quality as the landside traffic, handling activities (vehicles and ground power units), airport's power plant generators and normally the industries near the airport.

2.6 AVIATION FORECAST

Once the actual situation is analyzed, is necessary to know the future trends for the aeronautic sector. ICAO made in 2016 a report about the capacity and efficiency of the sector to develop a plan for the air navigation in the 2016-2030 periods.

The fuel consumption previsions show that will be an increase of fuel consumption by 200% in 2030 and by 400% in 2050. This forecast just had considered the aircraft fleet renewal, but by introducing new efficient engines and alternative fuels an objective is set for 2050: the annual reduction by 2% in fuel consumption.

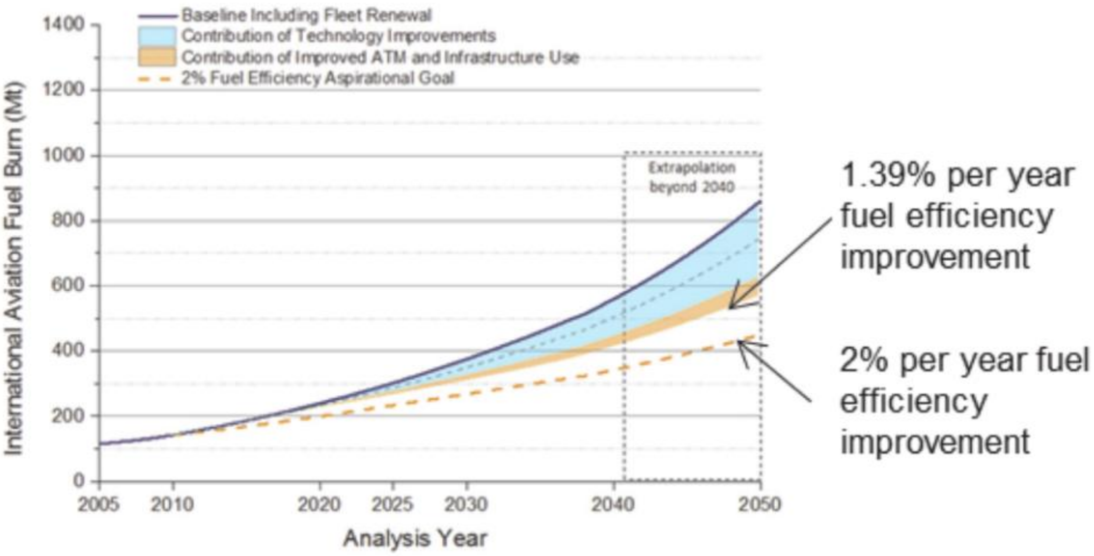


Figure 12: Aircrafts fuel consumption evolution and forecasts.

Source: ICAO environmental report. 2016

The next graphic shows the trend in CO_2 emissions by aircrafts engines, increasing by 200% in 2030 and 314% in 2040. Applying improvements in technology and the ATM, is possible to reduce the actual trend of emissions by a 33% facing 2050.

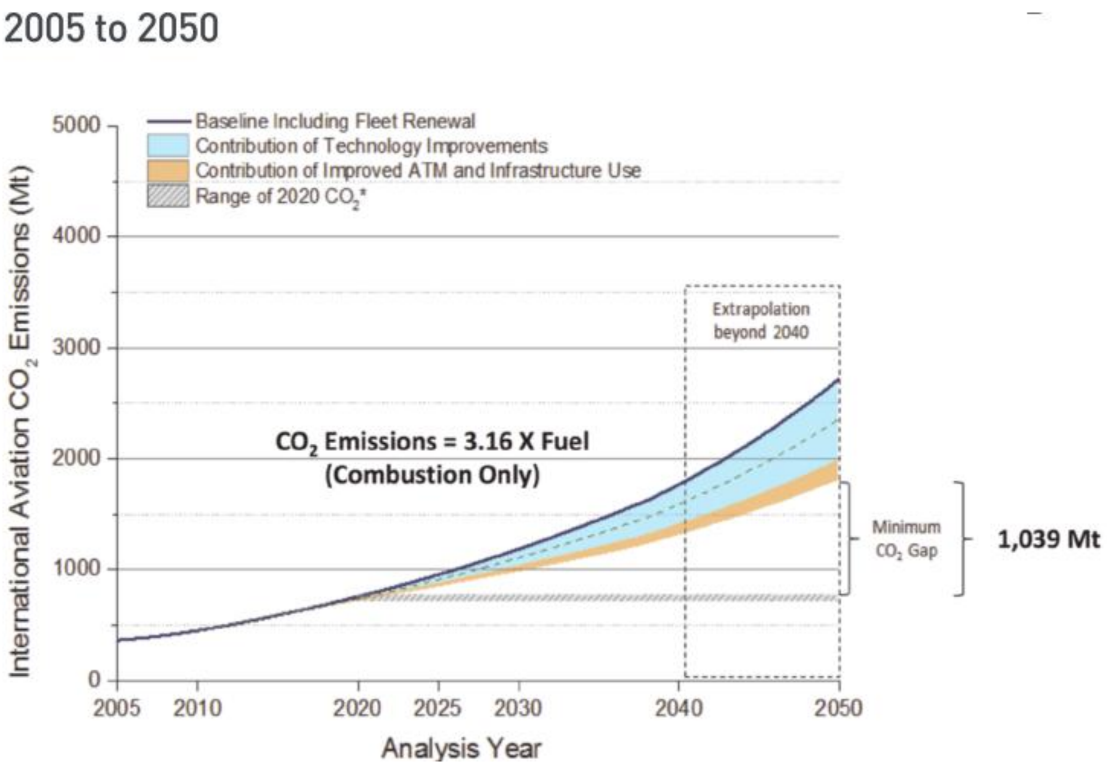


Figure 13: Aircrafts CO2 emissions evolution and forecasts.
Source: ICAO environmental report. 2016

2.7 AIRPORT SERVICES

In this part is explained the TITAN project (Turnaround Integration Trajectory and Network), created by ICAO, used to analyze which and how are the ground handling operations, their bottlenecks and the stakeholders involved.

Turnaround process (TAP), is defined as all the operations needed to attend the aircrafts arrival at the parking zone and set it up for the next departure. TAP can take from 20 minutes to 3 hours depending on the airport, the airline, the type of aircraft and the haul.

Every airport is different due their logistics, operations and infrastructures, so the procedures in the handling activities can vary between airports but always with the same aim, an efficient and safe TAP.

TAP's requires a lot of services often offered by different companies, and that makes these operations more complex with a higher inefficiency potential. Currently, the 26% of the delays are caused by conflicts during TAP operations. In the next scheme is shown the interactions between the airport services.

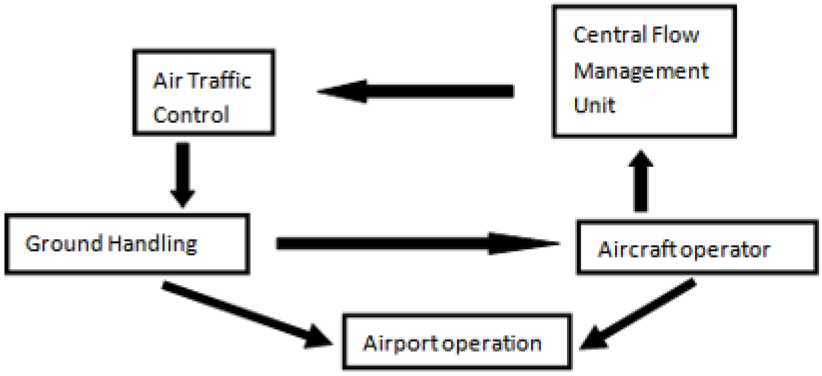


Figure 14: Airport services interactions.
Source: TITAN project

TAP's Description

The day before to the operations, the handling manager receives details about the incoming aircrafts types, stand localizations, estimated arrival time and the possible constrains. With this, a plan is developed according the flight schedule and the available resources. The output of this plan is a TAP estimation time given to the airlines.

The same day of the operations, the handling companies receive the details about the number of passengers, cargo and AIBT confirmations (Actual In Block Time) per aircraft. Before the aircraft's arrival at the anchorage point, the handling equipment have already deployed according to the plan, realizing the previous preparations at the stand and guiding the aircrafts to the stand (Follow Me vehicles).

Here is where TAP starts:

0) Marshall's guidance to final position
1) AIBT (Actual In Block Time). Aircrafts arrival
2) Placing of chocks in front of the aircraft's wheels
3) Use of GPU (Ground Power Units)
4) Stair/finger placement
5) Passenger's unload
6) Cargo/baggage unload
7) Post flight administration
8) Preflight administration
9) Aircraft cleaning and air conditioning
10) Refueling
11) Catering replenishment
12) Wastewater deflection and potable water refilling
13) Security checks
14) Passenger's load
15) Cargo/baggage load
16) Fuselage and wings deicing if necessary
17) Chock's removal for departure
18) Pushback/towing
19) AOBT (Actual Off block Time)

In the following tables, are schematized all the operations needed along an LTO cycle including TAP.

	LTO ACTIVITIES ACCORDING TO THE FLIGHT PHASES							
	Landing	**Taxi**	**Parking**	**Unload**	**Service**	**Load**	**Taxi**	**Departure**
Operations	ATC Flow control	Slot preparation	Marshall's guidance to final position	Stair/finger placement	Maintenance	Catering	Slot assignation	
	Slot assignation	Follow-me	Placing of Chocks	Passengers, baggage, cargo	Refueling	Passengers, cargo, baggage	Pushback	
					Cleaning and waste water deflection	Chock's removal	Taxi	
			Turnaround Process					

Table 2: LTO activities according to the flight phase.
Source: Own

	LTO ACTIVITIES ACCORDING TO THE TYPE OF SERVICE		
	TAP Operations	**Needed equipment**	**Considerations**
Passenger services	Stair/finger placement	Stairs use involves the use of buses and stair trucks	
	Passengers, unload		
	Cabin services	Cleaning, catering, maintenance, security checks	The cleaning operations are very variable depending on the types of flight and the airlines. They begin once the passengers have been unloaded. Up to three trucks (catering, water and cleaning) may be needed, or one if cleaning is done by the flight crew or catering refill is not required.
	Passengers load		
	Stairs/finger removal		
Baggage/cargo services	Open lateral cargo door		The operations of loading and unloading of baggage and cargo are simultaneous and independent to the passenger's unload. There are methods of loading and unloading suitcases and cargo by loading and unloading containers that are more efficient, but special cranes and equipment are required. Not all airports and airplanes are designed to be able to load the containers.
	Baggage unload	Unload with tapes and transported by carts	
	Cargo unload		
	Baggage/cargo load		
	Close lateral cargo door		
Aircraft services	Refueling	Pipe trucks or fixed pipelines system	Refueling is usually started once it has been unloaded, although depending on what circumstances, it may occur at the same time.
	Potable water service	Specialized equipment	
	Waste water service		
	Deicing		Only when climatic conditions make it necessary
	Ground Power units	Keeps on the electrical needs of an aircraft	Use of low pressure air for the air conditioning of the cabin and high-pressure air to start the engines.
	Pushback	Push the aircraft to the start point using tugs	Pushback is the operation of pushing the aircraft to the starting point of engines. It is not always necessary (it is usually only done in the finger parking type) and there are aircraft models that have autonomous pushback systems.

Table 3: LTO activities according to the type of service (passengers, baggage and aircraft services).
Source: Own

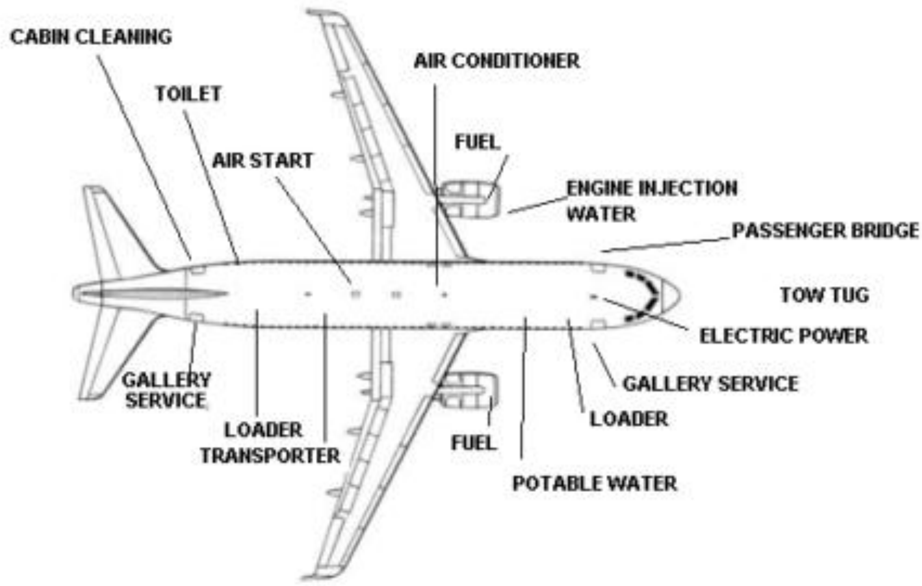


Figure 15: Aircraft service points
Source: TITAN project

This mentioned sequence is not fixed for each airport but contains all the steps that can be found during a TAP. These operations can be overlapped, according to the established handling manager's plan, always when the safety rules allow it. This chance of overlapping the activities allows the establishments of buffer times between them, absorbing the conflicts that may occur by having the change of extending one activity without alter AOBT.

TAP's delays are not produced just by conflicts on the airside (handling and runway zones), is also conditioned by conflicts on the landside (zone within the public road access until the boarding gate) like check in and security control delays and baggage transport management.

Currently, OPIS system is used (Opportunistic Intelligent scheduler). This system is predictive and reactive, capable of prevent and manage TAP, taxi times and ramp delays to make possible a reaction in front of conflicts without disabling airports functionality.

2.8 EL PRAT AIRPORT (LEBL)

This part is the closing of the first chapter of the project. Here it's analyzed how LEBL is managed, which are the operations developed, airport's configuration and the infrastructural facilities it has. This analysis is carried out through the El Prat Director's Plan (2003) and the "El Prat Report" from AENA (2015), which determines the operational and support areas of ground handling activities.

LEBL is surrounded by El Prat de Llobregat, Viladecans, Sant Boi and its 3 km far from Barcelona commercial harbor and Zona Franca industrial park. At the limits of the airport, there are some natural spaces, protected due their ecologic function as a wetland and as a ZEPA (bird zone protection).

In 2015, LEBL performed 288.878 operations (a 1.8% increment than 2014). These operations have transported over 40 million passengers, a 5.7% more than 2014, between 57 countries (199 total destinations) trough 83 different airlines.

The most highlighted airlines performing in LEBL are Vueling, Ryanair, Easyjet, Lufthansa and Air Europa, with an operation sharing of 37, 14, 7, 4 and 3%, respectively. A 67% of the airlines are LCC's (Low cost carriers).

The next graphic shows the evolution of passenger's transport, until reached the actual 40 million passengers. For the last 5 years, the average growth rate has been a 5%. The main milestones that increased this rate were the construction of the second terminal during the Olympic Games, in 1992, and the runway 07-25, in 2004. The next graphics shows this evolution and the growth rate, as well as the 2015 monthly traffic evolution. Is remarkable that in summer of 2015 were accumulated a 68% of the annual flights.

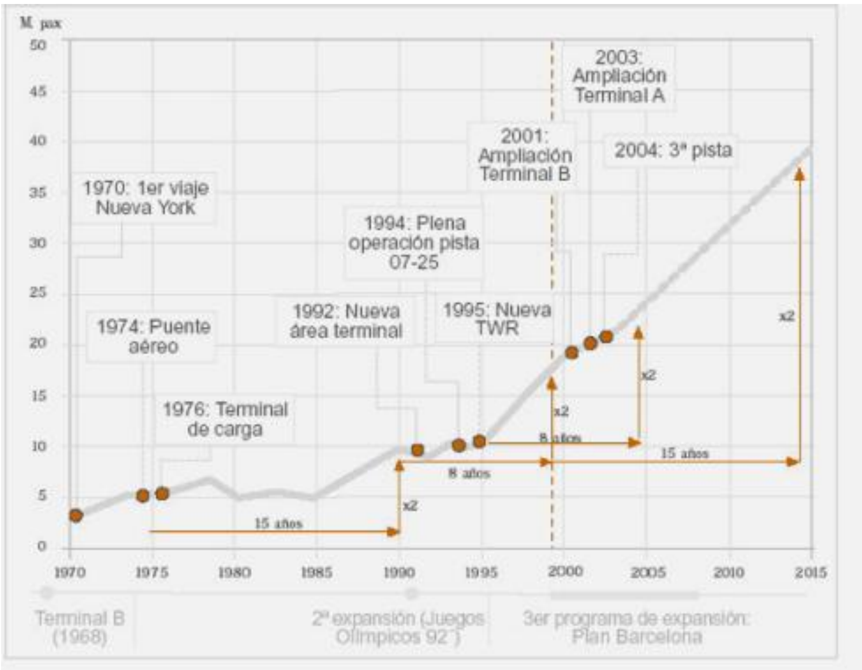


Figure 16: Passengers evolution at LEBL according to different events and milestones.
Source: El Prat director plan. 2003

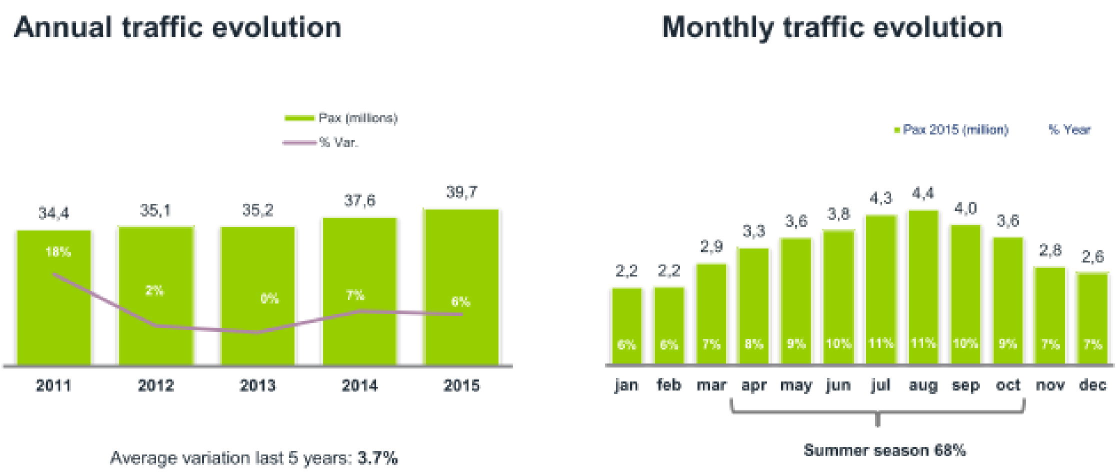


Figure 17: LEBL's annual and monthly traffic evolution.
Source: AENA report. 2015

Below are presented some operational data about el Prat airport.

LEBL data	
Airport area	1,533 Ha
Passengers in 2017	40 million
Operations per hour	76
Flight fields	2 parallel, 1 transversal and 4 “runway headers” *
Terminal Area	670,000m^2
Stands	168
Fingers	73
Desks	439
Tapes	31
Cargo terminal	160,000m^2
Airfield	50Ha
Runways El Prat (LEBL)	**Measure (m)**
02/20	2,528x45
07L/25R	3,352x60
07R/25L	2,660x60

		Arrivals	Departures	Total
Runway capacity	0:00 - 3:59	24	24	76 operations/hour
	4:00 - 4:59	18	30	
	05:00 - 20:29	38	40	
	20:30 - 22:30	26	22	
	22:30 - 23:59	24	24	

Table 4: LEBL characteristics, Runways measurement and capacity. *The Runway headers are the points where the taxi out phase ends and the Takeoff phase starts.
Source: LEBL’s director plan, 2003 and AENA report, 2015.

The airport has 180 parking slots for the aircrafts (without counting the parking slots of the cargo zone), which are conditioned for specific types of aircrafts, as it's shown on the table below. Currently, 73 parking zones dispose of finger, meaning that a 62% of the parking zones are in a remote position (positions where stair trucks and buses are needed).

Number of parking lots	Aircraft type
3	A-300-600
1	A380-800
13	A-320
82	A-321 / B-737
14	A-346 / B-747
2	A-330-300
17	B-757
28	B-767
2	B-787
1	CRJ-900
3	CRJ-1000
9	E-120
2	F-50
3	ATR-72

Table 5: Number of parking slots per aircraft type
Source: Google Earth

LEBL dispose of a decentralized network of energy and air that provides to the aircraft the energy required without using mobile vehicles. This network is only available when the aircrafts are parked on contact stands.

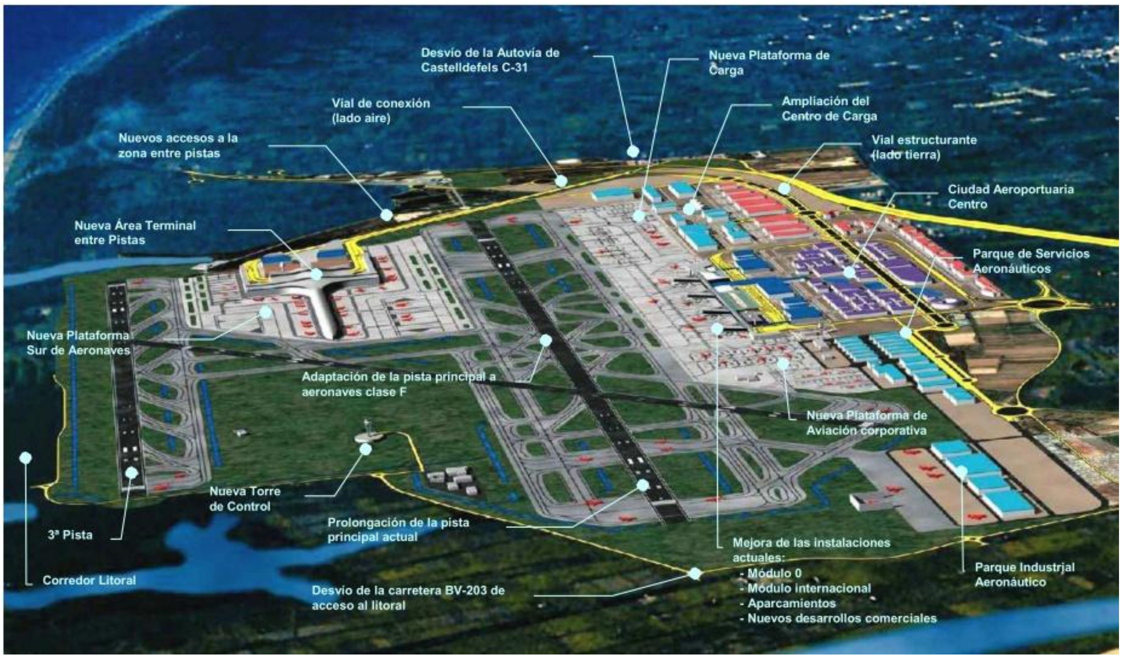


Figure 18: El Prat scheme.
Source: AENA. El Prat report 2015

Air quality evaluation at LEBL

To fulfill the legislation objectives, a monitoring air pollutant network has been set up inside the airport as well as the surrounding areas (Gavà, Viladecans and El Prat), evaluating the emission of pollutants and their affection on these areas.

In the director plan of Barcelona's airport was evaluated the effects on the atmospheric quality trough pollutants dispersion models, like the EDMS (Emission and Dispersion Modeling System) developed by EPA (Environmental Protection Agency) and the FAA (Federal Aviation Administration), introducing the emission data from the airports activities, forecasting the evolution of traffic growth, the ground equipment, the landside traffic, etcetera. The conclusion was that the impact over the air quality due the emission of pollutants is not significant because the airport emissions are lower than other emission sources as the road traffic and the industrial zone. Even so, the NOx levels previsions indicate a rise in NOx emissions, suggesting the applications of preventive measures.

The next table shows the air quality concentration levels in the 4 points of the monitoring network for 2012. These do not overcome the annual limits established by the European legislation.

Air quality values. 2012 annual average									
Sample point	CO (mg/m^3)	NO (ug/m^3)	NO_2 (ug/m^3)	O_3 (ug/m^3)	SO_2 (ug/m^3)	$PM_{2'5}$ (ug/m^3)	PM_{10} (ug/m^3)	Pb (ng/m^3)	C_6H_6 (ug/m^3)
Airport	0.39	10.6	27.7	55.1	5.9	14.6	24	22.7	0.8
El Prat	0.37	22.3	37.6	39.1	2.1	14.7	25.8	24	0.8
Viladecans	0.31	8.4	20	59	2.7	14.5	21	11.6	0.9
Gavà	0.25	5.4	14.6	59.4	2.5	13.4	22.5	10.6	0.8

Table 6: LEBL's air quality values
Source: LEBL's environmental report. 2012

The annual average limits established on the RD 102/2011 for the NOx and the PM are $40ug/m^3$.
Comparing the results above with the air pollutant concentration at Barcelona city in 2012, the average level of NO_2 was 40 micrograms per cubic meter, being the traffic road the responsible of a 70% of the emissions (Barcelona Air Quality Plan 2015-2018).

On the same study, a NOx and PM_{10} emissions forecast was carried out in the airport until 2018 due the increase of LTO's cycles, shown on the table below. The emission levels of PM_{10} in 2013 were 9.96 tons and the forecasts rises until 10.85 in 2018. On the same way, 1,494 tons were emitted in 2013, forecasting 1,629 in 2018. This data just considers the emission from jet engines.

NOx emissions and LTO cycles performed at LEBL						
	2013	2014	2015	2016	2017	2018
LTO cycles	138,250	138,643	141,551	144,351	147,401	150,701
NOx emissions (t/year)	1,494	1,499	1,530	1,569	1,593	1,629

Table 7: LTOs performed and NOx emissions
Source: Barcelona's air quality improvement plan. 2014

Bearing in mind the emissions from the Ground Power units and APUs, the total emission forecast for 2018 are 1,695 and 13.3 tons of NOx and PM10, an increase of 66 and 2.4 tons, respectively.
On the next tables is shown the data of LEBL emissions per sector, obtained from LEBL director plan (2003). Currently are not the same, but can be used to obtain knowledge about which are the

activities with more environmental burdens within. The results indicate that aircrafts engines and ground handling operations are the main emitters in the airport, representing a 46.5 and 45% respectively.

El Prat emissions characterization (El Prat director plan)

tons/year	CO	HC	NOx	SO_2	PM_{10}	
Aircrafts	2,549	393	2,294	110	-	
Handling vehicles	4,672	113	371	10	13	
Natural gas boilers	405	160	6	12	60	
Fuel tanks	-	3	-	-	-	
Vehicle's parking	162	19	6	0	0	
Access roads	104	14	14	0	0	
Fire extinguish practices	2	0,06	0,01		0	
Total	7,895	704	2,693	133	73	11,502.181

Table 8: El Prat emissions characterization
Source: El Prat Airport Director Plan. 2003

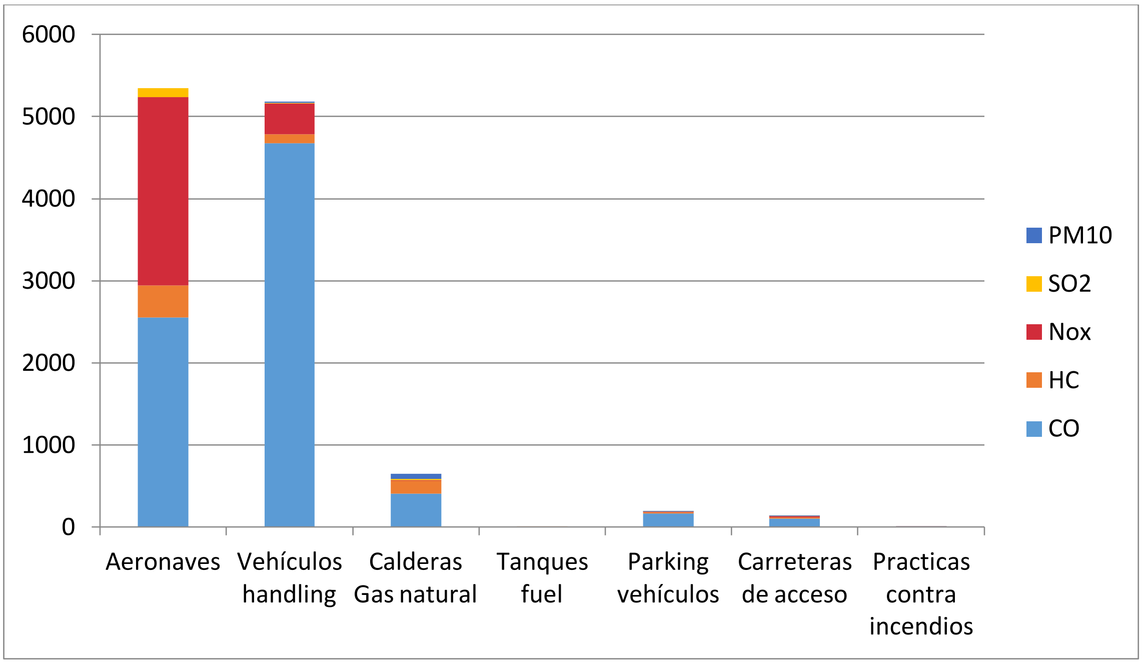


Figure 19: El Prat emissions characterization
Source: El Prat Airport Director Plan. 2003

CHAPTER III: METHODOLOGY

In this chapter is explained the methodology applied over the LTO and ground handling emission calculations, as well as the steps performed on SIMAPRO and MIVES software's to assess their environmental impact and for carrying the sustainability analysis.

With the aim of quantifying the exhaust gas emissions of the aircrafts and the ground handling activities, the operational flight schedule of LEBL is required. This schedule contains and registers every LTO in LEBL and specifies the real arrival and departure time per each aircraft (knowledge of possible delays), the gate allocation during the TAP (makes more exactly the modeling of aircraft taxiing and handling's phases) and the existence of charter flights.

This information is private and belongs to El Prat Airport, so the data collected is the one published by AENA in the website "infovuelos". In this web site are loaded all the arrivals and departures of each Spanish airport, showing the forecasted time arrival, the flight number, the airline, the terminal allocation, the baggage belt number and the aircraft type. In any case the gate allocation is shown. On this website are shown the commercial flights (passenger flights), but the cargo and private flights aren't.

3.1 DATA COLLECTION

Data collection has been done for two weeks, from the 3th until the sixteenth of April. This range has been set because the second week was Easter week, so this allows comparing one normal week against a "holiday period". The mentioned website gives the information in a range of -2h to +24h.

So, the data of every arrival in LEBL has been taken for two weeks, knowing the operation terminal, the airline and the aircraft type.

For the data treatment, the Belt number is not considered because its assumed to be a "landside operation" as the handling operators are not affected (they discharge all the cargo and the baggage at the same point and then are distributed according to the belt number), this point is called Service Point.

The real arrival time has not been possible to collect for every aircraft due the information in the web site is erased in a -2h period.

3.2 DATA TREATMENT

The main aim of the data treatment is to prepare the information as an input for the Simapro software, so the treatment is focused on a functional unit, explained on the chapter 3.41. But first, a characterization of all data is needed.

For every day, has been determinate the amount of arriving aircrafts per airline as well as the type of aircrafts used by each company, having at the end of the collection, the total arrival flights per airline and aircraft type and their operational terminal.

3.2.1 Analysis period

As commented before, the data collection has been taken during one normal and one holiday week with the purpose of registering the arrivals increase due a holiday period. The results are showed above, but there's not a significant difference between the two weeks, being 438 and 440 the arrivals average for week 1 and 2, respectively[1].

To estimate the total arrivals (and LTO cycles) in LEBL during 2017, the monthly passenger distribution of 2015 is used (figure 17). So, it's considered that the data taken (15 days in April) corresponds to a 3.8% of the total 2017 LTO's. Thus, the estimation for 2017 LTO cycles made in LEBL rises to 158439.

Comparing this number with the one published by AENA in a statistical report (2016), LEBL registered a total of 307,864 operations (153,932 LTO cycles), corresponding an increase of 2.85% for 2017 operations.

Another objective of this period setting, was to analyze the variation of incoming aircraft types during a holiday period.

3.2.2 Data characterization

As commented before, the data contained the aircraft type, the time arrival estimation, the airline and the arrival terminal.

Using the excel tool (count if with multiple criteria), the number of operated aircraft per airline, the percentage of aircraft types and the terminal distribution has been characterized[2]

Down here is shown the result for this characterization of the information. This is presented because it explains one assumption of the model: as it is observed on the accumulative line, a 95'91% of the total aircrafts is represented just by 12 types (A320, A321, A318, A319, A333300, A333200, A380, B738W, B763W, B772, E190 and CRJ900). So, as being a representative sample for the analysis, the modeling considers these aircrafts. For the resting 4.08% (37 distinct types), the most polluting aircraft within them has been selected as the representative of the accumulative tail, thus considering that a 4'08% of the total aircrafts operations in el Prat belongs to a B752.

[1] See annex 3.0

[2] See annex 3.1

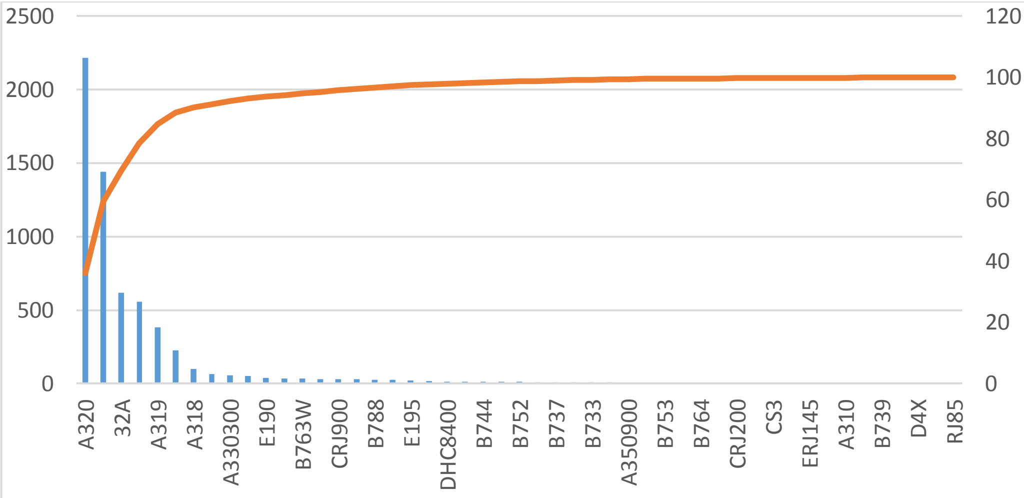


Figure 20: Registered LTO cycles on the analysis period. The right axis represents the accumulative line.
Source: Own

The models A320/32A, A321/32B, B763/B763W and B738/B738W are the same aircrafts in engine terms; the difference between them is the form of the end of the wing, having or not winglets. Winglets are aerodynamically structures that reduce drag of the aircraft (by decreasing the wing vortexes) at high altitude and speed. So, it's considered that there are no differences between these types of aircrafts during an LTO cycle.

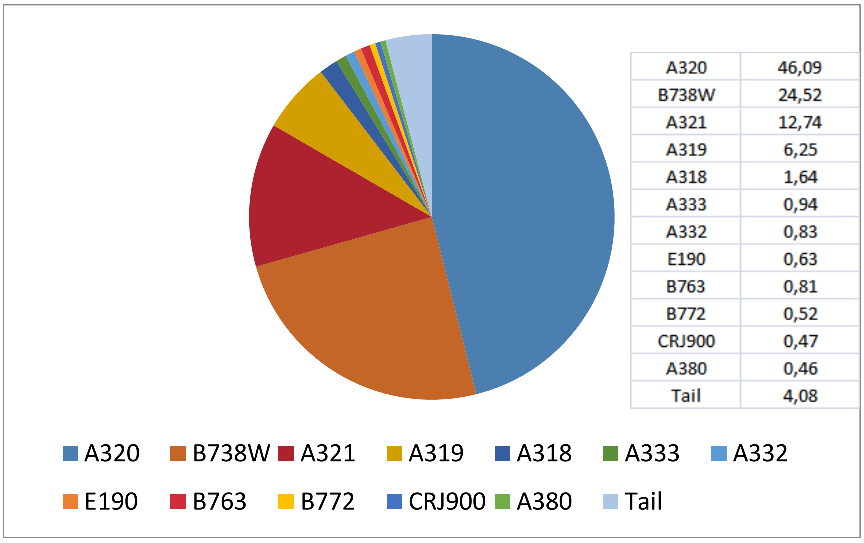


Figure 21: Characterization of the main 12 aircraft types.
Source: Own

Knowing the operation terminal of each airline, the different terminal activity has been set, showing that a 65% of the operations are in the T1, a 27% in T2B and an 8% in T2A. It's useful to know the aircraft type share by terminal, for the assessing of taxi distances and handling requirements, after in the model.

Below is presented a figure with the percentage distribution of aircrafts types by terminals, that differs from the same terminal share mentioned before, due this share is considering the summation of aircrafts with the same engine that may not belong to the same airline. This terminal share is: 70% T1, 4% T2A and 26% for T2B. This aircraft sharing terminal is used for the further methodology calculations.

Terminal usage per aircraft type (%)				
Aircraft	Total %	T1 %	T2A %	T2B %
A320	46	90	5	5
B738W	24.5	19	1	80
A321	12.7	93	7	0
A319	6.2	85	1	14
A318	1.6	100	0	0
A333	0.94	98	0	2
A332	0.83	98	2	0
E190	0.63	59	10	31
B763	0.81	98	0	2
B772	0.52	88	12	0
CRJ900	0.47	100	0	0
A380	0.46	100	0	0
Tail	4.08	68	9	23

Table 9: Terminal usage per aircraft type (%)
Source: Own

3.3 MODELING

In this part of the chapter are going to be explained how the data has been modeled, with the purpose of quantifying the total pollutant and GHG emissions. The modeling has been split in three parts:

- Taxi magnitudes: where the distances traveled across the airport by the aircrafts and the handling vehicles are set.
- LTO cycles: where the aircrafts emissions calculation methodology is described.
- Handling activities: where the handling vehicles (GSE) are described as well as methodological paths for the emissions calculation.

3.3.1 LEBL Taxi magnitudes (aircraft and handling)

Aircrafts taxi magnitudes

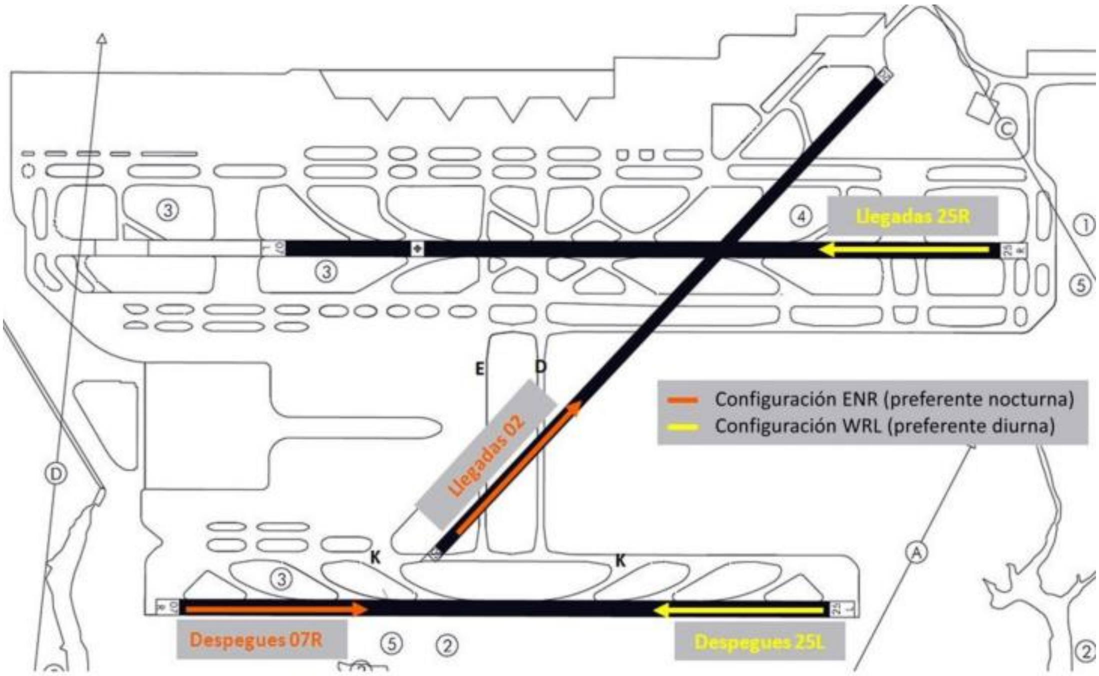
For establishing the taxi distances to each aircraft, an approximation trough Google Maps has been made using the scale factor and measuring the distances of each runway and accesses[3].

The distances between the exit of the landings runways to an averaged anchorage point per terminal (where TAP occurs), and from that point to the head of the departure runway, has been set as the taxi distance for all LTO configurations. The LTO configuration describes which runways are used for the landing and takeoff procedures.

According to the Director plan of LEBL and El Prat City Council, a predominant configuration is set, the West one for the day and the East one during the night. This is the less harming configuration in terms of noise and pollution for the local areas, because during the night period the landings are made from the sea (over runway 02) and the departures are made over the runway 07R (the one next to the sea, and is mandatory to head into the sea during the climb out once the takeoff is completed). With this configuration, take off's during the day are performed from the runway 25L (as well as the night period but on the opposite way) and the landings are performed on the runway 25R.

Previous studies of LEBL determine that this configuration works an 85% of the total time, and the variations of configurations are due meteorological issues. So, for this project, it will be considered this configuration as the only one for the distance calculation. Also, just a 5% of the data taken corresponds to the night period.

Below are presented the taxi distances for the aircrafts for any possible configuration, the highlighted distances belong to the previous defined configuration.



3 The annex 3.2 shows how the airport has been schematized for the distance determination, the terminals localization and a table with the distances associated to each taxi way (annex 3.2)

Aircraft's taxi phase distances (km)							
Distances From/to (km)		**T1**			**T2**		
		North	**Spine**	**South**	**Terminal**	**Teast**	**Tweast**
Landing	**25R**	**1,4**	**1**	**1,7**	**0,9**	**1,7**	**1,1**
	25L	2	1.3	0.7	2.3	3	3.5
	07R	2.5	1.5	1.7	2.1	3	3.8
	07L	2	2.5	2.5	1.8	1.3	3.2
	02	2.7	2.6	2.8	1	0.7	2.7
Departure	**25R**	3.7	2.6	4.3	2.4	1.7	3.9
	25L	**3.4**	**2**	**2.5**	**6.4**	**5.3**	**4.8**
	07R	3	2.2	0.4	5.6	3.6	4.5
	07L	0.6	2	3.4	1.8	2.9	0.6
	20	4.1	5.4	5.3	1.6	0.7	2

Table 10: Aircraft taxi distances. Teast corresponds to T2A, Ramp 3. TWeast corresponds to T2b, Ramp 1 (FIGURE 22). Highlighted (and green arrows on the image above): Day period; underlined (and orange arrows on the image above): night period. Source: Own. The image above belong to the newsletter IN-021 (4/2014)

Notice that T2C hasn't been considered for the modeling, due actually this terminal is just used for the passenger's distribution around the terminal 2, and there are no boarding activities from this terminal to the airplanes.

Handling taxi magnitudes

To determinate the handling distances over LEBL, the two service points (one per terminal) have been located. The T1 service point is located at the beginning of the spine and the T2 service point is just in the middle of the terminal. From these two points, all the GSE (Ground Support Equipment) and handling vehicles goes to the stands, do their labor and then return to the service point. It is considered that every vehicle needs to return to the service point after attending an aircraft.

The distances established to attend the stands is the average distances between all stands in the terminal and the service point. On the annex[4] are presented the schemas of the airport, and which stands belong to T1, T2A and T2B and the ramps associated.

It is considered that Ramps 0 and 4 (and the stands associated) does not belong to T2 in terms of commercial passenger flights, as the ramp 0 is used for the corporative aviation and ramp 4 is usually designated to cargo flights and "sleeping area" for the aircrafts.

For T1, the average distance between SPT1 (service point) and all the T1 stands is set at 0.35 meters. For T2A (ramps 3 and half part of ramp 2), the average distance SPT2-stands is set at 682.5 meters. For T2B (ramp 1 and the resting part of the 2), the distance is set at 692 meters. These values are multiplied by 2 on the model, for considering the travel back to the service point. Below is presented a schema of the airport, showing all the references used for the calculations.

[4] See annex 3.2. El Prat airport scheme

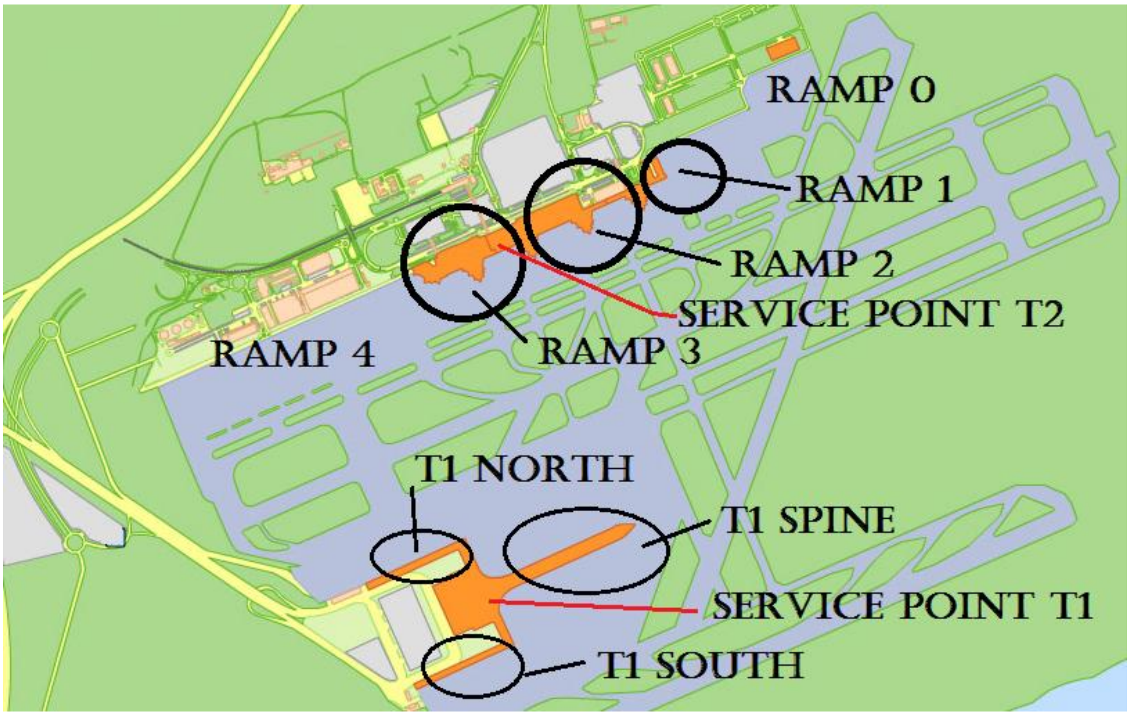


Figure 22: Schema of El Prat airport. The T2A contains the ramp 3 and the half of the ramp 2. T2B contains the rest of the ramp 2 and the ramp 1. The ramp 0 is used by the corporative aviation and the ramp 4 is the zone for the cargo flights.
Source: mapametrobarcelona

Taxi velocities

According to LEBL's policies, the aircrafts and the handling vehicles cannot exceed a velocity of 15km/h when circulating along the taxi ways. For the modeling, this velocity has been fixed as a constant value, considering that the aircrafts and the vehicles do straight their taxi travels without stopping.

The taxi travels may include stop and go operations according to the operating vehicle's density of the airport. During the stop and go, the fuel regime consume is higher than the regime when circulating, thus the fuel consumption for a "stop and go modeling" could have higher values than the constant speed model (the used one). This fact will be considered on the Simapro methodology chapter, where the vehicle's regime consumption (liters fuel/km) is set.

3.3.2 LTO cycles

With the aim of quantify LEBL's emissions from aircraft engines, two approaches are made: one trough the EPA model (based on ICAO) and another from the ICAO's engine data sheet.

The EPA modeling results will be used to determinate the total LEBL's aircraft emissions, as the characterization of pollutants are more detailed in this model than the ICAO's data sheets[5]. Tough, the ICAO data sheets are going to be used to compare which phase within the LTO cycle has more emissions assessed. Moreover, a result comparison between the two models will be carried, using the pollutants characterized for both models.

[5] See annex 3.3. Aircraft emission factors for EEA and ICAO data sheet engines.

EEA model

The European Environmental Agency (EEA) developed a tool called “master emission calculator for aviation”, where the emission per LTO cycle and aircraft types are quantified. In this document are defined the times for an LTO cycle for a busy European airport that differs from the American one, as it’s shown below, due the extended taxi times of the American airports.

Default LTO cycle times (hh:mm:ss)		
Phases	ICAO default	Default for a busy European airport, year 2015
Taxi	0:26:00	0:20:06
Take off	0:00:42	0:00:42
Climb out	0:02:12	0:02:12
Approach	0:04:00	0:04:00
TOTAL	**0:32:54**	**0:27:00**

Table 11: Time spent by the flight phases
Source: ICAO

EEA’s model doesn’t specify the emissions for each phase, being as final output the total emissions for one LTO of one specific aircraft for the following greenhouse gases and pollutants: CO_2, H_20, HC, NOx, SOx, CO and particulate matter.

For calculating the total aircraft emissions, the percentage of aircraft type has been multiplied for the total forecasted LTO cycles for 2017 (158,439 cycles) and then by the emission factor, resulting the total emissions for each aircraft type.

$$Aircraft\ 2017\ emissions = \sum emissions\ per\ aircraft\ type\ = Aircraft\ emissions * Forecasted\ LTO * \%\ Aircraft\ types$$

Also, the fuel burn per flight phase for one LTO cycle has been calculated multiplying the fuel flow (for each flight phase) by the time used at those phases. These results are calculated by engine, so they need to be multiplied by the number of engines mounted by the aircrafts.

$$Fuel\ consumed\ per\ LTO = \ Fuel\ flow * time * number\ of\ engines$$

ICAO’s emission databank (engines data sheet)

A second approach has been made through the ICAO’s emission databank. This contains a sheet per every engine, giving the emission factors and the fuel flow (according to the percentage of throttle required) for each flight phase. The limitation for this approach remains on the quantity of pollutants detailed, as ICAO just have certifications over HC (Hydrocarbons), CO and NOx.

The emission factors for the PM_{10} are not regulated equally as the other pollutants, and the engine manufacturers are not transparent with this kind of data. Thus, in these sheets are quantified the “smoke number”, which contemplate all solid particles exhausted from the engines, not just the PM_{10}.

The engine type used for each aircraft is the defined by ICAO, the most common engine in 2015 used for mounting this aircraft type. The engine models are the following ones:

Types of engines used		
Aircraft	Engine ID	Number of engines
A320	3CM026	2
B738	8CM051	2
A321	3IA008	2
A319	3CM027	2
A318	7CM048	2
A333	14RR071	2
A332	14RR071	2
E190	11GE146	2
B763	12PW101	2
B772	8GE100	2
CL900RJ	8GE110	2
A380	8RR046	4
B752	5RR038	2

Table 12: Engines used according to the aircraft type.
Source: ICAO’s engines data sheets.

The emissions calculation procedure is the same than the EEA model, but having in mind the exactly emission factors for each flight phase. The fuel burn has been as well calculated using the fuel flow for each LTO phase.

$$LTO\ emissions\ by\ flight\ phase = Fuel\ flow\ per\ phase\ \left(\frac{Kg}{h}\right) * time(h) * Emission\ factor * Forecasted\ LTO * \%\ aircraft\ type * number\ of\ engines$$

Aircraft Taxi phase

This part of the LTO modeling is focused on the calculation of the time spent by the aircrafts during the taxi phase, just using the taxi magnitudes calculations, explained above. This calculation won’t be used as a parameter for the emissions quantification, instead are used to determinate the averaged taxi time for LEBL, making a possible comparison between the taxi times set for ICAO.

Thus, this result doesn't have an influence over the emissions calculation. Moreover, the fuel spent can be as well calculated.

For the modeling of this phase, the table 9 is used (in this figure is shown how are shared all the aircrafts at the different terminals). Combining this information with the taxi distances for the West configuration (table 10), the total distance traveled by aircraft type can be obtained. The taxiways chosen are the shortest ones without crossing any runway.

For the determination of the distances traveled by the aircrafts with anchorages at T1, the average distance between the three parts of T1 (during the day) is set as the LTO taxi phase distance (4,090 meters).

For T2A, the distance has been set as the LTO day on Terminal (7,338 meters), and for T2B, T2Weast is chosen (5,950 meters).

Thus, multiplying the total LTO cycles, the aircraft types and the terminal percentage by the distance traveled per LTO, the total taxi distances for 2017 are obtained by aircraft type and terminal. This number can be transformed into time required for traveling that distance by using a maximum allowed velocity of 15km/h.

Having the time spent by each aircraft going to any terminal and the fuel flow associated to the taxi phase, the total fuel burned is calculated. Then, the ICAO's Data Sheet Engine emission factors are used to obtain the total emissions associated to the taxi phase of LEBL. The next table shows the emission factors used in taxi (IDLE) phase and the calculations previous to the results.

ICAO Data Sheet. Taxi phase emission factors				
g emitted / kg fuel*engine	HC IDLE	CO IDLE	NOx IDLE	SM IDLE
A320	4.6	23.4	4.3	0.5
B738W	1.9	18.8	4.7	0
A321	0.1	9.317	5.2	2.4
A319	6.2	30	3.8	0.6
A318	6.5	32.9	3.4	0.6
A333	2.46	23.97	4.6	0.2
A332	2.46	23.97	4.6	0.2
E190	4.02	41.73	3.6	0.5
B763	11.63	44.46	3.7	0.1
B772	0.41	12.69	6	2.5
CRJ900	0.1	18.2	4.6	0
A380	0.2	15.1	5.1	0.7
Tail	0.27	20.3	4.4	0.4

Table 13: Taxi phase emission factors
Source: ICAO engine data sheets.

Time spent, total distances traveled and fuel consumption for the taxi phase													
AC type	**% AC**	**2017 LTO's**	**T1 %**	**T2A %**	**T2B %**	**T1 travels (km)**	**T2A travels (km)**	**T2B travels (km)**	**Total (km)**	**Hours**	**Fuel Flow**	**Engines**	**Fuel burned (T)**
A320	46	73019	90	5	5	1.8E+05	2.9E+04	6.6E+04	2.8E+05	1.8E+04	374	2	1.4E+04
B738 W	24.5	38856	19	1	80	2.4E+04	2.5E+03	1.8E+05	2.1E+05	1.4E+04	406	2	1.1E+04
A321	13	20188	93	7	0	5.9E+04	9.3E+03	3.1E+02	6.9E+04	4. 6E+03	489	2	4.5E+03
A319	6	9901	85	1	14	1.6E+04	7.6E+02	2.9E+04	4.5E+04	3.0E+03	338	2	2.0E+03
A318	1.6	2604	100	0	0	8.2E+03	0.0E+00	0.0E+00	8.2E+03	5.4E+02	338	2	3.7E+02
A333	1	1495	98	0	2	4.6E+03	0.0E+00	1.5E+02	4.8E+03	3.2E+02	972	2	6.2E+02
A332	1	1315	98	2	0	4.0E+03	1,9E+02	0.0E+00	4.2E+03	2.8E+02	972	2	5.5E+02
E190	0.5	1006	59	10	31	1.9E+03	7.6E+02	1.8E+03	4.5E+03	3.0E+02	316	2	1.9E+02
B763	1	1289	98	0	2	4.0E+03	0.0E+00	1.5E+02	4.1E+03	2.7E+02	741	2	4.1E+02
B772	0.5	825	88	12	0	2.3E+03	7.6E+02	0.0E+00	3.0E+03	2.0E+02	1065	2	4.3E+02
CRJ900	0.47	748	100	0	0	2.3E+03	0.0E+00	0.0E+00	2.3E+03	1.6E+02	230	2	7.2E+01
A380	0.46	722	100	0	0	2.3E+03	0.0E+00	0.0E+00	2.3E+03	1.5E+02	1080	4	6.5E+02
Tail	4.08	6472	68	9	23	1.4E+04	4.2E+03	8.9E+03	2.7E+04	1.E+03	648	2	2.3E+03

Table 14: Time spent, total distances traveled and fuel consumption for the taxi phase
Source: Own

3.3.3 Handling activities

In this chapter are described the methods used for the pollutant emission calculation over the ground handling activities. Fourteen different activities have been determined, involving 14 different GSE (Ground Support equipment). Aldo, the APU (Auxiliary Power Unit) is introduced into the model.

Ground Support equipment

Below is presented a table with all the vehicles associated to the handling operations. It is shown the power of the engine, the vehicle type (Heavy Duty Vehicles >3.5 tons [HDV] or Light Duty Vehicles < 3.5tons [LDV]), and the load factor associated [6].

GSE	Description	Vehicle type	Power (kW)	Load (%1)
	Cars (Follow me, coordinator)	LDV	60	0.5

[6] Engine's power and load factors data have been taken from an emission environmental report at Zurich airport (2004).

	Line Maintenance Truck	LDV	70-120	0.25
	Baggage Kart	LDV	53-60	0.25
	Water truck	HDV	127	0.25
	Catering truck	HDV	85-130	0.1-0.25
	Refueling Dispenser truck	HDV	66-110	0.1-0.5
	Refueling truck	HDV	90	0.1-0.2
	Cleaning	HDV	132	0.1-0.6
	Cargo tapes	HDV	33	0.25
	Stair trucks	HDV	30-65	0.25

	Buses	HDV	100	Euro 2*
	GPU	HDV	105-149	0.5
	Narrow body Tugs	HDV	95	0.25
	Wide body Tugs (A330200/300, A380, B772)	HDV	400	0.25
	Mobile Air conditioner	HDV	150	0.5

Table 15: Types of GSE. *The emission factors of the buses used contemplates the load factor.
Source: environmental report at Zurich airport (2004).

Emission factors

Two sets of emission factors are used, the EEA (Environmental European Agency) and the NRME European directive (Non-Road Machinery Emissions). This is due a complementarily reason, as the EEA emission factors doesn't include data over the particulate matter.

So, the emission EEA emission factor is used to characterize and quantify all the gasses emissions and the NRVE emission factor is used to determine the particulate matter emissions.

<u>EEA Emission factors</u>

The EEA Emission Inventory guidebook for diesel heavy and light duty vehicles is showed below in grams emitted by MJ (mega joule) of energy consumed. The light duty vehicles are: the follow me, the coordinator, the baggage karts and the maintenance vehicles, the rest are considered heavy duty vehicles.

EEA emission factors		
g/MJ	**LDV**	**HDV**
NOx	0.373	0.995
CH_4	0.001	0.006
VOC	0.109	0.192
CO	0,412	0,857
N_20	0.004	0.003
CO_2	73.8	73.8

Table 16: EEA emission factors for Heavy and Light Duty Vehicles.
Source: Environmental European Agency.

Using this emission factors, implies the conversion of the kWh consumed by each activity into MJ (1kWh is equal to 3.63 MJ).

Non-road machinery and vehicles emission standards

The non-road machinery and vehicles emission standards of the European Union (Directive 97/68/EC) categorize the emissions factors according to the engines power, in kW, and according to the directive implementation stage. It is considered that the fleet vehicles of LEBL have an average life of 10 years, so the Stage IIIA emission factors are the ones introduced in the model.

Non-Road Machinery and Vehicles Emission Factors						
g/kWh	Power (kW)	CO	HC	NO_X	PM	Directive Year
Stage 1	37-75	6.5	1.3	9.2	0.85	2001
	75-130	5	1.3	9.2	0.7	
	130-560	5	1.3	9.2	0.54	
stage 2	18-37	5.5	1.5	8	0.8	2001
	37-75	5	1.3	7	0.4	2004
	75-130	5	1	6	0.3	2003
	130-560	3.5	1	6	0.2	2002
Stage IIIA	19-37	5.5	1.1	6.4	0.6	2007
	37-75	5	0.7	4.0	0.4	2008
	75-130	5	0.6	3.4	0.3	2007
	130-560	3.5	0.6	3.4	0.2	2006
Stage IIIB	37-56	5	0.7	4.0	0.025	2013
	56-75	5	0.19	2	0.025	2012
	75-130	5	0.19	3.3	0.025	2012
	130-560	3,5	0.19	3.3	0.025	2011
Stage IV	56-130	5	0.19	0.4	0.025	2014
	130-560	3,5	0.19	0.4	0.025	2014

Table 17: NRMV emission factors.
Source: Directive 97/68/EC

Thus, for both set of emission factors, the energy consumed (in MJ and kWh) by activity and vehicle is needed.

Handling activity time

For establishing the energy consumption, is necessary to determinate the time spent for the vehicles traveling the airport distances and for carrying their activities. These distances are established in the chapter 3.3.1, by each terminal. For the follow me car, it has been set the same distance established for the aircraft taxi modeling (from the runway to the anchorage and from there to the departure runway). Then, these distances traveled at a maximum speed of 15km/h, gives the time usage of the handling engines.

For the Baggage Karts, it is considered that they travel the double of distance in comparison with the other GSE due they need to go back to the aircraft stand (after the baggage discharge at the service point) to pick up and transport the new passenger baggage's to the airplane.

Traveled distances by the GSE vehicles						
	Distances (km)	Follow me (km)	Rest GSE (Km)	Baggage karts (min)	Follow me (minutes)	Rest GSE (minutes)
SPT1	**T1**	4	0.7	5.6	16	2.8
SPT2	**T2A**	6.3	1.38	11.02	25	5.51
	T2B	6.8	1.39	11.07	27	5.53

Table 18: Traveled distances by the GSE vehicles according to the terminal
Source: Own

Moreover, the activity time related with the operation of each vehicle is set according to the type of aircraft (long haul or short haul). This set of time is extracted from the document "Emissions from Aircraft and Handling Equipment in Copenhagen Airport", showed below.

GSE activity time		
Minutes	Long Haul	Short haul
Follow me	0	0
Coordinator	0	0
Maintenance	0	0
Karts	0	0
Water services	15	7
Catering	5	3
refueling	30	12
Cleaning	20	10
Cargo tape	40	20
Stair trucks	0	0
Buses	0	0

Table 19: GSE activity time, according to the aircraft type.
Source: Emissions from Aircraft and Handling Equipment in Copenhagen Airport

Thus, this time needed to fulfill the requested aircraft preparation is added to the time travels mentioned before, showed on the next time table per vehicle.

Total time spent by handling vehicle, terminal and aircraft type

Handling times (min)	Aircraft type	Follow me	Coordinator	Maintenance	Karts	Water services	Catering	refueling	Cleaning	Cargo tape	Stair trucks	Buses
T1	Short haul	16.4	2.8	2.8	5.7	9.8	5.8	14.8	12.8	22.8	2.8	2.8
	Long haul	16.4	2.8	2.8	5.7	17.8	7.8	32.8	22.8	42.8	2.8	2.8
T2A	Short haul	25.2	5.5	5.5	11	12.5	8.5	17.5	15.5	25.5	5.5	5.5
	Long haul	25.2	5.5	5.5	11	20.5	10.5	35.5	25.5	45.5	5.5	5.5
T2B	Short haul	27.2	5.5	5.5	11.1	12.5	8.5	17.5	15.5	25.5	5.5	5.5
	Long haul	27.2	5.5	5.5	11.1	20.5	10.5	35.5	25.5	45.5	5.5	5.5

Table 20: Total time spent by handling vehicle, terminal and aircraft type
Source: own

Operation factor modeling

The operation factor has been used in the model for determining the number of vehicles needed per aircraft to attend their needs, and in which percentage the aircrafts need that specific activity. The next table is an example used for the T1[7].

Vehicles needed per TAP										
	Coordinator	**Maintenance**	**Karts**	**Water service**	**Catering**	**Refueling**	**Cleaning**	**Cargo tape**	**Stair trucks**	**Buses**
A320	1	1	1	1	1	1	1	1	2	3
B738	1	1	1	1	1	1	1	1	2	3
A321	1	1	1	1	1	1	1	1	2	3
B736	1	1	1	1	1	1	1	1	2	4
A318	1	1	1	1	1	1	1	1	2	2
A319	1	1	1	1	1	1	1	1	2	2
A330200	1	1	2	1	1	1	1	2	2	6
A330300	1	1	2	1	1	1	1	2	2	6
A380	1	1	4	1	1	1	1	2	2	12
B772	1	1	2	1	1	1	1	2	2	6
CRJ900	1	1	1	1	1	1	1	1	2	2
E190	1	1	1	1	1	1	1	1	2	2
Tail	1	1	1	1	1	1	1	1	2	3

Table 21: Vehicles needed per one Turnaround Process
Source: Own

Excepting the baggage karts, the stair trucks, the buses and the cargo tapes, the number of vehicles needed is just one per aircraft. For the buses, it is assumed that one bus can carry 70 passengers, so dividing the maximum capacity of the aircrafts (multiplied by the occupancy factor determined by ICAO as 80%) by 70, the number of buses per aircraft type is set. The same happens for the baggage karts. Every Kart can carry 4 baggage wagons, and it's possible to fit 50 baggage at one wagon.

About the cargo tape, its assumed that one tape it's enough for the short haul aircraft types, and 2 tapes are needed for the long-haul ones (A330200/300, A380 and B772).

Number of Buses, Karts and kart wagons required per aircraft type				
	Seats	Buses	Karts	Baggage karts
A320	180	2	1	3
B738	175	2	1	3

[7] See annex 3.4. Operation factor modeling used for T2A and T2B.

A321	186	2	1	3
B736	260	3	1	4
A318	132	2	1	2
A319	156	2	1	2
A330200	406	5	2	6
A330300	440	5	2	7
A380	853	10	3	14
B772	440	5	2	7
CRJ900	90	1	1	1
E190	124	2	1	2
Tail	239	3	1	4

Table 22: Number of Buses, Karts and kart wagons required per aircraft type.
Source: Own

Furthermore, not all the aircrafts are having all the activities during the same TAP. Usually, low cost airlines fill the fuel tank once every two LTO cycles, and the cleaning operations are made by the same flight crew. Now is presented, in percentage over one, the activities deployed per aircraft for T1. Follow me, baggage karts, maintenance and coordinator vehicles are not presented as they are always present in any TAP (percentages for these vehicles are always equal to 1).

Percentage of activities deployed per aircraft type. Values for T1							
A320	Water services	Catering	refueling	Cleaning	Cargo tape	Stair trucks	Buses
B738	0.25	0.6	0.5	0.2	1	0.5	0.2
A321	0.25	0.6	0.5	0.2	1	0.5	0.2
B736	0.25	0.6	0.5	0.2	1	0.5	0.2
A318	0.25	0.6	0.5	0.2	1	0.5	0.2
A319	0.25	0.6	0.5	0.2	1	0.5	0.2
A330200	0.25	0.6	0.5	0.2	1	0.5	0.2
A330300	1	1	1	1	1	0	0
A380	1	1	1	1	1	0	0
B772	1	1	1	1	1	0	0
CRJ900	1	1	1	1	1	0	0
E190	0.25	0.6	0.5	0.2	1	0.5	0.2
Tail	0.25	0.6	0.5	0.2	1	0.5	0.2

Table 23: Percentage of activities deployed per aircraft type. The values belong to T1.
Source: Own

It's considered that the long-haul aircrafts will be provided of every activity, and that they will have priority over the stands with a direct connection to the terminal (by fingers), so buses are not required. For the rest of planes, it's considered that not everyone is going to be provided of all activities, as they already did those activities in other airports, obtaining these percentages over 1. The percentage activity assessed to water service, catering, refueling and cleaning are the same for T1 and T2.

For the determination of stair trucks and buses percentage, the type of stand per terminal has been analyzed, considering that all the remote stands needs of a couple of stair truck per aircraft. On the other hand, not all remote stands needs of buses, due that some parking slots does not have finger but are in contact with the terminal. The next table shows the variation of this requirement for the terminals.

Stair truck vehicles and buses needed per terminal				
Stands	Remote	Finger	% Remote (stairs needed)	% buses needed
T1	51	50	0.50	0.2
T2A	24	15	0.62	0.4
T2B	24	15	0.62	0.4

Table 24: Stair truck vehicles and buses needed per terminal.
Source: Own

Usage of emission factor

EEA Emission Inventory guidebook

As commented before, knowing the time usage of the engines can be multiplied by the power of the engines, and then this consumption data can be transformed into MJ. Multiplying the energy consumed, the emission factor, the operation factor modeling and the percentage of aircraft types per terminal, the total emissions are found. Those results must be normalized according to LEBL operations, so it's needed to multiply them by the total 2017 LTO cycles

$$\begin{aligned} Vehicles\ emissions &= Energy\ consumed\ per\ activity\ (MJ) * Emission\ factor \\ &* Number\ of\ vehicles\ required\ per\ aircraft * Percentage\ of\ needed\ activity \\ &* \%\ Aircraft\ type * Forecasted\ LTO\ cycles \end{aligned}$$

Non-road machinery and vehicles emission standards

On this approach, the emission factors are given in consume terms (kWh). Knowing the activities working time, can be multiplied by the emission factor, the load factor, the engine power and the operation factor modeling, resulting the total emissions per activity and aircraft.

$$Vehicles\ emissions = Energy\ consumed\ per\ activity\ (kWh) * Emission\ factor * Load\ factor * Number\ of\ vehicles\ required\ per\ aircraft * Percentage\ of\ needed\ activity * \%\ Aircraft\ type * Forecasted\ LTO\ cycles$$

Below, is presented a figure with the activity time per handling vehicle at the terminals, as well as the consumption energy in kWh and MJ. The first table corresponds to the short haul aircrafts and the second one to the long-haul aircrafts.

Total energy consumed per vehicle and terminal for attending a short-haul aircraft						
	KWH			**MJ**		
	T1	**T2A**	**T2B**	**T1**	**T2A**	**T2B**
Follow me	16.4	25.2	27.2	58.9	90.7	97.9
Coordinator	2.8	5.5	5.5	10.2	19.9	19.9
Maintenance	5.7	11	11.1	20.4	39.7	39.9
Karts	5.7	11	11.1	20.4	39.7	39.9
Water services	19.2	24.4	24.4	69.0	87.9	88.0
Catering	12.6	18.5	18.5	45.5	66.4	66.6
refueling	27.2	32.1	32.1	97.9	115.6	115.7
Cleaning	28.2	34.1	34.2	101.6	122.9	123.0
Cargo tape	12.6	14.0	14.0	45.2	50.5	50.6
Stair trucks	3.1	6.0	6.0	11.0	21.5	21.6
Buses	4.7	9.2	9.2	17.0	33.1	33.2

Table 25: Total energy consumed per vehicle and terminal for attending a short haul aircraft.
Source: Own

Total energy consumed per vehicle and terminal for attending a long-haul aircraft						
	KWH			MJ		
	T1	T2A	T2B	T1	T2A	T2B
Follow me	16.4	25.,2	27.2	58.9	90.7	97.9
Coordinator	2.8	5.5	5.5	10.2	19.9	19.9
Maintenance	5.7	11	11.1	20.4	39.7	39.9
Karts	5.7	11	11.1	20.4	39.7	39.9
Water services	34.8	40.0	40.0	125.2	144.0	144.2
Catering	17	22.8	22.8	61.1	82	82.2
refueling	60.2	65.1	65.1	216.7	234.4	234.5
Cleaning	50.2	56.1	56.2	180.8	202.1	202.2
Cargo tape	23.6	25.0	25.0	84.8	90.1	90.2
Stair trucks	3.1	6.0	6.0	11.0	21.5	21.6
Buses	4.7	9.2	9.2	17.0	33.1	33.2

Table 26: Total energy consumed per vehicle and terminal for attending a long haul aircraft.
Source: Own

Other GSE: Tugs, APU, Air Conditioner, GPU

These vehicles and the APU are the remaining source of pollutant emissions to be characterized and quantified. For methodological reasons haven't been included on the previous vehicles descriptions and calculations, due these activities have some constrains within, explained below per each vehicle. Even so, both set of emission factors are used in the same way than the vehicles on the previous chapter.

Tugs

Tugs are the vehicles used to push the aircrafts that are parked in contact with the terminal. The modern aircrafts dispose of an autonomous pushback system, but for the model it will be considered that all in contact stands will require of a tug for the pushback (moreover, airport policies restrict the main engine start up when in contact with the terminal). Thus, for T1 the pushback is needed in a 90% of the aircrafts (due the 90% of the stands are in contact with the terminal). For T2A and T2B pushback is used in every contact stand, so for these terminals a 38% of the aircrafts will need a pushback.

The pushback duration is set at 5 minutes for el Prat airport. For the short-haul aircrafts, a power of 95Kw is needed and for the long-haul aircrafts, a 400Kw tug is required.

For the calculation of tug's time usage, the time travel average from the service points to the stands per terminal is added to the time required for the pushback (5 min). Thus, the tug time usages by terminal are 7.83, 10.51 and 10.53 minutes for T1, T2A and T2B, respectively.

Tug's emissions can be calculated by terminal using the methodology followed for the GSE (Non-road machinery and vehicles emission standards, using the stage I emission factors and the EEA's emission inventory guidebook for heavy duty vehicles)

$$Tugs\ emissions\ (EEA) = Energy\ consumed\ (MJ) * Emission\ factor\ (\frac{Kg}{MJ}) * Percentage\ of\ needed\ activity * \%\ Aircraft\ type * Forecasted\ LTO\ cycles$$

$$Tugs\ emissions\ (NRME) = Energy\ consumed\ per\ activity\ (kWh) * Emission\ factor * Load\ factor * Percentage\ of\ needed\ activity * \%\ Aircraft\ type * Forecasted\ LTO\ cycles$$

Ground power units and Auxiliary power units

Auxiliary power units (GPU and APU), are energy sources that provides electrical energy to the aircraft while the main engines are not running. The electrical needs of the aircraft are the system functionality, the cabin air renewal, the cooling and heating systems and the main engine start operations.

This energy is provided by the APU or a ground power unit, depending on the type of stand, the airport procedures restrictions and the duration of the TAP.

In the case of LEBL, the turnaround process duration set in the model has been 35 minutes for the short haul and 75 minutes for the long-haul aircrafts. Moreover, LEBL's has a restriction over the usage of APU's, as is indicated in an environmental study made by the government of Catalonia. This document says that the aircraft anchored in contact with the terminal can run the APU a maximum of 7 minutes. For the remote stands, APU can be running a maximum of 20 minutes for the short haul aircraft and 65 minutes for the long haul. Below is presented a table with the usage times of this two power units for one turnaround process.

It is considered the preference of Long haul aircrafts at the contact stands; they are always in contact stands. Furthermore, LEBL dispose of a decentralized network of energy and air that provides to the aircraft the energy required without using mobile GPU or the APU, so for the aircraft in contact with the terminal there are no GPU operations. But, for the man engine start operations, APU is always needed (this operation is done after the pushback operation).

APU time usage according to the type of stand and aircraft type (minutes)

	APU		GPU		TAP time	
	Remote	Contact	Remote	Contact	Remote	Contact
Short haul	20	7	15	0	25	35
Long haul	0	7	0	0	0	75

Table 27: APU time usage
Source: ICAO, Airport Air Quality Management

Thus, knowing the time usage per equipment, having the aircraft share per terminal, and the type of stand per terminal; the emission factors can be applied: the non-road vehicles, stage 1 emission factors for the GPU and the ICAO's emission factors for APU's (from the document Airport quality manual). In this document are set the pollutants emissions for a specific period, 45 minutes and 75 minutes for short and long haul respectively. Assuming the same fuel flow usage during all the time, the emissions for 20 and 7 minutes can be found, as it's shown on the next figure.

APUs fuel burn and gasses emissions according to the time of usage

	ICAO Default		Remote Stand		Contact Stand	
	short haul	**long haul**	**short haul**	**long haul**	**short haul**	**long haul**
fuel burn (kg)	**80**	**300**	**35.6**	**28**	**12.4**	**28.0**
Duration	**45**	**75**	**20.0**	**7**	**7.0**	**7.0**
Nox (g)	700	2,400	311.1	224	108.9	224.0
HC	30	160	13.3	14.9	4.7	14.9
CO	310	210	137.8	19.6	48.2	19.6
PM10	25	40	11.1	3.7	3.9	3.7
Fuel flow (kg/m)	1.8	4	1.8	4.0	1.8	4

Table 28: APU fuel consumption and gas emissions.
Source: ICAO. Airport Air Quality Management

$$APU\ emisisons = (Emissions\ of\ remote\ stands * \%\ of\ aircraft\ types * \%\ remote\ stands * forecasted\ LTO) + (Emissions\ of\ contact\ stands * \%\ of\ aircraft\ types * \%\ contact\ stands * forecasted\ LTO)$$

As explained on the introduction (chapter 2.8), LEBL disposes of a decentralized energy and conditioned air system. This means that every contact stands have the capability of supplying energy and air to the aircrafts without using any mobile source. The electric and air cables can be plugged by the maintenance vehicle operator, and are fed by the electrical network of the terminals.

$$GPU\ emissions\ (EEA) = Energy\ consumed\ (MJ) * Emission\ factor\ \left(\frac{Kg}{MJ}\right) * \ \%\ Aircraft\ type * \%\ remote\ stands * Forecasted\ LTO\ cycles$$

$$GPU\ emissions\ (NRME) = Energy\ consumed\ per\ activity\ (kWh) * Emission\ factor * Load\ factor\%\ Aircraft\ type * \%\ remote\ stands * Forecasted\ LTO\ cycles$$

The time introduced on the GPU modeling corresponds to the time fixed per TAP plus the time required for travelling the service points distances per terminal (as explained on the 3.3.3, Handling activity time). Using the same methodology but with the NRVE emission factors, the emissions of PM_{10} are founded.

<u>Air conditioning vehicle</u>

This GSE is the one used to renew, cool or heat the cabin air. As before, the activity of this GSE depends on the type of stand used. For the contact stands, LEBL dispose of a decentralized air conditioning by a pipe system, so no vehicles are needed.

The time has been set as 3 minutes (activity time) plus the time traveling from the service points to the stands. Once the time is set per terminal (5.8 minutes, 8.51 and 8.53 for T1, T2A and T2B respectively), can be multiplied by the engine power to obtain the MJ consumed, the EEA emission factor, and the aircraft terminal distribution, knowing the total emissions assessed to the air conditioning activity. Using the same methodology but with the NRVE emission factors, the emissions of PM_{10} are founded.

$$AC\ emissions\ (EEA) = Energy\ consumed\ (MJ) * Emission\ factor\ \left(\frac{Kg}{MJ}\right) * \ \%\ Aircraft\ type * \%\ remote\ stands * Forecasted\ LTO\ cycles$$

$$AC\ emissions\ (NRME) = Energy\ consumed\ per\ activity\ (kWh) * Emission\ factor * Load\ factor\%\ Aircraft\ type * \%\ remote\ stands * Forecasted\ LTO\ cycles$$

3.3.4 ASSUMPTIONS

Now are explained the assumptions assimilated on the model.

- Every in-flight is going to make a daily LTO (so will be a departure per each arrival at the same day).
- Winglets aircrafts are considered the same in terms of consumption at low level flights and speeds.
- 15km/h is the maximum velocity which aircrafts and the handling vehicles can travel.
- It is considered that every vehicle needs to return to the service point after attending an aircraft.
- The aircraft taxi magnitudes have been set as the shortest way without crossing landing runways, using the airport's runways west configuration.
- The number of LTO cycles is set at 158,439.
- Constant aircraft type distribution for the whole year.
- Operation factor modeling: the number of vehicles needed per aircraft type and the percentage of activities deployed per aircraft.
- The refueling activity needs the same type of vehicle for contact and remote stands (even having a decentralized fuel pipeline for the contact stands)
- Electric energy supply and air conditioning activities don't require a vehicle when in contact stands.
- The NRME emission factors used corresponds to the stage IIIA (vehicles from 2004 to 2007).
- APU and GPU time restrictions in contact and remote stands.
- Long haul aircrafts always are going to perform their TAP in contact stands.
- Turnaround process duration set in the model are 25 minutes for the short haul and 45 minutes for the long-haul aircrafts

3.4 SIMAPRO

Simapro is a tool that allows the characterization and the quantification of the environmental impacts around processes or life cycle products through LCA methodologies. The goal of this part of the project is to quantify the environmental impacts for all LTO's cycles at LEBL and their associated handling activities.

The results obtained from the data modeling (the amount of emissions generated by the vehicles and by the aircrafts), are treated and used as an input for this software. In this chapter is explained how these inputs are treated and which methodological impact assessment has been followed.

As well, it's needed to establish the limits of the study; contained on the airside of the airport (it just will consider the direct environmental impacts of the airport activity involving aircrafts and the handling vehicles).

For the environmental impacts quantification, Simapro uses diverse types of "processes" according to the aim of the study. These processes contain parameters that reflect the environmental impacts assessed to the studies targets, and may involve any type of inputs and outputs (material or energetic inputs; and material, energetic and waste outputs) according to the aim of the study and their functional unit.

Two procedures can be followed for selecting those processes. First, is possible to check if the processes inside the software that are good enough to reflect the aim of the study. These processes already created have been programmed according other studies. Secondly, it's possible to create or edit processes inside the software, according to the own data of the projects.

For this project, the second editing procedure is used. Main processes have been selected for describing the environmental impact due the engines combustion, and the parameters contained on these processes (environmental emissions) have been substituted by the emission results obtained from the Modeling chapter. This is because the aim of the study is to quantify the final environmental impact of the airside part of the airport during 2017 due the LTO cycles and the associated handling activities. Moreover, the inventory of emissions is already found for each vehicle and aircraft, thus specific processes can be edited on Simapro, making a focused analysis of LEBL's environmental impact activities.

3.4.1 Functional unit

First, for this software is necessary to determinate a functional unit, which allows the comparison between the different airport vehicles and aircrafts trough one standardized unit.

Usually, for LCA's involving transport, the functional unit is set over the "kg of weight carried" or over "passengers". In this way, the environmental impact assessed per passenger or per Kg carried can be found. But, the aim of this project is to quantify the total environmental impact of LEBL's activities, thus it's possible to use "kWh" instead of "kWh/passenger" because the environmental impact results of "kWh/passenger" needs to be normalized multiplying them for the passengers carried per aircraft (which is an 80% of the total capacity according to the ICAO's reference).

So, the functional unit for the handling vehicles has been set as "kWh" of energy consumed. Through this functional unit applied on a process, the environmental impact generated in a combustion chamber for producing 1kWh of energy for moving a vehicle is known.

The functional unit for the APU's and the aircrafts has been set as Kg of kerosene burned in an aircraft engine.

3.4.2 Creation of processes

Once the functional unit is established, is necessary to create every process on Simapro. For all the GSE, the process "Energy, from diesel burned in machinery" is selected, that describes the energy produced by combusting diesel in (agricultural) machinery and their environmental impacts. Noticeably, GSE are not agricultural machinery but the typology of vehicles is similar, being both catalogued as non-road vehicles.

This process includes two considerations or "known inputs from the "techno sphere": the diesel consumption and the previous transport of that diesel from the refinery. The second consideration (the transport) has been erased from the process, due the limit of the study is set at the airside of the airport. So just is considered the diesel burned to produce 1 kWh, a process called in Simapro "Diesel, from crude oil, consumption mix, at refinery 200ppm suplhure EU-15". Moreover, this process does not have into account the combustion engines efficiency, which is a 20%. Thus, Simapro environmental impact results for all the GSE needs to be multiplied by 1.8 for considering the efficiency of the engines.

Also, this process has associated within a specific set of emissions to the air. This data has been substituted by the own emission factors presented below (Kg pollutant emitted/kWh*LTO) for each vehicle.

Kg gasses emitted / kWh for attending one LTO							
	NOx	**VOC**	**CO**	**N_20**	**CO_2**	**HC**	**PM**
Follow me	1.3E-03	4.0E-04	1.5E-03	1.4E-05	0.27	4.0E-04	2.0E-04
Coordinator	1.3E-03	4.0E-04	1.5E-03	1.4E-05	0.27	4.0E-04	2.0E-04
Maintenance	1.3E-03	4.0E-04	1.5E-03	1.4E-05	0.27	2.0E-04	1.0E-04
Karts	1.3E-03	4.0E-04	1.5E-03	1.4E-05	0.27	2.0E-04	1.0E-04
Water services	3. 6E-03	7.0E-04	3.1E-03	1.1E-05	0.27	2.0E-04	1.0E-04
Catering	3.6E-03	7.0E-04	3.1E-03	1.1E-05	0.27	2.0E-04	1.0E-04
refueling	3.6E-03	7.0E-04	3.1E-03	1.1E-05	0.27	5.0E-04	2.0E-04
Cleaning	3.6E-03	7.0E-04	3.1E-03	1.1E-05	0.27	6.0E-04	1.0E-04
Cargo tape	3.6E-03	7.0E-04	3.1E-03	1.1E-05	0.27	4.0E-04	2.0E-04
Stair trucks	3.6E-03	7.0E-04	3.1E-03	1.1E-05	0.27	3.0E-04	1.0E-04
Buses	3.6E-03	7.0E-04	3.1E-03	1.1E-05	0.27	1.3E-03	4.0E-04

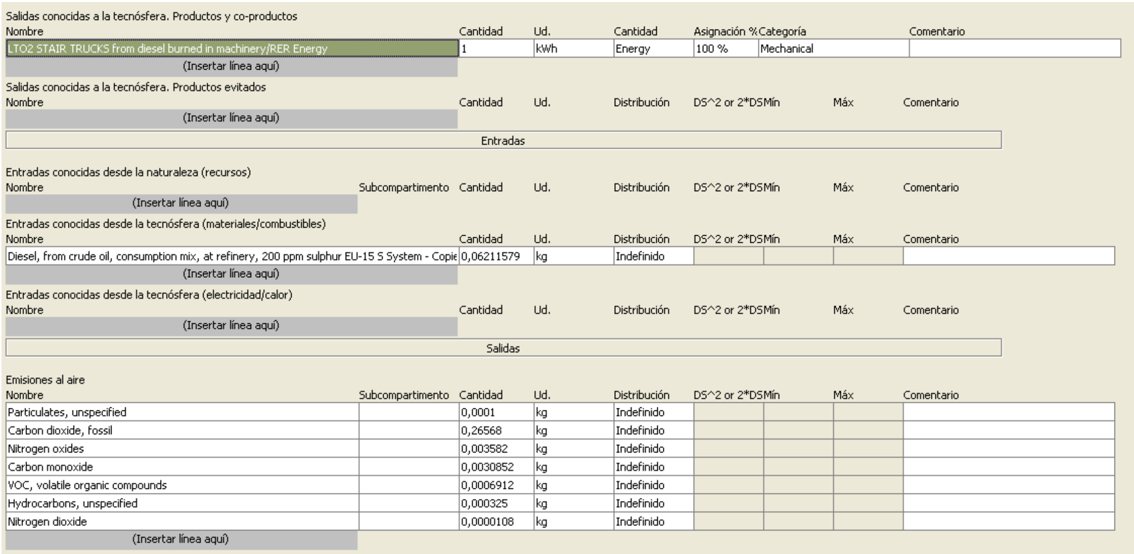
Table 29: Kg gasses emitted / kWh
Source: Own

For the Ground Power Unit and the air conditioning vehicles, the methodology followed is the same than before: having the engine's power, the operation time and the emission inventory, the kg of pollutants emitted per kWh is found. As these vehicles are considered heavy duty vehicles, the functional unit is the same than the previous heavy handling vehicles:

kg emitted/kWh*LTO (GPU, Air conditioning vehicles and Tugs)	
NOx	3.6E-03
HC	1.3E-03
VOC	7.0E-04
CO	3.1E-03
N_20	1.1E-05
CO_2	0.27
PM	1.0E-04

Table 30: Kg emitted/kWh*LTO (GPU, Air conditioning vehicles and Tugs)
Source: Own

For all the GSE, excepting the tugs, one process per vehicle has been created, introducing the standardization of the study at 1 kWh, the diesel burned (in Kg) for generating that kWh and the emissions related to that kWh. For the tugs two processes have been created, one for the long haul and another one for the short haul. This is because tugs use different power engines when pushing a short or a long haul aircraft. Instead, the other GSE uses the same power engine for both types of aircrafts, but in some activities, takes more time in a long haul aircraft. Below are presented two examples of the processes.[8]



Salidas conocidas a la tecnósfera. Productos y co-productos

Nombre	Cantidad	Ud.	Cantidad	Asignación %	Categoría	Comentario
LTO2 STAIR TRUCKS from diesel burned in machinery/RER Energy	1	kWh	Energy	100 %	Mechanical	
(Insertar línea aquí)						

Salidas conocidas a la tecnósfera. Productos evitados

Nombre	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
(Insertar línea aquí)							

Entradas

Entradas conocidas desde la naturaleza (recursos)

Nombre	Subcompartimento	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
(Insertar línea aquí)								

Entradas conocidas desde la tecnósfera (materiales/combustibles)

Nombre	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
Diesel, from crude oil, consumption mix, at refinery, 200 ppm sulphur EU-15 S System - Copie	0,06211579	kg	Indefinido				
(Insertar línea aquí)							

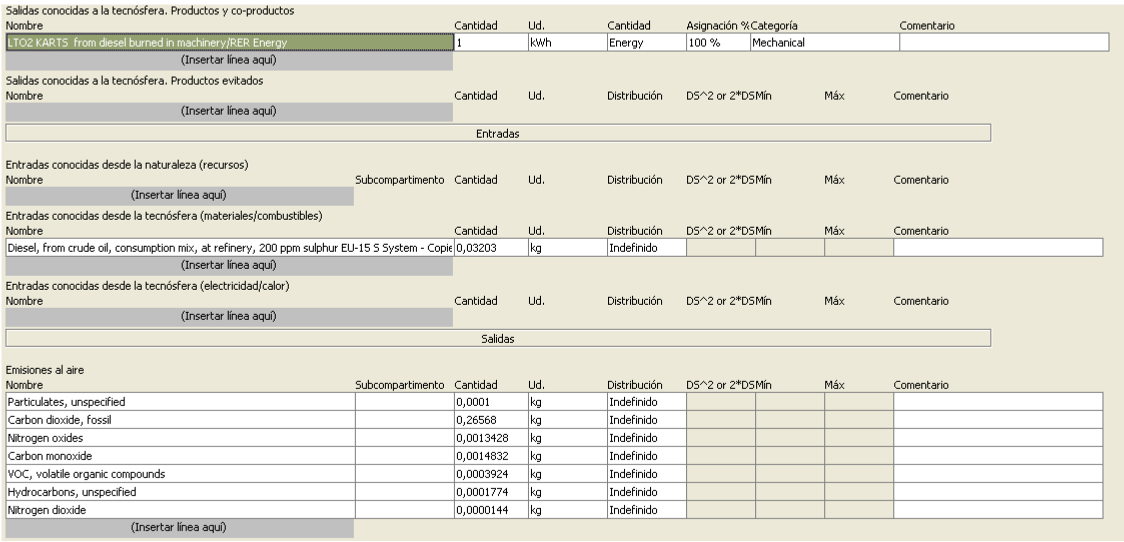
Entradas conocidas desde la tecnósfera (electricidad/calor)

Nombre	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
(Insertar línea aquí)							

Salidas

Emisiones al aire

Nombre	Subcompartimento	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
Particulates, unspecified		0,0001	kg	Indefinido				
Carbon dioxide, fossil		0,26568	kg	Indefinido				
Nitrogen oxides		0,003582	kg	Indefinido				
Carbon monoxide		0,0030852	kg	Indefinido				
VOC, volatile organic compounds		0,0006912	kg	Indefinido				
Hydrocarbons, unspecified		0,000325	kg	Indefinido				
Nitrogen dioxide		0,0000108	kg	Indefinido				
(Insertar línea aquí)								



Salidas conocidas a la tecnósfera. Productos y co-productos

Nombre	Cantidad	Ud.	Cantidad	Asignación %	Categoría	Comentario
LTO2 KARTS from diesel burned in machinery/RER Energy	1	kWh	Energy	100 %	Mechanical	
(Insertar línea aquí)						

Salidas conocidas a la tecnósfera. Productos evitados

Nombre	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
(Insertar línea aquí)							

Entradas

Entradas conocidas desde la naturaleza (recursos)

Nombre	Subcompartimento	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
(Insertar línea aquí)								

Entradas conocidas desde la tecnósfera (materiales/combustibles)

Nombre	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
Diesel, from crude oil, consumption mix, at refinery, 200 ppm sulphur EU-15 S System - Copie	0,03203	kg	Indefinido				
(Insertar línea aquí)							

Entradas conocidas desde la tecnósfera (electricidad/calor)

Nombre	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
(Insertar línea aquí)							

Salidas

Emisiones al aire

Nombre	Subcompartimento	Cantidad	Ud.	Distribución	DS^2 or 2*DS	Mín	Máx	Comentario
Particulates, unspecified		0,0001	kg	Indefinido				
Carbon dioxide, fossil		0,26568	kg	Indefinido				
Nitrogen oxides		0,0013428	kg	Indefinido				
Carbon monoxide		0,0014832	kg	Indefinido				
VOC, volatile organic compounds		0,0003924	kg	Indefinido				
Hydrocarbons, unspecified		0,0001774	kg	Indefinido				
Nitrogen dioxide		0,0000144	kg	Indefinido				
(Insertar línea aquí)								

Figure 23: Examples of the processes used on Simapro. The first process belongs to a Stair Truck and the second one to a Baggage Kart.
Source: Simapro screenshot

For the calculation of the fuel consumed by kWh, the highest EEA consume factors reference is taken: 31.6 l/100km for the HDV and 15 for the LDV. Thus, knowing the travel times per vehicle and the velocity, the distances traveled per vehicle can be found (Table 18) and using the EEA reference the consumption of diesel in liters or kg (density of 0.85l/kg) can be calculated.

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[8] See anex 3.5. On this annex are detailed the processes for all the vehicles and aircrafts.

It is considered that these consumption regimes are maintained during the service time activity of the water, catering, refueling, cleaning and cargo tapes servicing. For the long-haul tugs, it is considered a consumption of 55 liters/100km, as the pushback time is the same than the short haul but being higher the energy consumption. Below are presented the diesel consumptions by terminal and LTO cycle.

Determination of the fuel and energy consumed per vehicle and aircraft type.

Per one LTO	T1					
	Short-haul			Long-haul		
	kWh	Kg fuel	Kg fuel/kWh	kWh	Kg fuel	Kg fuel/kWh
Follow me	16.36	0.52	0.03	16.36	0.52	0.03
Coordinator	2.83	0.09	0.03	2.83	0.09	0.03
Maintenance	5.66	0.09	0.02	5.66	0.09	0.02
Karts	5.66	0.18	0.03	5.66	0.18	0.03
Water services	19.17	0.66	0.03	34.77	1.20	0.03
Catering	12.64	0.39	0.03	16.97	0.53	0.03
refueling	27.19	1.	0.04	60.19	2.21	0.04
Cleaning	28.23	0.86	0.03	50.23	1.54	0.03
Cargo tape	12.56	1.54	0.12	23.56	2.88	0.12
Stair trucks	3.07	0.19	0.06	3.07	0.19	0.06
Buses	4.72	0.19	0.04	4.72	0.19	0.04
AC	14.58	0.39	0.03	14.58	0.39	0.03
GPU	17.83	1.20	0.07	17.83	1.20	0.07
Tugs	12.40	0.53	0.04	52.20	0.92	0.02

Table 31: Determination of the fuel consumed per vehicle and the type of aircraft attended. Terminal 1
Source: Own

Determination of the fuel and energy consumed per vehicle and aircraft type.

Per one LTO	T2A					
	Short Haul			Long Haul		
	kWh	Kg fuel	Kg fuel/kWh	kWh	Kg fuel	Kg fuel/kWh
Follow me	25.20	0.81	0.03	25.20	0.81	0.03
Coordinator	5.52	0.18	0.03	5.52	0.18	0.03
Maintenance	11.03	0.18	0.02	11.03	0.18	0.02
Karts	11.03	0.35	0.03	11.03	0.35	0.03
Water services	24.41	0.84	0.03	40.01	1.38	0.03
Catering	18.45	0.57	0.03	22.78	0.71	0.03
refueling	32.11	1.18	0.04	65.11	2.39	0.04
Cleaning	34.14	1.04	0.03	56.14	1.72	0.03
Cargo tape	14.03	1.72	0.12	25.03	3.06	0.12

Stair trucks	5.98	0.37	0.06	5.98	0.37	0.06
Buses	9.19	0.37	0.04	9.19	0.37	0.04
AC	21.28	0.57	0.03	21.28	0.57	0.03
GPU	20.51	1.38	0.07	20.51	1,38	0.07
Tugs	16.64	0.71	0.04	70.07	1,24	0.02

Table 32: Determination of the fuel consumed per vehicle and the type of aircraft attended. Terminal 2A
Source: Own

Determination of the fuel and energy consumed per vehicle and aircraft type.						
Per one LTO	T2B					
	Short Haul			Long Haul		
	kWh	Kg fuel	Kg fuel/kWh	kWh	Kg fuel	Kg fuel/kWh
Follow me	27.20	0.87	0.03	27.20	0.87	0.03
Coordinator	5.54	0.18	0.03	5.54	0.18	0.03
Maintenance	11.07	0.18	0.02	11.07	0.18	0.02
Karts	11.07	0.35	0.03	11.07	0.35	0.03
Water services	24.45	0.84	0.03	40.05	1.38	0,03
Catering	18.49	0.57	0.03	22.83	0.71	0.03
refueling	32.15	1.18	0.04	65.15	2.39	0.04
Cleaning	34.18	1.05	0.03	56.18	1.72	0.03
Cargo tape	14.04	1.72	0.12	25.04	3.06	0.12
Stair trucks	6.00	0.37	0.06	6	0.37	0.06
Buses	9.23	0.37	0.04	9.23	0.37	0.04
AC	21.33	0.57	0.03	21.33	0.57	0.03
GPU	20.53	1.38	0.07	20.53	1.38	0.07
Tugs	16.67	0.71	0.04	70.20	1.24	0.02

Table 33: Determination of the fuel consumed per vehicle and the type of aircraft attended. Terminal 2B
Source: Own

The process creation for the APU and the aircrafts is a bit different because of the type of fuel used. Instead of diesel, these engines run with Kerosene. So, the main process selected from Simapro is “Transport, airplane, Boeing 742/Global”. This process describes the environmental impacts of aircraft transport due burning kerosene in the engines (main engines or APU). As well as the GSE, the fuel input parameter is selected (kerosene, from crude oil, consumption mix at refinery) and the emission data contained in the process in substituted by the own emissions data as kilograms of pollutants emitted per kilogram of kerosene burned in one LTO cycle, both for APU and aircrafts, presented below.

This main process is selected due is the only process on Simapro which environmental impact is measured trough the kilograms of kerosene burned. Moreover, it’s shown that this process reflects the environmental impact of a Boeing 742, but when the own emission factors per aircraft type are substituted, the environmental impact for each type of aircraft can be found.

One process has been created for each aircraft and three processes for the APU, two for the short haul aircrafts (when in contact and remote stands) and one for the long-haul aircrafts (at stands)[9].

APU emissions per kg of kerosene consumed			
Kg emitted/kg fuel*LTO	Remote (20 minutes)	Contact (7 minutes)	
	Short haul	Short haul	Long haul
NOx	8.8E-03	8.8E-03	8.0E-03
HC	3.8E-04	3.8E-04	5.3E-04
CO	3.9E-03	3.9E-03	7.0E-04
PM_{10}	3.1E-04	3.1E-04	1.3E-04

Table 34: APU emissions per kg of kerosene consumed according to the type of stand.
Source: Own

Below are presented the set of emissions introduced on the Simapro processes per each aircraft.

Aircraft emissions per Kg of kerosene burned								
Kg emitted/Kg kerosene*LTO	CO_2	NOx	SOx	H_2O	CO	HC	PM non-volatile	PM volatile (organic + sulphurous)
A320	3.2	1.5E-02	8.4E-04	1.2	9.0E-03	1.7E-03	1.0E-05	7.0E-05
B738	3.2	1.5E-02	8.4E-04	1.2	7.0E-03	7.0E-04	3.0E-05	6.0E-05
A321	3.2	1.8E-02	8.4E-04	1.2	4.0E-03	1.0E-04	1.2E-04	5.0E-05
A319	3.2	1.2E-02	8.4E-04	1,2	1.2E-02	2.5E-03	1.0E-05	8.0E-05
A318	3.2	1.0E-02	8.4E-04	1.2	1.3E-02	2.6E-03	1.0E-05	8.0E-05
A333	3.2	1.7E-02	8.4E-04	1.2	8.0E-03	8.0E-04	2.0E-05	5.0E-05
A332	3.2	1.7E-02	8.4E-04	1.2	8.0E-03	8.0E-04	2.0E-05	5.0E-05
E190	3.2	1.1E-02	8.4E-04	1.2	1.6E-02	1.5E-03	2.0E-05	6.0E-05
B763	3.2	1.6E-02	8.4E-04	1.2	1.5E-02	3.7E-03	1.0E-05	8.0E-05
B772	3.2	2.7E-02	8.4E-04	1.2	4.0E-03	2.0E-04	1.0E-05	5.0E-05
CRJ900	3.2	1.0E-02	8.4E-04	1.2	8.0E-03	1.0E-04	1.0E-05	5.0E-05
A380	3.2	1.8E-02	8.4E-04	1.2	6.0E-03	1.0E-04	1.0E-05	5.0E-05
B752	3.2	1.2E-02	8.4E-04	1.2	8.0E-03	1.0E-04	7.0E-05	5.0E-05

Table 35: Aircraft emissions per Kg of kerosene burned
Source: Own

[9] See annex 3.5. Main Simapro aircraft and APU processes used.

3.4.3 Normalization

Once all the processes are created, is necessary to determinate the normalization of the data due the processes are standardized on a functional unit (kWh of energy consumed or Kg of kerosene burned). So, the normalization is established as the number of vehicles used in 2017 multiplied by the kWh consumed per LTO and vehicle. The normalization is required due the environmental impact results are set per each vehicle and per one kWh (or kg of kerosene for the aircrafts and the APU's), thus, multiplying them by the total vehicles and kWh (or kg of kerosene) consumed during all 2017 LTO's, the total environmental impact can be found.

The normalization of the functional unit for the handling vehicles has been made through the engines power of each vehicle and their operating hours (according to the aircraft needs, the terminal distribution and the aircraft types, tables 25 and 26), thus the energy consumption (kWh) for attending one LTO by vehicle is the parameter selected for the first normalization of the functional unit, represented on the figure below.

Energetic normalization. kWh consumed per vehicle, LTO and terminal			
kWh * LTO	T1	T2A	T2B
Follow me	16.4	25.2	27.2
Coordinator	2.8	5.5	5.5
Maintenance	5.7	11.0	11.1
Karts	5.7	11.0	11.1
Water services	19.2	24.4	24.4
Catering	12.6	18.5	18.5
refueling	27.2	32.1	32.1
Cleaning	28.2	34.1	34.2
Cargo tape	12.6	14	14
Stair trucks	3.1	6	6
Buses	4.7	9.2	9.2

Table 36: GSE Energetic normalization. kWh consumed per vehicle and LTO.
Source: Own

For the Follow me, Maintenance, Coordinator, Baggage Karts, Water servicing, Catering, Refueling, Cleaning, Cargo tapes, Stair trucks and buses, the number of 2017 LTO cycle is needed as well as their terminal sharing. Multiplying the percentage of aircraft type per terminal by the total of LTO and the operation factor modeling (number of vehicles per aircraft and the percentage of usage per activity, explained on chapter 3.3.3) the total vehicles by terminal are determined.
Once the number of vehicles is established, is necessary to multiply it by the kWh consumed in each activity giving the normalization of the GSE. Here below is presented the normalization used for the T1[10].

[10] See annex 3.6. T2A and T2B normalization

Vehicles normalization. Vehicles used for all LTO cycles in 2017 on T1																
	kWh/vehicle*LTO (T1)															
	SH	LH	A320	B738	A321	B736	A318	A319	A330200	A330300	A380	B772	CRJ900	E190	Tail	Total needed
Follow me	16.36	16.4	58,064	7,555	18,873	1,263	2,604	4,976	1,470	1,289	722	748	593	722	4,409	103,288
Coordinator	2. 8	2.8	58,064	7,555	18,873	1,263	2,604	4,976	1,470	1,289	722	748	593	722	4,409	103,288
Maintenance	5.6	5.7	58,064	7,555	18,873	1,263	2,604	4,976	1,470	1,289	722	748	593	722	4,409	103,288
Karts	5. 6	5.7	58,064	7,555	18,873	1,263	2,604	4,976	2,939	2,578	2,888	1,495	593	722	4,409	108,961
Water services	19.1	34.8	14,516	1,889	4,718	316	651	1,244	1,470	1,289	722	748	148	180	1,102	28,993
Catering	12.6	17	34,838	4,533	11,324	758	1,562	2,986	1,470	1,289	722	748	356	433	2,645	63,664
refueling	27.1	60.2	29,032	3,777	9,437	632	1,302	2,488	1,470	1,289	722	748	297	361	2,204	53,758
Cleaning	28.2	50.2	11,612	1,511	3,775	253	521	995	1,470	1,289	722	748	119	144	882	24,040
Cargo tape	12.5	23.6	58,064	7,555	18,873	1,263	2,604	4,976	2,939	2,578	1,444	1,495	593	722	4,409	107,517
Stair trucks	3.0	3.1	58,064	7,555	18,873	1,263	2,604	4,976	0	0	0	0	593	722	4,409	99,060
Buses	4.7	4.7	34,838	4,533	11,324	1,011	1,042	1,990	0	0	0	0	237	289	2,645	57,910

Table 37: T1 Vehicles normalization. Vehicles needed for all LTO cycles in 2017
Source: Own

So, knowing the total vehicles per terminal, and multiplying them by the kWh used per vehicle and aircraft type, the results are the following ones.

Total 2017 kWh consumed				
GSE	T1	T2A	T2B	TOTAL GSE
Follow me	1.7E+06	1.6E+05	1.3E+06	3.2E+06
Coordinator	2.9E+05	3.5E+04	2.7E+05	6.0E+05
Maintenance	5.9E+05	7.0E+04	5.4E+05	1.2E+06
Karts	6.2E+05	7.1E+04	5.9E+05	1.3E+06
Water services	6.2E+05	4.1E+04	3.0E+05	9.6E+05
Catering	8.2E+05	7.1E+04	5.4E+05	1.4E+06
refueling	1.6E+06	1.0E+05	7.9E+05	2.5E+06
Cleaning	7.7E+05	4.6E+04	3.4E+05	1.2E+06
Cargo tape	1.4E+06	9.0E+04	6.9E+05	2.2E+06
Stair trucks	3.0E+05	4.5E+04	3.5E+05	7.0E+05
Buses	2.7E+05	6.9E+04	5.2E+05	8.6E+05

Table 38: Total kWh consumed by the GSE
Source: Own

For the Ground power units and the Air Conditioning, the total LTO cycles per terminal has been multiplied for the percentage of short haul aircrafts and the percentage of remote stands per terminal (due the contact stands doesn't require of GPU or AC, and the long-haul aircrafts are always in contact stands).

Ground Power Unit normalization			
GPU	**Number needed 2017**	**Energy consumed*LTO (kWh)**	**Total 2017 kWh consumed**
T1	1.1E+04	18	2E+05
T2A	4.5E+03	21	9.3E+04
T2B	2.3E+04	21	4.7E+05

Table 39: Ground Power Unit normalization
Source: Own

Air conditioning vehicle normalization			
Air conditioning	Number needed 2017	Energy consumed*LTO (kWh	Total 2017 kWh consumed
T1	1.1E+04	15	1.6E+05
T2A	4.5E+03	21	9.6E+04
T2B	2.3E+04	21	4.9E+05

Table 40: Ground Power Unit normalization
Source: Own

For the tugs normalization, the total LTO cycles per terminal has been multiplied by the percentage of aircrafts in contact stand (remote stands don't require pushback) and by the percentage of short and long-haul aircrafts.

Tugs normalization						
	Sort Haul	**Long Haul**	**kWh SH*LTO**	**kWh LH*LTO**	**Total 2017 kWh SH**	**Total 2017 kWh LH**
T1	9.8E+04	4.2E+03	12	52	1.2E+06	2.2E+05
T2A	2.8E+03	5.2E+01	17	70	4.6E+04	3.6E+03
T2B	1.4E+04	1.0E+02	17	70	2.4E+05	7.2E+03

Table 41: Tugs normalization
Source: Own

For the APU's normalization, the number of aircrafts per terminal is multiplied by the aircraft type, the type of stand and the fuel burned per LTO. This result gives the total fuel burned by the APUs, value used for the normalization.

$$APU\ Normalization = Number\ of\ aircrafts\ per\ terminal * \%\ aircraft\ type\ (short\ or\ long\ haul) * \%\ Type\ of\ stand * Fuel\ burned * Forecasted\ LTO$$

APUs fuel consumption normalization

	APU Usage STAND				APU Usage Remote	
	Number SH	Kg fuel consumed 2017	Number LH	Kg fuel consumed 2017	Number SH	Kg fuel consumed 2017
T1	9.8E+04	1.2E+06	4.2E+03	1.2E+05	1.1E+04	3.9E+05
T2A	2.8E+03	3.4E+04	52	1.4E+03	4.5E+03	1.6E+05
T2B	1.4E+04	1.8E+05	103	2.9E+03	2.3E+04	8.2E+05

Table 42: APUs fuel consumption normalization
Source: Own

For the aircrafts normalization, the total amount of kerosene burned during all LTO's is required. Multiplying the fuel consumed per aircraft and LTO cycle by all the LTO cycles performed the total kerosene burned is found.

Percentage of operating aircrafts at LEBL and their fuel consumption per LTO

Aircraft	%	Kg fuel
A320	46,1	743
B738W	24,5	801
A321	12,7	938
A319	6,2	622
A318	1,6	618
A333	0,9	1977
A332	0,8	1977
E190	0,6	589
B763	0,8	1584
B772	0,5	2197
CRJ900	0,5	435
A380	0,5	3718
Tail	4,1	1235

Table 43: Percentage of operating aircrafts at LEBL and their fuel consumption per LTO
Source: The fuel burn per LTO is taken from the ICAO engines data sheets.

3.4.4 Spanish energetic mix

The electricity used to charge the electric vehicles has environmental burdens within due that energy is partially generated by nonrenewable energies. The environmental impact resulting from the generation of one kWh in Spain is required, and it depends on the countries electrical mix.

The Simapro process "Electrical country mix, Spain b250" contains data of the environmental impact assessed to the production of one kWh coming from different energy sources according to the 2004 Spanish electrical mix. As opposite to the process used for the GSE, this one considers the efficiency of the electricity generation.

These values of the electrical mix contained on the process have been substituted by the 2016 electrical mix values, taken from the REE (Red Electrica de España), presented below.

The results for this electrical mix analysis will show the environmental impact assessed to the consumption of electrical energy produced in Spain. The environmental impact assessed to the transport of that energy from the generation points to the consumption point hasn't been considered, as the limits of the study are set on the airside of the airport.

Spanish electrical mix (%)	
Hydraulic	14.9
Coal	14.3
Fuel oil	2.6
Gas	11.2
Nuclear	21.4
Wind power	18.2
Solar	6.3
Cogeneration	11.1

Table 44: Spanish electrical mix
Source: Spanish electric network

The normalization of the electrical mix values corresponds to the total kWh that the electric vehicles will consume from the electric network to provide the handling services to the aircraft (explained on the chapter 3.5.5, economic values)

kWh consumed by the electric vehicles in 2017			
Follow me	Coordinator	Karts	Bus
4.1E+04	7.6E+03	1.6E+04	7.1E+04

Table 45: kWh consumed by the electric vehicles in 2017
Source: Own

3.4.5 Environmental impact assessment methodology

For analyzing and comparing the processes introduced on Simapro, the choice of analysis methods is required. The analysis methods used are the ReCipe Endpoint (with a hierarchic perspective) and IPCC Global Warming 100y.

ReCipe is a method that translates the emissions and resource extractions into a limited number of environmental impact scores expressed in DALY's, loss of species per year and economic cost. The IPCC GW method describes the contribution to the global warming expressed in Kg of CO_2 eq.

The Daly's, or "Disability Adjusted Life Year", reflects the loss of full healthy years over the population due diseases, illness or early death, and involves the following environmental impact categories: Climate change (human health), ozone depletion, human toxicity, photochemical oxidant formation, particulate matter formation and ionizing radiation.

The loss of species per year includes the categories of Climate Change Ecosystems, freshwater eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, agricultural land occupation, urban land occupation, natural land transformation.

Then, in the economic score ($), the environmental impacts categories are metal and fossil depletion.

3.5 MIVES METHODOLOGY

MIVES (Integrated Value Model for a Sustainable Evaluation) software has been created and developed by the UPC, the UPV and Labein-Tecnalia, and is based on combined value analysis techniques. This method converts diverse types of variables to the same unit, considering the relative importance of each aspect included on the sustainable evaluation of an LCA, a product, a process or a decision.

This software allows the comparison between different scenarios or alternatives through their sustainability analysis, having into account environmental, social, functional and economic factors.

So, this software is used to compare the actual LEBL's scenario with the purposed one, explained below, with the aim of quantify their sustainability index.

3.5.1 SCENARIO'S DEFINITION

Two scenarios are compared for this sustainability analysis. The first scenario (S1) reflects the actual situation, where all the vehicles used by the ground handling services are diesel engine vehicles.

The second scenario (S2) involves the substitution of a certain types of combustion engines vehicles to electric engines. Not all the ground handling vehicles have been chosen to be substituted, due most of the vehicles are considered "Heavy Duty Vehicles" and their activities can involve high loading operations that the electric vehicles couldn't manage at high performance levels over the years. Thus, the vehicles chosen for the substitution are the "Light Duty Vehicles" (Follow me, Coordinator and Baggage Karts), except the maintenance vehicle, considered light duty vehicle but their tasks may involve loading operations.

For the same reason, the bus fleet is a substitution target even as being HDV, due the buses do not have high loading operations and the actual technology over the electric bus engines are developed enough to consider their substitution.

Thus, the second scenario will consider the substitution of a 50% of each vehicle type mentioned (Follow me, coordinator, Baggage Karts and Buses). This means that 53 electric vehicles and 10 buses are needed.

For the electric vehicles, the Renault Zoe is chosen as substitution vehicle, and for the buses a report is chosen as a reference ("Real World Performance of Hybrid and Electric Buses", developed by Grütter Consulting), where a global and regional diagnosis of the electric buses is made. Below are presented the technical features for these vehicles.

Electrical vehicles technical features

	Power (kW)	Autonomy (km)	Theoretical consume (kWh/km)	Recharge time (11kW)	Recharge time (22kW)	Batteries useful life (recharging cycles)	Vehicle Prize (€)	Battery prize per unit (€)
ZOE	65	210	0.1	1	2	3,000	16,000	5,000
BUS	200	180	1	8	5	3,000	575,000	287,500

Table 46: Electrical vehicles technical features
Source: Renault Zoe technical sheet and the report "Real World Performance of Hybrid and Electric Buses", by Grütter Consulting

3.5.2 REQUIREMENT TREE

The requirement tree is a hierarchical scheme where the distinct characteristics of the evaluated product are defined. The tree is divided in 3 levels; the first two levels (requirements and criteria) are used to establish a desegregated structure of the system, having an overall view of the study. The third level is the Indicator level, where are defined the specific characteristics of the evaluated process.

For this project, the requirements have been set as environmental, social and economic requirements. The functional requirement has not been used because all the parameters involving this requirement are overlapped with the economic ones (the results of gaining or loosing functionality parameters are quantified in economic terms).

Environmental requirement

This requirement considers the main results of the environmental impact obtained from Simapro software. The criteria level established for the evaluation of the environmental requirement are: the affection over the Human Health, over the ecosystems, over the resources and the global warming potential.

The criteria Human health involves two indicators, the affection of climate change over the population and the formation of particulate matter, both measured in DALY's. As commented on the Simapro Results chapter, there are more environmental impacts deteriorating the human health, but haven't been included on the requirement tree due they represent less than the 1% of the environmental impacts over the human health.

The criterion Ecosystems includes an indicator that evaluates the affection over the species due the climate change, measured in loss of species per year. The criterion Resources contain the indicator of fossil depletion, measured in Euros (€), reflecting the environmental cost of the fossil resources extraction.

As well as before, there're more environmental impacts (indicators) for each criterion according to SIMAPRO's results, but the previous mentioned accumulates the 99% for each criterion. It is considered that by just introducing the main environmental impact as indicators on MIVES, the results are going to be reliable. Moreover, in case of introducing all the environmental impacts, the hypothetical weigh assessed to them should be set as less than 1%, which barely could have a contribution to the final results.

Finally, the last criterion used is the global warming potential over 100 years, measured in tons of CO_2 equivalent emitted. It's known that this indicator is somehow related to the climate change indicators of human health and ecosystems, as the environmental impact results obtained by the IPCC methodology (CO_2 eq) have into account the affection over the human health and the ecosystems (with less accuracy than the ReCipe methodology), between others. But, it's considered that it's a good indicator in communication and divulgation terms, and for this reason it's introduced on MIVES as an indicator, but with a lower weight assessed than the rest of the environmental criteria.

Social requirement

The social requirement quantifies the contribution to the sustainability of each scenario according to their affectation over the population. For this project, the social perception of the scenarios is quantified through a survey and 53 samples[11].

The survey questions are related with the social perception of the emissions impact, the acoustic pollution and the security (in terms of accidents) over the usage of diesel and electric vehicles.

The results are given in terms of personal satisfaction over the two raised situations, from 0 to 5, being 0 the minimum satisfaction and 5 the highest.

Economic requirement

The economic requirement measures the contribution to the sustainability of each scenario according to their cost.

The first criterion established is the direct cost, associated to the first investment of any project. In this case the direct cost indicators are two, the investment (for buying vehicles) and the parking zone remodeling due the construction of electrical recharge points for the electric vehicles. It is considered that the parking remodeling is part of the investment, but they can be set as separated indicators using the correct weighing between them.

[11] See annex 3.7. Survey questions.

The second criterion is the indirect cost, associated to the costs that cannot be paid on the investment. The indicators set for this criterion are the maintenance cost of the vehicles per year and the usage cost (cost of diesel and electricity) per year.

The last criterion used to represent the economic requirement is the economic amortization of the scenarios and his indicator is the NPV (Net Present Value). This indicator measures the economic viability of one project, considering the investment, the indirect costs and the amortization of the vehicles. It's known that this criterion is overlapped with the direct and indirect costs criteria, but for communicative and diffusion reasons, it is introduced on MIVES with a lower weight. Moreover, it is necessary to reflect the economic cost of the amortization of the actual diesel fleet. VPN calculations have been made for a period of 20 years investment, the same period than the averaged useful life time for the electric vehicles.

The NPV includes the costs of purchasing the needed batteries for the electric vehicles for a period of 20 years.

Below is presented the scheme of the requirement tree. The red, blue and green circles represent the Requirements, the criteria and the indicators, respectively.

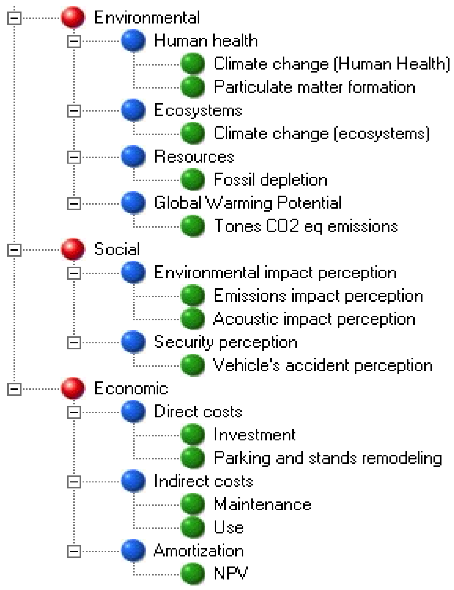


Figure 24: MIVES Requirement tree
Source: Own

3.5.3 VALUE FUNCTIONS

Once the requirement tree is done, it's necessary to establish the value functions. These functions are set per each indicator, and through the general theory of decision making and multiple criteria methods, allows the conversion of different units and magnitudes to a single dimensionless value, making possible the comparison between different indicators.

Using a graphical function, where are represented the satisfaction degree over the magnitude of one indicator, the setting of minimum and maximum satisfaction values is required.

Minimum satisfaction values

The minimum satisfaction values attributed to all the environmental indicators and the indirect cost indicators are set as a 20% more of the values obtained for the S1 environmental impacts and a 20% more of the costs of S1 indirect costs.

For the direct costs and NPV indicators, the minimum satisfaction value is set as the cost of renewing the 100% of the chosen vehicles type instead of the 50%.

And, for the social indicators, the minimum satisfaction has been set as 0 (according to the survey results).

Maximum satisfaction value

The maximum satisfaction values set for the environmental indicators correspond to the environmental impacts values when the 100% of the fleet has been substituted by electric vehicles. The maximum satisfaction values for the indirect costs are set as well as the cost when the fleet is renewed in a 100%.

For the social indicators, the maximum satisfaction value is 5, according to the survey.

For the direct costs, the maximum satisfaction value is 0€, representing the continuity of the S1, where no investments are needed.

For the VPN, the maximum satisfaction value is set to 1,000,000€. It would be possible to set it to 0€, like the direct costs indicators, but in economic terms the aim of an investment is to obtain benefits and not just amortize it, thus the value of one million is set.

Function shapes

When the maximum and minimum parameters are set, is necessary to determine the shape type for each function value, which determinates the trends over the satisfaction values.

The environmental impact indicators are represented by decreasing concave functions, where the trend to the maximum satisfaction is promoted. Thus, more satisfaction means less emissions and vice versa.

Social indicators use growing concave functions, having more satisfaction when the survey's answers values are higher.

For the economic indicators, the investment and the use costs indicators are represented by decreasing "S" form curves. The parking remodeling and maintenance costs indicators use decreasing concave functions. With these functions, the maximum satisfaction point is reached when there are fewer costs.

NPV's indicator uses growing convex functions, where the maximum satisfaction values coincide with the highest values for the NPV.

Below are presented the value function for each indicator.

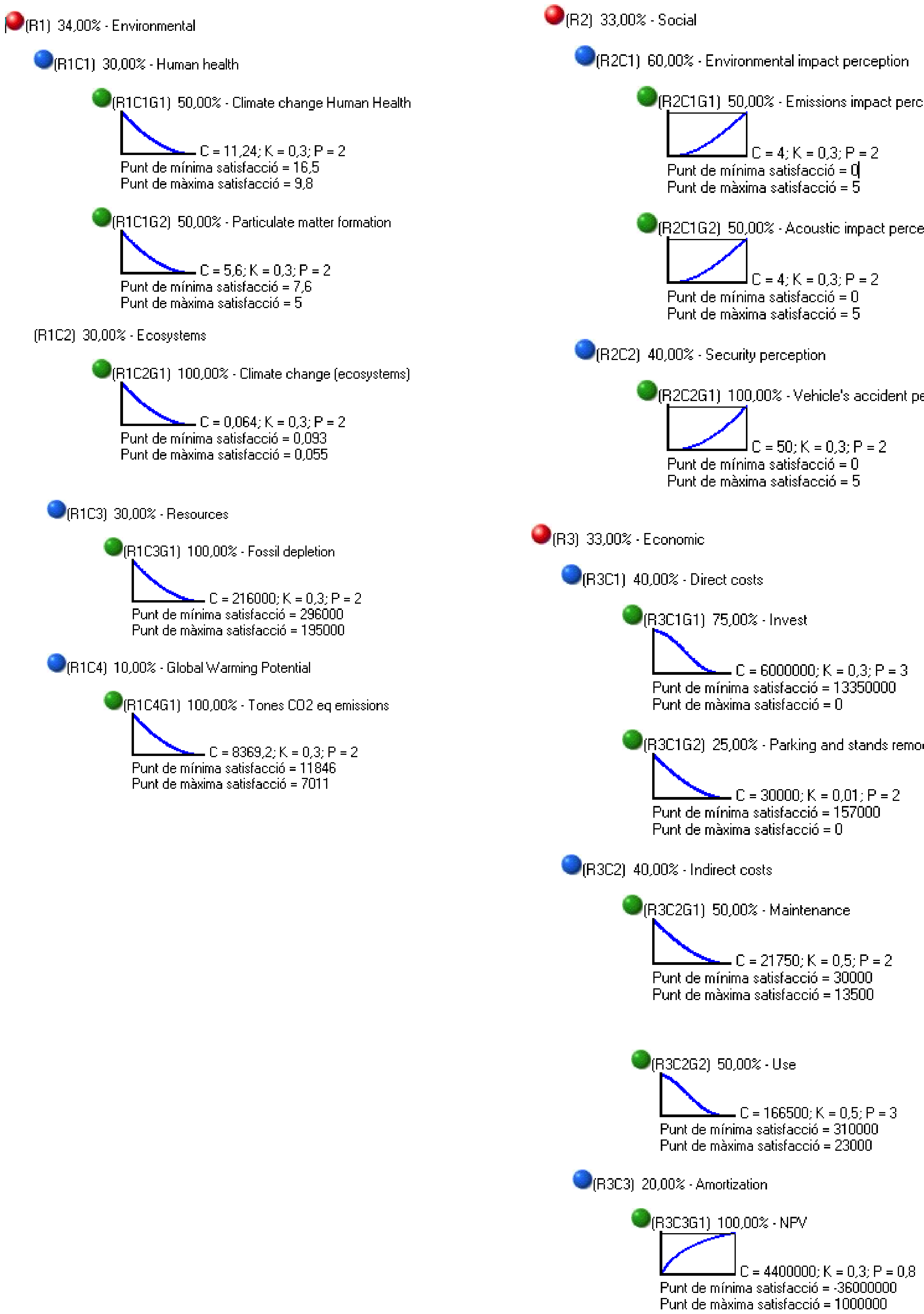


Figure 25: Value function set in MIVES
Source: Own

3.5.4 REQUIREMENT TREE WEIGHING

Once the value functions are set, the tree weighting is needed for the three levels: requirements, criteria and indicators. This step is very important for the process, due the analysis results can vary significantly depending on the assessed weights.

For this analysis, the requirements weighting has been shared equally, giving the same importance over the three requirements and trying to obtain the most equal results. Thus, a 34%, 33% and 33% are the weights for the environmental, social and economic requirements, respectively.

Environmental requirement criteria

The weights for the environmental criteria are shared equally except for the Global Warming Potential, which have less weight assessed because, as explained before, their impact values are related to the other climate change criteria. So, for the criteria Human health, Ecosystems and Resources the weight assessed is a 30% each. For the GWP criteria the weight assessed is a 10%.

The criteria human health has two indicators (Climate change human health and Particulate matter formation), which weight have been shared equally at 50%.

Social requirement

The social requirement has two criteria, the environmental perception and the security perception. As the aim of the project is related with environmental goals, the environmental perception has a higher weight assessed than the security perception, but for being this last a principal factor over the social parameters, a weight of 40% is set. Thus, a 60% is set for the environmental perception.

The environmental perception criterion contains two indicators, the emission impact perception and the acoustic impact perception, which weights are shared equally.

Economic requirement

There are three criteria inside the economic requirement. As the NPV calculation includes the direct and indirect costs within, this criterion has less weight assessed than the other two criteria. Thus, a 40% is set for the direct and indirect costs and a 20% is set for the NPV.

The criterion direct costs contain two indicators, the investment and the parking remodeling. A 75% of the weighting is assessed to the investment, and a 25% to the parking remodeling because as commented before, the parking remodeling is included on the investment cost, for this reason it has less importance inside the direct cost criterion.

For the indirect cost criterion, the weights have been distributed equally between his two indicators, 50% for the maintenance and 50% for the use.

Below is presented a figure with the weights assessed to each requirement, criteria and indicator.

(R1) Environmental Peso: 34,00 %	(R1C1) Human health Peso: 30,00 %	(R1C1G1) Climate change Human Health Peso: 50,00 %
		(R1C1G2) Particulate matter formation Peso: 50,00 %
	(R1C2) Ecosystems Peso: 30,00 %	(R1C2G1) Climate change (ecosystems) Peso: 100,00 %
	(R1C3) Resources Peso: 30,00 %	(R1C3G1) Fossil depletion Peso: 100,00 %
	(R1C4) Global Warming Potential Peso: 10,00 %	(R1C4G1) Tones CO2 eq emissions Peso: 100,00 %
(R2) Social Peso: 33,00 %	(R2C1) Environmental impact perception Peso: 60,00 %	(R2C1G1) Emissions impact perception Peso: 50,00 %
		(R2C1G2) Acoustic impact perception Peso: 50,00 %
	(R2C2) Security perception Peso: 40,00 %	(R2C2G1) Vehicle's accident perception Peso: 100,00 %
(R3) Economic Peso: 33,00 %	(R3C1) Direct costs Peso: 40,00 %	(R3C1G1) Invest Peso: 75,00 %
		(R3C1G2) Parking and stands remodelation Peso: 25,00 %
	(R3C2) Indirect costs Peso: 40,00 %	(R3C2G1) Maintenance Peso: 50,00 %
		(R3C2G2) Use Peso: 50,00 %
	(R3C3) Amortization Peso: 20,00 %	(R3C3G1) NPV Peso: 100,00 %

Figure 26: MIVES requirement tree weighting
Source: Own

3.5.5 SCENARIO EVALUATION

In this chapter are going to be presented the values introduced on the MIVES User module, according to both scenarios, and how the calculations are made for each indicator.

Scenario 1 corresponds to the actual situation, where a 100% of the vehicles are diesel vehicles.

Scenario 2 corresponds to the substitution of a 50% of the follow me vehicles, coordinator, karts and buses (a total of 53 vehicles and 10 buses from combustion engines to electric ones, meaning that a 20% of the total ground handling fleet is substituted).

Environmental Values

The environmental values are the ones obtained as an output from Simapro. Below is presented a table containing the results for the environmental impacts for both scenarios, as well as the maximum and minimum satisfaction values (corresponding to the environmental impact if a 100% of the vehicles chosen would be substituted and corresponding to the environmental impact of the S1 plus a 20%, respectively).

Environmental parameters set					
Impact category	**Climate change Human Health (Daly)**	**Particulate matter formation (Daly)**	**Climate change Ecosystems (species/year)**	**Fossil depletion (€)**	**IPCC GWP 100a (kg CO_2 eq)**
Environmental impact (S1)	14	6.3	0.08	2.5E+05	9.9E+03
Environmental impact (S2)	12	5.8	0.07	2.2E+05	8.4E+03
Minimum Satisfaction values	17	8	0.09	3E+05	1.2E+04
Maximum Satisfaction values	10	5	0.06	2E+05	7E+03

Table 47: Environmental parameters set on MIVES
Source: own

Social Values

The social values introduced are the ones obtained from the survey, showed below, being 5 the most satisfaction perception value and 0 the minimum.

Social parameters set		
Survey values	**S1**	**S2**
Emissions impact perception	3.7	4.3
Acoustic impact perception	2.9	4.1
Accidents perception	3.6	2.2

Table 48: Social parameters set on MIVES
Source: own

Economic values

Direct costs – investment and parking remodeling

The investment for the S1 is 0€. This is due the actual diesel fleet has associated within an amortization cost, meaning that the cost of purchasing new diesel vehicles is already contemplated for the ground handling companies, thus is not considered an investment cost for the S1. Tough, this amortization cost is considered in the NPV indicator.

The acquisition of electric vehicles (S2) needs an investment of 6.5 million of Euros. Firstly, the number of vehicles needed is calculated according to LEBL's maximum operations capacity, set as 38 LTO cycles per hour.

Having an average of 1 vehicle needed per LTO for the follow me and the coordinator, an average of 2 baggage kart per LTO and an average of 3 buses per LTO cycle when in remote stands; and having the percentage of aircrafts that needs these ground handling activities, the total number of vehicles operating at LEBL is found. Moreover, a factor of 0.7 is used as a simultaneity coefficient.

All LTO cycles uses a follow me, a coordinator and baggage karts. For the buses, it is considered the LTO terminal distribution (65% T1 and 35% T2) and the percentage of remote stands, where the buses are needed (20% on T1 and 40% on T2).

Thus, for attending a rush hour, the numbers of vehicles needed are the following ones:

Number and prize of vehicles needed

	Number vehicles per TAP	Aircraft needs (%)	Total vehicles in LEBL	Vehicles to be substituted	Prize per Vehicles (€)
Follow me average(meters)	1	100%	26	13	1.6E+04
Coordinator	1	100%	26	13	1.6E+04
Karts	2	100%	53	27	1.6E+04
Buses	3	T1: 20% T2: 40%	21	10	5.8E+05

Cost (€)	Total vehicles	Total buses	Total vehicle investment
	8.4E+05	5.7E+06	6.6E+06

Table 49: Number of vehicles needed, electric vehicles prizes and total cost.
Source: Own

The prize of the electric vehicles corresponds to a Renault Zoe. The prize of the electric buses is taken from the report “Real World Performance of Hybrid and Electric Buses”, developed by Grütter Consulting. This report details the environmental and financial performance of hybrid and battery electric transit buses in a global and regional scale.

The investment must include the cost of the parking's remodeling due the adaptation for the electrical charge points. Taking as reference the study developed by Audatex, “Vehicle and savings according motorization”, the cost of installation of recharging points is 1,500€. It is considered the double amount for the bus recharging points.

The total electric vehicles to be purchased are 63. Applying a simultaneity recharging factor of 0.7, because the vehicles shouldn't be recharging all at the same time, a total of 45 recharging points are needed, 37 for the vehicles and 8 for the buses. The parking remodeling cost rises to 78,500€.

Thus, the total investment cost for S2 is 6.68E+06€.

These costs are used to establish the minimum satisfaction values of the valor functions, as explained before. The double of the investment, according to renew the 100% of the vehicles is chosen as the minimum satisfaction value for the investment indicator (13.3E+06€).

The cost of the parking remodeling is multiplied by a 2, finding the minimum satisfaction value for the parking remodeling indicator (157,000€ corresponding to the construction of 90 recharging points)

For both indicators, the maximum satisfaction value corresponds to 0€, where no investments are made.

Economic requirement. Direct costs values

	Investment	Parking remodeling
Cost S1 (€)	0	0
Cost S2 (€)	6.6E+06	7.8E+04
Maximum satisfaction value	0	0
Minimum satisfaction value	1.3E+07	1.5E+05

Table 50: Economic requirement. Direct costs parameters introduced on MIVES
Source: Own

<u>Indirect costs – Maintenance and use</u>

The calculations over the maintenance costs are based on the Audatex reference, where it's described the differences between the combustion and electric engines over a maintenance framework. In this study, are set that the maintenance cost in € per km: 0.017 and 0.009 for the diesel and electric vehicles, respectively.

Knowing the total kilometers traveled per vehicle in 2017(chapter 3.3.3), the total maintenance cost per year is found.

The use reflects the cost of diesel and electricity consumed. Setting a diesel prize per liter of 1.05€ (lowest average cost in Spain) and the prize of the electricity to 0.084 €/kWh (corresponding the cheapest electricity prize in Spain), and knowing the kilometers traveled and the kWh consumed per km, the cost for the use is founded.

Kilometers traveled and kWh consumed by the electric vehicles in 2017		
	Total km traveled per vehicle type	**kWh consumed**
Follow me	4.0E+05	4.1E+04
Coordinator	7.5E+04	7.6E+03
Karts	1.6E+05	1.6E+04
Buses	6.5E+04	7.1E+04

Table 51: Kilometers traveled and kWh consumed by the electric vehicles in 2017
Source: Own

The minimum satisfaction values for these indicators are set as a 20% more of the Scenario 1 costs. The maximum satisfaction values are set as the cost when a 100% of the vehicles are substituted.

Economic requirement. Indirect costs values		
	Maintenance	Use
Cost S1 (€). 100% Diesel	24,949	257,478
Cost S2 (€). 50% é/ 50% d	19,204	133,452
Maximum satisfaction value	13,500	23,000
Minimum satisfaction value	30,000	310,000

Table 52: Economic requirement. Indirect costs parameters introduced on MIVES
Source: Own

Bear in mind that the maintenance and use costs of S1 corresponds to a 100% of diesel vehicles fleet and for the S2 corresponds to a 50% diesel vehicle and 50% electric vehicles fleet. Both scenarios are just considering the costs of the follow me and the coordinator vehicles, the baggage karts and the buses.

<u>Amortization – NPV</u>

The Net Present Value has been determined for both scenarios over a 20 years period, needing the yearly cash flow of the scenarios (profits minus costs).

For the S1 NPV, the following costs per year are set: diesel consumption and maintenance (explained before) and the amortization of the entire diesel fleet (106 vehicles and 20 autobuses). This amortization is determined according to the investment that once was realized for purchasing the actual diesel vehicles fleet and the years applied to amortize them.

The following figure shows the amortization years of the different diesel vehicles, taken from the Spanish tax agency. For the electric vehicles, the amortization years differs depending on the source and the engines manufacturer, so an average of different references (Seat e-mobility project, "Urbaser" fleet renewal) is taken.

Amortization years

Diesel	Vehicles	10
	Buses	14
Electric	Vehicles	9
	Buses	10
Parking remodeling	Installations	20

Table 53: Amortization years set per vehicle for the NPV calculation
Source: Seat e-mobility project, "Urbaser" fleet renewal and Spanish Tax Agency

A cost of 10,000 Euros has been set as the prize for the diesel vehicles and a prize of 250,000€ for the diesel buses (Grütter Consulting report). So, the investment once made for purchasing 106 diesel vehicles and 20 diesel autobuses were 6 million Euros and the amortization cost per year over the S1 rises to 463,143€.

For the S2 NPV, the following costs per year are set: the investment, the diesel consumption and maintenance of the diesel vehicles (53 vehicles and 10 buses), electricity consumption and maintenance of the electric vehicles (53 vehicles and 10 buses), the amortization of the resting 50% of the diesel fleet, the amortization of the electric vehicles and the replacement cost of the electric batteries over 20 years.

Having a look at the batteries, it is considered on the Zoe's technical sheet that the batteries offers 3,000 recharging cycles with an autonomy of 210 km (autonomy set for the electric bus: 180km). Dividing the autonomy by the distances traveled per each vehicle, the maximum number of TAP's that one vehicle can attend before recharging is found. Moreover, a factor of 0.9 is applied, minimizing the number of TAPs before recharging.

Number of TAP before recharging

	Follow me	Coordinator	Baggage karts	Buses
Terminal 1	46	208	133	114
Terminal 2	28	106	68	59

Table 54: Number of TAP performed before recharging.
Source: Own

Taking as reference 500 LTO cycles per day performed at LEBL, the average operations performed per day and vehicle are 37 (for the vehicles) and 27 and 55 for the buses of T1 and T2, respectively. Thus, dividing the average daily operations per vehicle per the number of TAPs before recharging, the number of recharges needed per day and vehicle is found, showed below.

Number of recharges/day

	Follow me	Coordinator	Baggage karts	Buses
Terminal 1	0.8	0.2	0.3	0.2
Terminal 2	1.4	0.4	0.6	1

Table 55: Number of recharges per day needed per vehicle
Source: Own

Then, considering the 3,000 recharging cycles of useful life for the batteries, the years when the batteries needs to be replaced are shown on the following table, as well as the number of replacements needed per vehicle for 20 years.

	Batteries replacement year	**6**	**8**	**10**	**14**
Number of battery replacements	Follow me	3	0	5	0
	Coordinator	0	0	0	0
	Karts	0	0	0	8
	Buses	0	3	0	0

Table 56: Number of batteries per vehicle needed to be change over 20 years
Source: Own

For the battery prize calculations, is determined on the report “Real World Performance of Hybrid and Electric Buses” that the actual prize for the bus batteries rises until a 50% of the total investment cost, and for the vehicles a 30% of the total investment cost is set. Thus, the cost for renewing the batteries for a period of 20 years is 942,500€. The batteries cost has been included on S2 NPV calculation, on the corresponding yearly cash flow.

So, when the NPV is calculated for the S1, the result shows a value of -7.6 million. For the S2 NPV calculations, the value decreases to -18 million[12].

12 See annex 3.8. NPV’s and cash flows calculations for each scenario.

Economic requirement. NPV value

S1	-7.6E+06
S2	-1.8E+07
Maximum satisfaction value	1.E+06
Minimum satisfaction value	-36E+07

Table 57: Economic requirement. NPV parameter set on MIVES
Source: Own

Scenario evaluation summary

Below is presented a summary table containing all the parameters introduced on the MIVES software.

MIVES parameters set. Summary

Weight	Requirement	Indicator	Minimum satisfaction limits	Maximum satisfaction limits	S1 Values	S2 Values
34	Environmental	CC HH	17	10	14	12
		PM form.	8	5	6	6
		CC ES	9.3E-02	5.5E-02	7.8E-02	6.6E-02
		FD	3E+05	2E+05	2.5E+05	2.2E+05
		IPCC	1.2E+04	7E+03	9.9E+03	8.4E+03
33	Social	EP	0	5	3.8	4.2
		ACP	0	5	3	4
		VSP	0	5	3.6	2.2
33	Economic	Investment	13.3E+6	0	0	6.6E6
		P Remodeling	1.5E+05	0	0	7.8E+04
		Maintenance	3E+04	1.3E+04	2.5E+04	1.9E+04
		Use	3.1E+05	2.3E+04	2.5E+05	1.3E+05
		NPV	-3.6E+07	1E+06	-7.6E+06	-1.8E+07

Table 58: Summary of the all parameters introduced on MIVES
Source: Own

3.5.6 SENSITIVITY ANALYSIS

The first quantification over the sustainability of the scenarios is made according to the previous mentioned parameters. Moreover, a sensitivity analysis is made with the aim of measuring how the results are affected by changing some of MIVES's parameters.

Firstly, the mentioned minimum satisfaction values of the valor functions are modified. These values were set as a 20% more than the values obtained for the S1 indicators (for all the environmental indicators and the indirect costs indicators). To carry out the sensitivity analysis, a minimum satisfaction values of +5%, +10%, +30% and +40% are set, but the maximum satisfaction values remain constant.

Sensitivity analysis. Minimum satisfaction limits

Indicators	5%	10%	20%	30%	40%	Maximum satisfaction values
CC HH	14.5	15	16.5	18	20	10
PM form	6,6	7	7,6	8	9	5
CC ES	0.081	0.085	0.093	0.1	0.1092	0.05
FD	2.6E+05	2.7E+05	3E+05	3.2E+05	3.5E+05	2E+05
IPCC	1E+04	1.1E+04	1.2E+04	1.3E+04	1.4E+04	7E+03
EP	0	0	0	0	0	5
ACP	0	0	0	0	0	5
VSP	0	0	0	0	0	5
Investment	0	1.3E+07	1.3E+07	1.3E+07	0	0
Remodeling	0	1.6E+05	1.6E+05	1.6E+05	0	0
Maintenance	2.6E+04	2.8E+04	3E+04	3.3E+04	3.5E+04	1.4E+04
Use	2.7E+05	2.8E+05	3.1E+05	3.4E+05	3.6E+05	2.3E+04
NPV	-3.6E+07	-3.6E+07	-3.6E+07	-3.6E+07	-3.6E+07	1E+06

Table 59: Sensitivity analysis parameters
Source: Own

Secondly, the weights over the requirements will be changed. These weights were 34%, 33% and 33% for the environmental, social and economic requirement, respectively. For the sensitivity analysis, the weights are changed to 60/20/20, 20/60/20 and 20/20/60. In this way, it's possible to see how the results are going to vary according to the different perspectives that a project can take (environmental project, administrative project or business project). Moreover, a 40/20/40 analysis will be carried.

CHAPTER IV: RESULTS

In this chapter are described the results obtained from the data characterization, the modeling, Simapro and MIVES. Some of the results have been shown on the methodology chapter, as they are used for methodological steps.

4.1 MODELING RESULTS

4.1.1 AIRCRAFT MODELING RESULTS

Now are going to be presented the results taken from the data characterization. First, the flight variances per day registered are shown. Notice that there's not a significant difference between the first and the second week, even being the second week a holiday period.

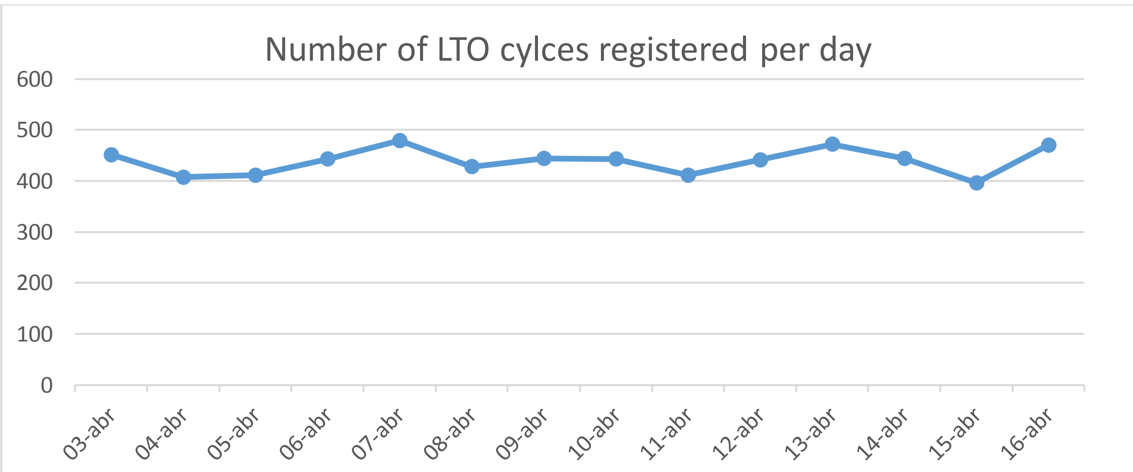


Figure 27. Registered LTO cycles per day
Source: Own

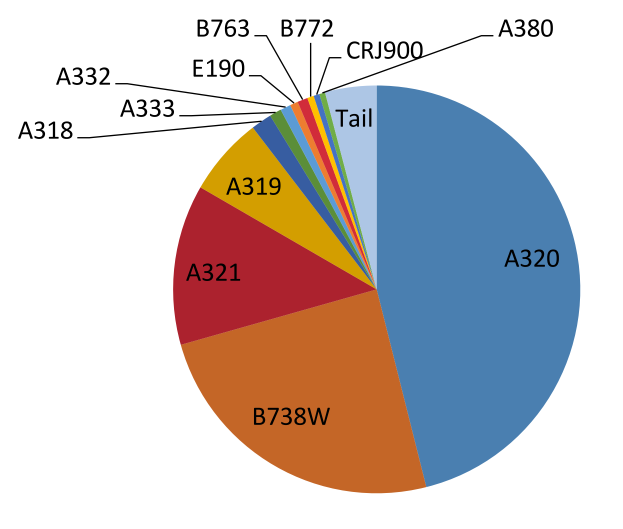
There aren't notorious differences in the variation of aircraft types. The main 12 types of aircrafts remain constant and the new aircrafts appeared along the second week (B773ER, B735, B739, D4X, CRJ85, CS1 and BAe146) belong to the "tail" of the study[13]. So, with the data collected is not possible to determinate this variation of aircraft types for a holiday period, and it will be considered a constant rate of aircraft types for the entire year.

[13] See annex 3.0. Variation of aircraft types due a holiday period.

It's considered that during the summer the number of charter flights is higher rather than other seasons, and the aircraft types may vary. As before, this possible variation is absorbed by the tail of the accumulative line, being the B752 the representative (and most polluting) aircraft on this tail.

As it's showed on the methodology chapter, 12 diverse types of aircrafts (over 49) represent a 95.91% of the total LTO cycles at LEBL. The percentage of aircraft types operating in LEBL, is the shown below.

Percentage of aircraft operations at LEBL



A320	46,09
B738W	24,52
A321	12,74
A319	6,25
A318	1,64
A333	0,94
A332	0,83
E190	0,63
B763	0,81
B772	0,52
CRJ900	0,47
A380	0,46
Tail	4,08

Figure 28: Percentage of aircraft type operating at LEBL
Source: Own

In terms of activity share, 99 different airlines have been registered, being Vueling, Ryanair, Easy Jet, Iberia, Lufthansa and Norwegian the airlines with more activity in LEBL (35, 13, 7 and 5%, respectively).

LTO cycles – EEA emission model

Using the EEA's modeling tool, the results for the total emissions of 2017 according to the aircraft type percentage, are the ones showed below.

Total aircraft LTO emissions during 2017

Tons/ 2017 LTO by aircraft	Fuel burn	CO_2	NOx	SOx	H_2O	CO	HC	PM non-volatile	PM [1]	PM TOTAL
A320	5.4E+04	1.7E+05	800.7	45.5	6.7E+04	476.3	94.7	4.8E-01	3.9	4.4
B738W	3.1E+04	9.8E+04	463.2	26.2	3.8E+04	216.1	22.2	8.8E-01	1.8	2.7
A321	1.9E+04	6.0E+04	338.9	15.9	2.3E+04	72.3	1.2	2.3E+00	1	3.3
A319	6.2E+03	1.9E+04	71.4	5.2	7.6E+03	74.2	15.3	3.0E-02	0.5	0.5
A318	1.6E+03	5.1E+03	16.9	1.4	2.0E+03	21.3	4,2	1.0E-02	0.1	0.1
A333	3.0E+03	9.3E+03	51.5	2.5	3.6E+03	24.8	2.4	6.0E-02	0.2	0.2

A332	2.6E+03	8.2E+03	45.3	2.2	3.2E+03	21.8	2.1	5.0E-02	0.1	0.2
E190	5.9E+02	1.9E+03	6.2	0.5	7.3E+02	9.6	0.9	1.0E-02	0.0	0.1
B763	2.0E+03	6.4E+03	33.7	1.7	2.5E+03	29.9	7.6	3.0E-02	0.2	0.2
B772	1.8E+03	5.7E+03	49.5	1.5	2.2E+03	8.0	0.3	3.0E-02	0.1	0.1
CRJ900	3.2E+02	1.0E+03	3.1E+00	0.27	4.0E+02	2.5	0.0	0.0	0.0	0.0
A380	2.7E+03	8.5E+03	4.7E+01	2.3	3.3E+03	16.8	0.2	0.0	0.1	0.2
Tail	8.0E+03	2.5E+04	9.3E+01	6.7	9.8E+03	62.5	0.9	0.6	0.4	1.0
Total	1.3E+05	4.2E+05	2.0E+03	111.8	1.6E+05	1036	152	4.5	8.5	13.0

Table 60: LEBL Aircrafts total emissions. 1: PM volatile (organic + sulphurous)
Source: Own

The main gases emitted are the carbon dioxide and vaporous water (71 and 28% respectively) and the resting 1% corresponds to the polluting gases.

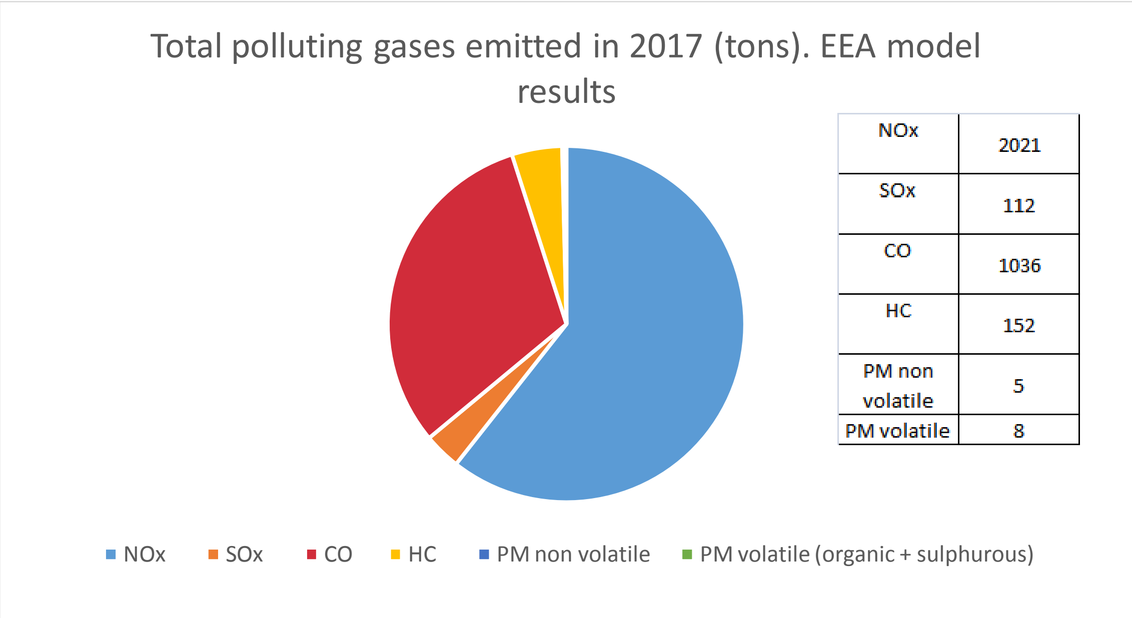


Figure 29. Total polluting gases emitted in 2017 due the LTO cycles (tons)
Source: Own

The total emission contribution per aircraft type is closely related to the assessed aircraft type's percentage distribution, being the A320, the B738W and the A321 the most contributors to the total emissions. The differences, in terms of aircraft type percentage, between these 3 aircrafts and the rest are notorious, but once this rest of aircrafts are analyzed, the total emission contribution differs from the total percentage of aircrafts types. For example, the A318 makes more LTO cycles at LEBL than the A330200, A330300, B763, B772 or the A380, but the total emission contribution of this aircrafts is higher than the A318. This information is showed below.

Comparison between the total emissions contribution per aircraft type and the percentage of LTO performed per aircraft types													
Aircraft type	A320	B738W	A321	A319	A318	A333	A332	E190	B763	B772	CRJ900	A380	B752
% Aircraft type	46.1	24.5	12.7	6.2	1.6	0.9	0.8	0.6	0.8	0.5	0.5	0.5	4.1
Tons emitted 2017	1512	762.5	427.2	184.3	49.1	85.6	75.6	19.6	81	59.1	6.3	68.3	174

Table 61: Comparison between the total emissions contribution per aircraft type and the percentage of LTO performed per aircraft types
Source: Own

LTO cycles - ICAO engines data sheet modeling

As explained on the methodology, another approach for the estimation of the aircrafts emissions is the usage of the engines data sheets. The total emission results using this approach are similar than the ICAO's LTO modeling, showed below. Thus, for the determination of the total emissions the EEA model is used, but using the engines data sheets allows knowing the flight phase which is more pollutant.

Comparison between models			
Total tons emitted LTO cycles 2017	HC	CO	NOx
Total ICAO engine datasheet	192	1,309	2,003
Total ICAO LTO model	152	1,036	2,021

Table 62: EEA and ICAO data sheet modeling results comparison
Source: Own

The emission results analyzed by flight phase shows that for the taxi phase, the main pollutant emitted is the carbon monoxide, and for the rest of the flight phases (approach, take off and climb out), the main pollutant are the nitrogenous oxides. This fact is due during the taxi phase, the combustion is more incomplete than the other flight phases, and so the carbon cannot completely oxidize to carbon dioxide and is emitted as carbon monoxide. During the take-off, the climb out and the approach, more thrust power is used so the engines temperatures are much higher, being a more completely combustion and capable of oxidizing more of the atmospheric nitrogen (N_2) to NOx[14]. Finally, below are presented the results of the total 2017 emissions when the engines data sheets are used. Notice that instead of particulate matter, the information is given in "smoke number", and this value reflects the amount of particles of any size, not just the PM_{10}, contained on the exhaust gases. This is another reason why these sets of emission factors are not used for the determination of the total emissions.

[14] See annex 4.9. Comparison of the aircrafts emissions according to the flight phase

LTO phases emissions. ICAO data sheet engines model results.				
2017 emissions (tons)	HC	CO	NOx	SM
TO	2	10	503	127
CO	5	28	957	249
APP	8	56	275	25
IDLE	177	1,216	268	40

Table 63: LTO phases emissions. ICAO data sheet engines model results.
Source: Own

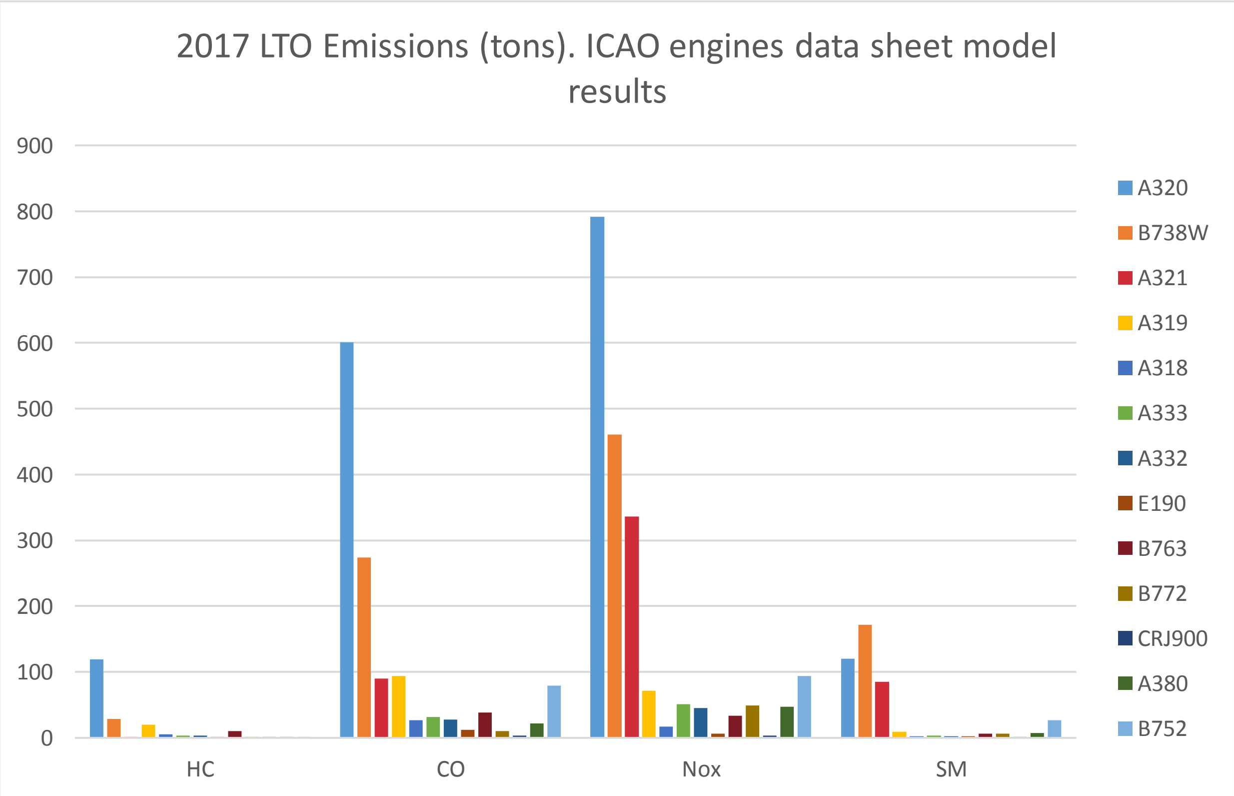


Figure 30. 2017 LTO Emissions (tons). ICAO engines data sheet model results
Source: Own

Taxi phase

Once the data obtained (% of aircraft types and the terminal sharing) is introduced on the model, the distances traveled are found (according to the table 10) as well as the time spent in the taxi phase at LEBL. The results show that the average taxi time in LEBL is 17 minutes, which is a little bit less than the standardized ICAO's taxi time for busy European airports, due LEBL is smaller in terms of passengers traffic and taxiways distances than the main European airports like Barajas, Heathrow or Amsterdam Schiphol. Moreover, the delays haven't been considered, making higher the difference between the estimated taxi time at LEBL and the ICAO's reference.

4.1.2 GROUND SUPPORT EQUIPMENT

Once the GSE (excepting tugs, APUs, GPUs and air conditioning vehicles) are modeled, the emission of pollutants is quantified. Due these LEBL's handling activities, a total of 93 tons of pollutants gases and 4,100 tons of CO_2 are emitted. Below it is shown the percentage emissions (and the tons) for the pollutant gasses, being NO_x and CO, the main gasses emitted.

Pollutant gasses emitted for the GSE		
	%	Tons
NOx	45.5	42.4
CH4	0.2	0.2
VOC	9.6	9
CO	41.3	38.5
$N_2 0$	0.2	0.2
PM_{10}	3.2	2.9

Table 64: Pollutant gasses emitted for the GSE (excepting the tugs, APUs, GPUs and air conditioning vehicles)
Source: Own

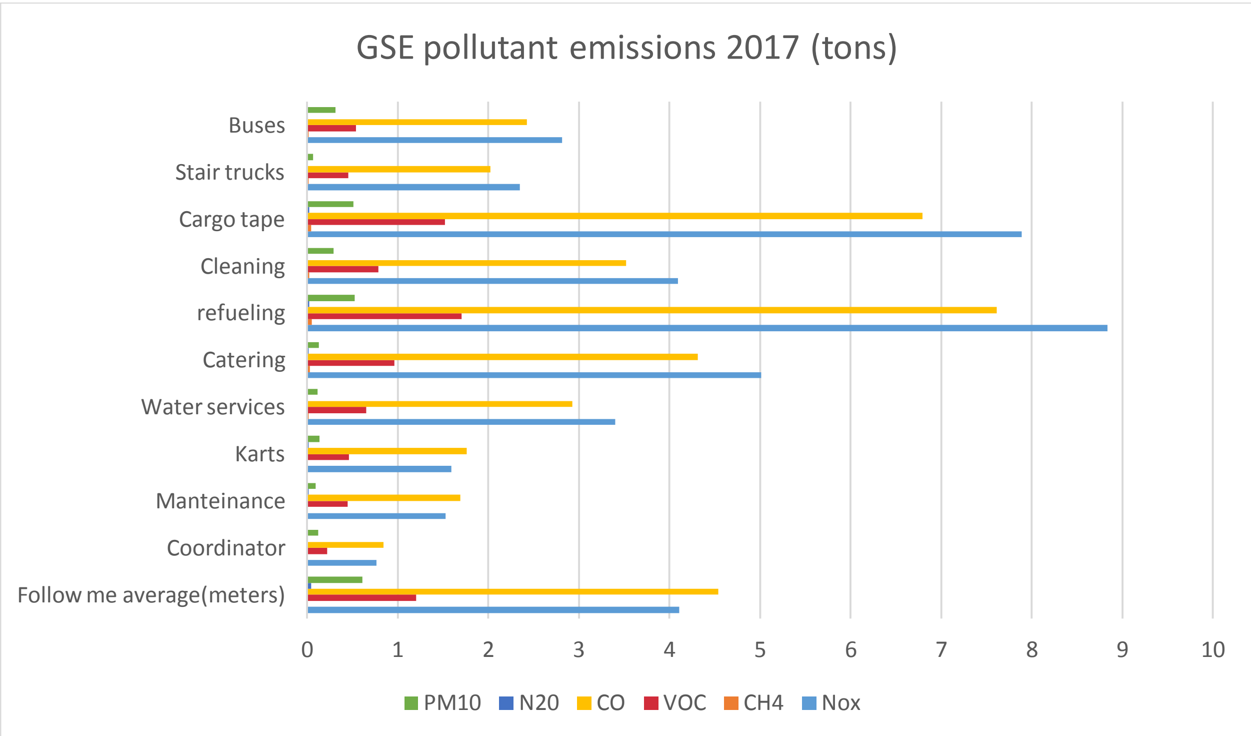


Figure 31. GSE pollutant emissions for attending all LTO cycles in 2017
Source: Own

The principal emissary sources of pollutant gases involving the GSE in absolute terms are the refueling, the cargo tapes, catering vehicles and the follow me cars. Bearing in mind the emission factors introduced and the activity time of the GSE, is logic that the refueling and the cargo tapes (being heavy duty vehicles and having the longest activities time) are the main pollutant sources, as well as the follow me for being the vehicle that travels the highest distances. Below, the total pollutant emissions by vehicle, in percentage and tons emitted[15].

GSE pollutant emissions in 2017 (tons ; %)

Vehicle	Tons
Follow me	11
Coordinator	2
Maintenance	4
Karts	4
Water service	7
Catering	10
refueling	19
Cleaning	9
Cargo tape	17
Stair trucks	5
Buses	6

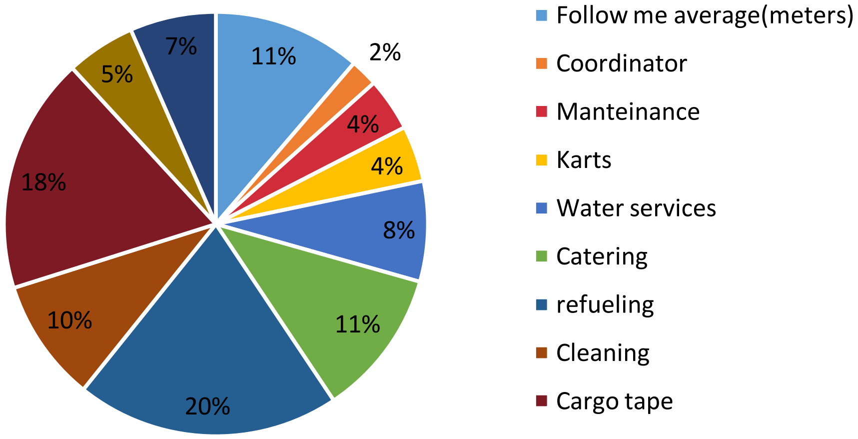


Figure 32. GSE pollutant emissions for attending all LTO cycles in 2017 (tons and percentage)
Source: Own

For the carbon dioxide emissions, the total emissions contribution per vehicle varies, as it's shown on the next graphic. Now, the main CO_2 emitter vehicles are the follow me car, refueling and cargo tapes. This is due the emission factors used, as for both heavy and light duty vehicles the CO_2 emission factor is the same. It is considered that the efficiency and restrictive policies over the engines were firstly focused on CO_2 emission reductions rather than the pollutant emissions. Thus, the Heavy-Duty Vehicles have the same emission factors than the light ones.

GSE CO_2 Emissions in 2017 (%)

Vehicle	Tons
Follow me	813
Coordinator	151
Maintenance	303
Karts	315
Water service	252
Catering	372
refueling	656
Cleaning	304
Cargo tape	585
Stair trucks	174
Buses	209

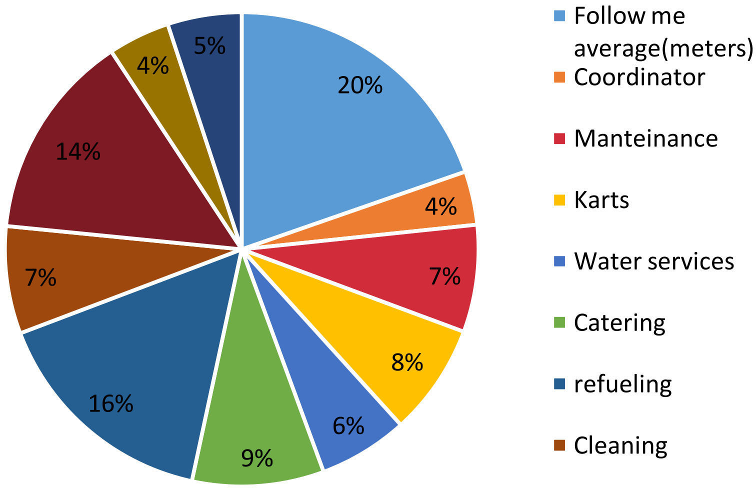


Figure 33. GSE CO2 emissions for attending all 2017 LTO cycles
Source: Own

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[15] See annex 4.10. Vehicle emissions contributions

Regarding at the pollutant emissions by terminal, it's shown that the main emitters are the refueling and cargo tapes vehicles. It's possible to see that for the activities that does not have any activity time set (follow me, coordinator, maintenance and baggage karts) the emissions for T2 A and B are higher than T1 due the distances traveled by vehicle are longer. Oppositely, the rest of GSE have more emissions on the terminal 1, because more aircrafts are attended. For the stair trucks and the buses, as there are more contact stands at the T1 (that doesn't require that service) their emissions are lesser than in the T2. The next figure shows the pollutant emission percentages per vehicle and terminal.

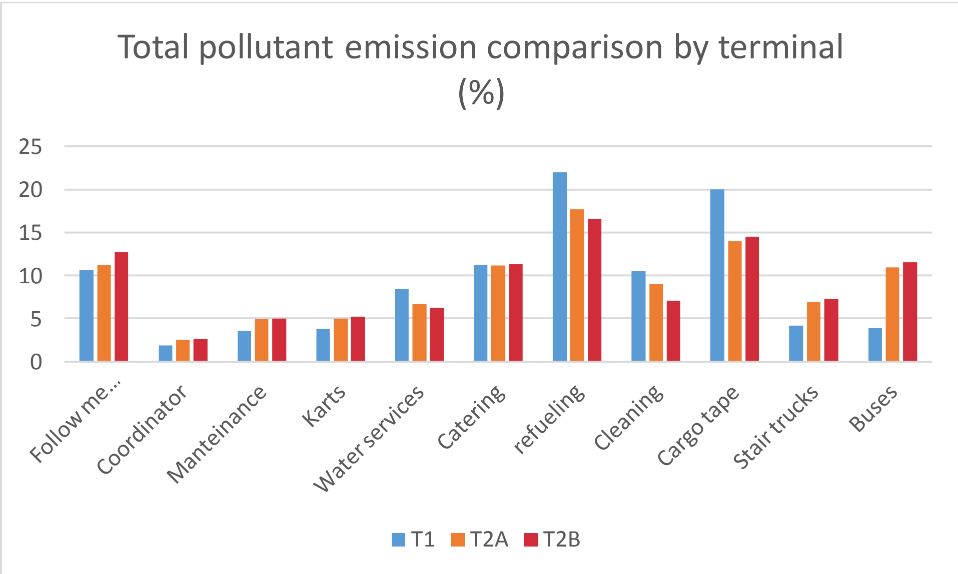
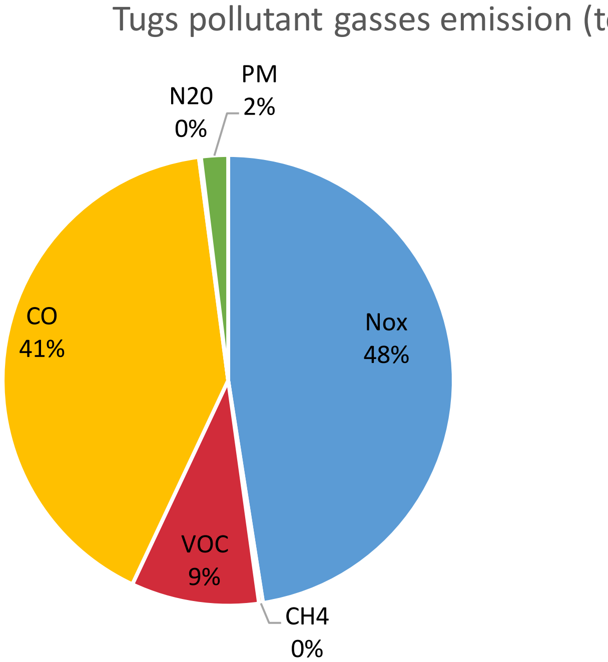


Figure 34. Pollutant emission by vehicle (%). Terminal comparison
Source: Own

4.1.3 OTHER GSE: TUGS, APU, GPU, AIR CONDITIONER

Tugs

The total gas emissions for the tugs activities rises to 467 tons, which a 97% of these emissions belongs to CO_2 (453 tons). The remaining 3% are polluting gases, being NOx and CO the main pollutant gases (6 and 5 tons respectively). Below is presented the pollutant emissions in tons due the tugs activity, and the percentage of emissions by terminal. As the terminal 1 have more contact stands where the pushback is required, a higher percentage of pollutants are emitted from T1 rather T2 (A or B).



Tugs emissions (tons)	
Nox	6
CH4	0,04
VOC	1
CO	5
N20	0,02
CO2	453
PM10	0

% Tug's pollutant emissions by terminal	
T1	83
T2A	3
T2B	14

Figure 35. Tugs pollutant gasses emissions in 2017
Source: Own

Ground Power Unit

The results show that the GPUs vehicles emissions are 158 tons of gases (95% CO_2). The rest of the pollutant gases are NOx (51%), CO (36%), HC (8%) and PM_{10} (5%).

The case of the GPU is different than the tugs, because there are more contact stands in T1 and the GPU vehicle it's no needed at these stands. Thus, a 63% of the emissions are generated in T2B, and a 12 and 24% are generated in T2A and T1, respectively. Below is presented a figure with the emission values in tons.

GPU total emissions in 2017

	T1	T2A	T2B	TOTALS
NOx	0.9	0.4	2.2	3.5
HC	0.1	0.1	0.3	0.5
CO	0.6	0.3	1.5	2.5
PM_{10}	0.1	0.0	0.2	0.3
CO_2	37.3	18.6	95.5	151.4

Table 65 : GPU total emissions in 2017.
Source: Own

Air conditioning

The air conditioning vehicles emits 205 tons, 198 tons of carbon dioxide and 6 tons of pollutant gases. Again, as the GPU's, the air conditioning vehicle is just needed at the remote stands, so at T2B are generated a 65% of the emissions, a 13% at T2A and a 21% at T1.

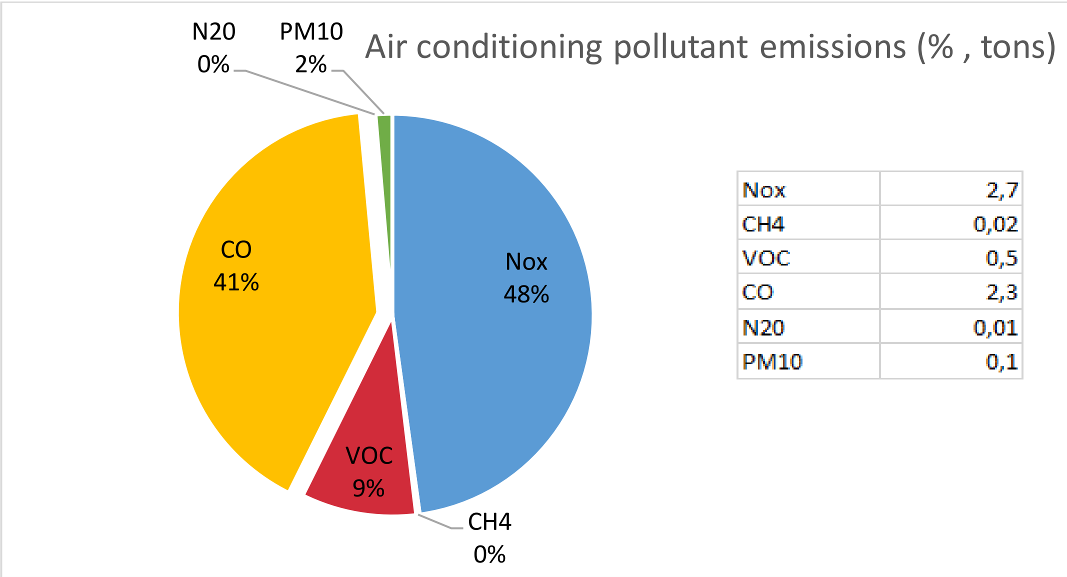


Figure 36: Air conditioning vehicle pollutant emissions in 2017
Source: Own

APU

Due the APU usage, the pollutant gasses emissions rise to 38 tons, without considering the carbon dioxide, which is not detailed on the ICAO's emission factors. On the Simapro results chapter, an approximation of the total CO_2 emitted by the APUs can be made through the IPCC methodology, which uses as indicator the total of CO_2 equivalent emitted. It is 5,278 tons of CO_2 eq (bear in mind that this value contains within the contribution of all the gasses emitted, not just the CO_2).

For the polluting gases contained on the ICAO's emission factor, the results show that the main specie emitted are NOx and CO (66 and 29% respectively), followed by the hydrocarbons (3%) and the particulate matter (2%).

Even being the APU usage higher at the terminal 2 (A and B), due there are more remote stands (so the APU is used during more time than in the contact stands), the APU emissions are mainly located at the T1 (59% of the total APU emissions). This is explained because the amount of aircrafts that operates on the T1 offset the time usage of the T2. Moreover, it is considered on the model that all the long-haul aircrafts are always making the turnaround processes on contact stands, which means that is not available to use the APU during their whole TAP process.

Total APU emissions in 2017 (tons)

	T1	T2A	T2B	Totals	% pollutants emitted
NOx	15.0	1.7	8.8	25.4	66.2
HC	0.7	0.1	0.4	1.1	2.9
CO	6.3	0.8	3.9	11	28.5
PM10	0.5	0.1	0.3	0.9	2.3

Table 66: APU emissions in 2017
Source: Own

4.1.4 MODEL SUMMARY RESULTS

. Tons emitted 2017		NOx	CH_4	VOC	CO	N_20	PM_{10}	CO_2	Total
GSE	Follow me	4.1	0.011	1.2	4.5	0.04	0.6	813.4	823.9
	Coordinator	0.8	0.002	0.2	0.8	0.01	0.1	151.3	153.2
	Maintenance	1.5	0.004	0.4	1.7	0.02	0.1	302.6	306.3
	Karts	1.6	0.004	0.5	1.8	0.02	0.1	315.5	319.4
	Water services	3.4	0.021	0.7	2.9	0.01	0.1	252.2	259.3
	Catering	5.0	0.030	1.0	4.3	0.02	0.1	371.7	382.2
	refueling	8.8	0.053	1.7	7.6	0.03	0.5	655.6	674.3
	Cleaning	4.1	0.025	0.8	3.5	0.01	0.3	303.5	312.2
	Cargo tape	7.9	0.048	1.5	6.8	0.02	0.5	585.1	601.9
	Stair trucks	2.4	0.014	0.5	2.0	0.01	0.1	174.4	179.3
	Buses	2.8	0.017	0.5	2.4	0.01	0.3	208.9	215.0
	GPU	3.5	0.020	0.5	2.5	0.01	0.3	151.4	158.2
	Conditioning air	2.7	0.016	0.5	2.3	0.01	0.1	199.0	204.6
	Tugs	6.1	0.037	1.2	5.3	0.02	0.2	453.0	465.8
APU	APU	25.4	-	-	11.0	-	0.9	-	-
Aircrafts	LTO cycles	2,020.6	-	-	1,036.0	-	13.0	419,142	422,211

Table 67: Modeling results summary
Source: Own

Below are presented two figures containing a summary of all emissions of LEBL along all 2017 (GSE, APU and LTO cycles). Notice that for the APU and the aircrafts there are no data of CH_4, VOC and NO_2. These values are smaller in comparison with the other pollutants, and taking as reference the main pollutant emitted of the GSE (NOx), the emissions of CH_4 and NO_2 represents a 0.5/1% of the NOx emissions. Thus, these values are not considered for the comparison. According to the GSE results, VOC's emissions represents a 20% of the total NOx emitted, which is not a depreciable value, but as no literature has been found for the VOCs emissions in aircrafts engines or APU's, so GSE's VOCs emission data are not used for the incoming comparison

Emission sources comparison (tons)

	GSE	APU	LTO
Nox	54.7	25.4	2,020.6
CO	48.5	11.0	1,036.0
PM10	3.6	0.9	13.0
CO2	4,937.4	5,276.2*	419,142.3
Total pollutants	106.8	37.3	3,069.6

Table 68: Emission sources comparison. *This value has been estimated using the CO_2 emission factors of the aircrafts (3.15 tons/kg kerosene).
Source: Own

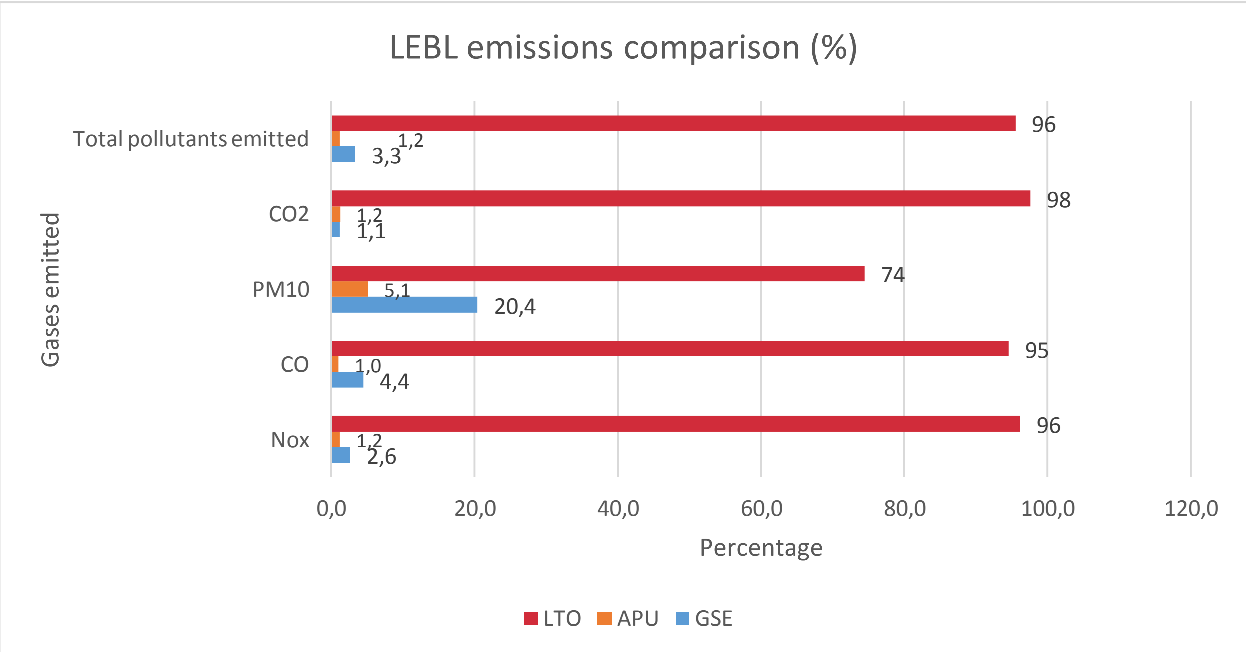


Figure 37: LEBL gases emission comparison for 2017
Source: Own

Clearly the LTO cycles performed at LEBL are the main contributors of the total airside airport emissions both for pollutant gases and CO_2. For the pollutant gases, a 4.5% of the total emissions are generated to fulfill the TAP needs of the aircrafts (GSE and APU) and the resting 95.5% of the emissions belongs to the aircraft operations. Particularly, the particulate matter is the pollutant which has fewer differences in terms of comparison between the LTO cycles and the GSE/APU, being both emitters of a 25% of the total particulate matter emissions. The contribution of CO_2 emissions for the GSE and APU decays to 2.3% in comparison with the LTO cycles contribution (97.7%).

The handling vehicles that have more pollutant emissions in LEBL due the servicing of all 2017 LTO cycles are: Refueling (16%), Cargo tapes (14%), Tugs (11%), Follow me (9%), Catering (9%), Cleaning (7%), Water (6%), GPU (6%), Buses (6%), Conditioning air (5%), Stair trucks (4%), Baggage karts (3%), Maintenance (3%) and the Coordinator vehicle (2%).

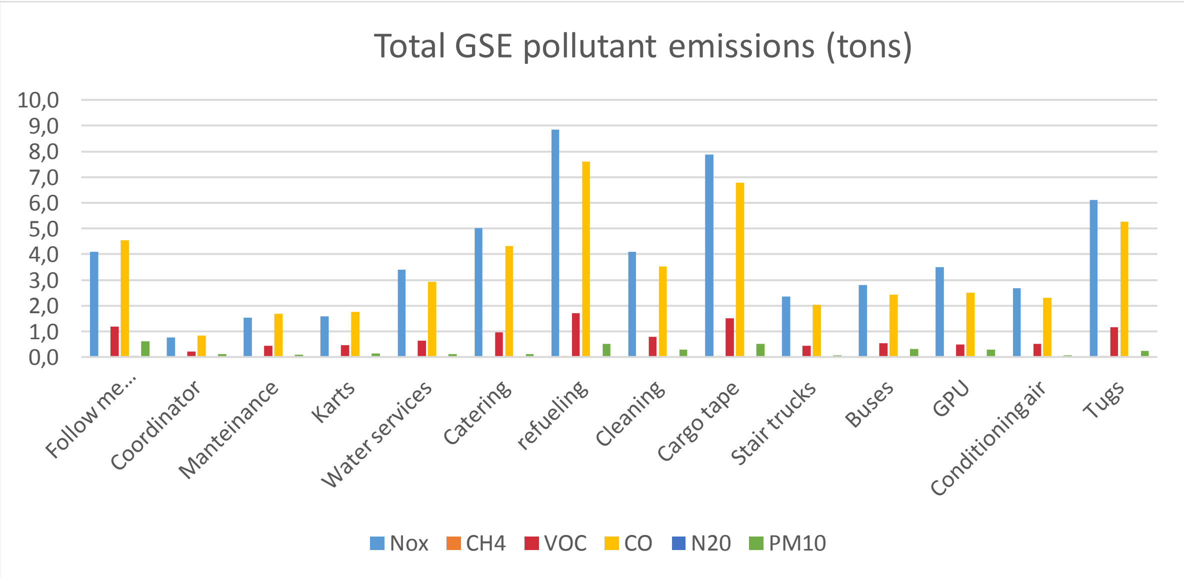


Figure 38: Total GSE vehicles pollutant emission comparison
Source: Own

So, it’s shown on the results that the main pollutant sources within the GSE, due their activities for attending all the Turnaround Processes are, by increasing order: Refueling, Cargo tapes, Tugs, Catering, follow me and catering vehicles.

Regarding at the aircrafts, below is presented a figure comparing the total emissions contribution according the aircraft type.

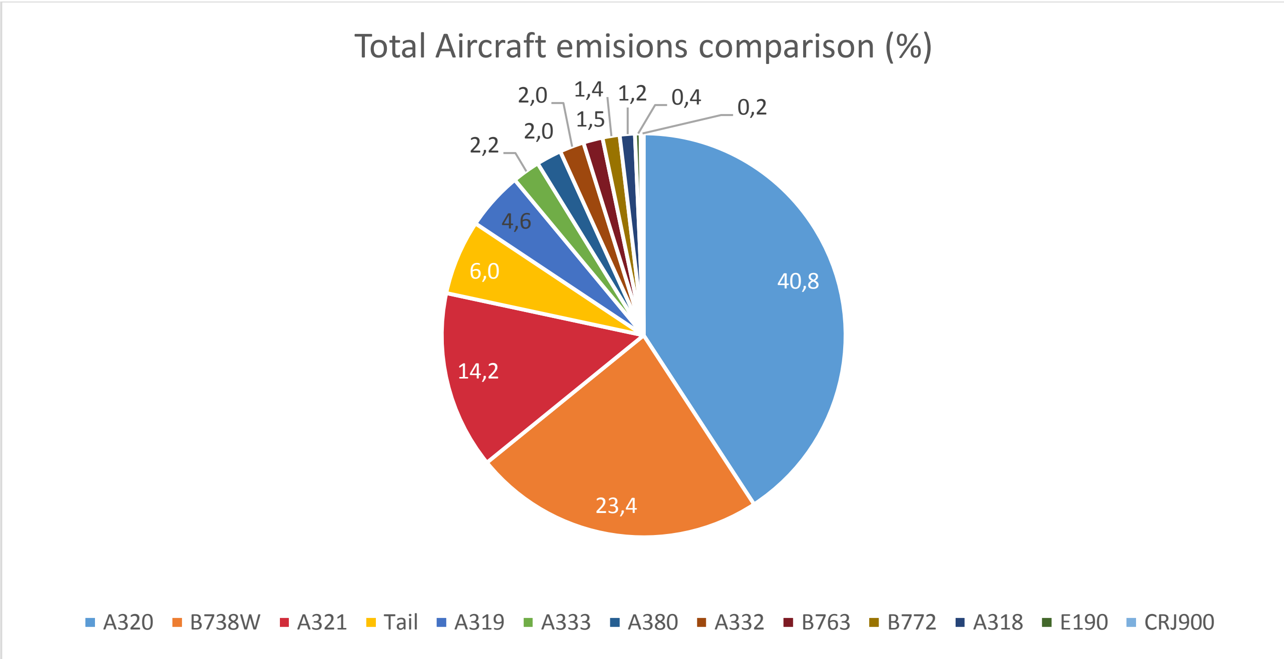


Figure 39: Total Aircraft emissions contribution
Source: Own

4.2 SIMAPRO RESULTS

Once all the processes created are analyzed, different outputs are founded according to the impact assessment methodologies used (ReCipe Endpoint H and IPCC GW). When using ReCipe methodology 14 impact categories are founded, involving 3 types of units for the quantification (explained on the methodology):

- DALYS (disability Adjusted Life Years)
  - Climate change Human Health
  - Ozone depletion
  - Human Toxicity
  - Photochemical oxidant formation
  - Particulate matter formation
  - Ionizing radiation
- Loss of species per year
  - Climate change Ecosystems
  - Terrestrial acidification
  - Freshwater eutrophication
  - Terrestrial ecotoxicity
  - Freshwater ecotoxicity
  - Marine ecotoxicity
- Cost ($)
  - Metal depletion
  - Fossil depletion

The main categories, the ones that accumulate more impact according to the final results, are shown on the following figure:

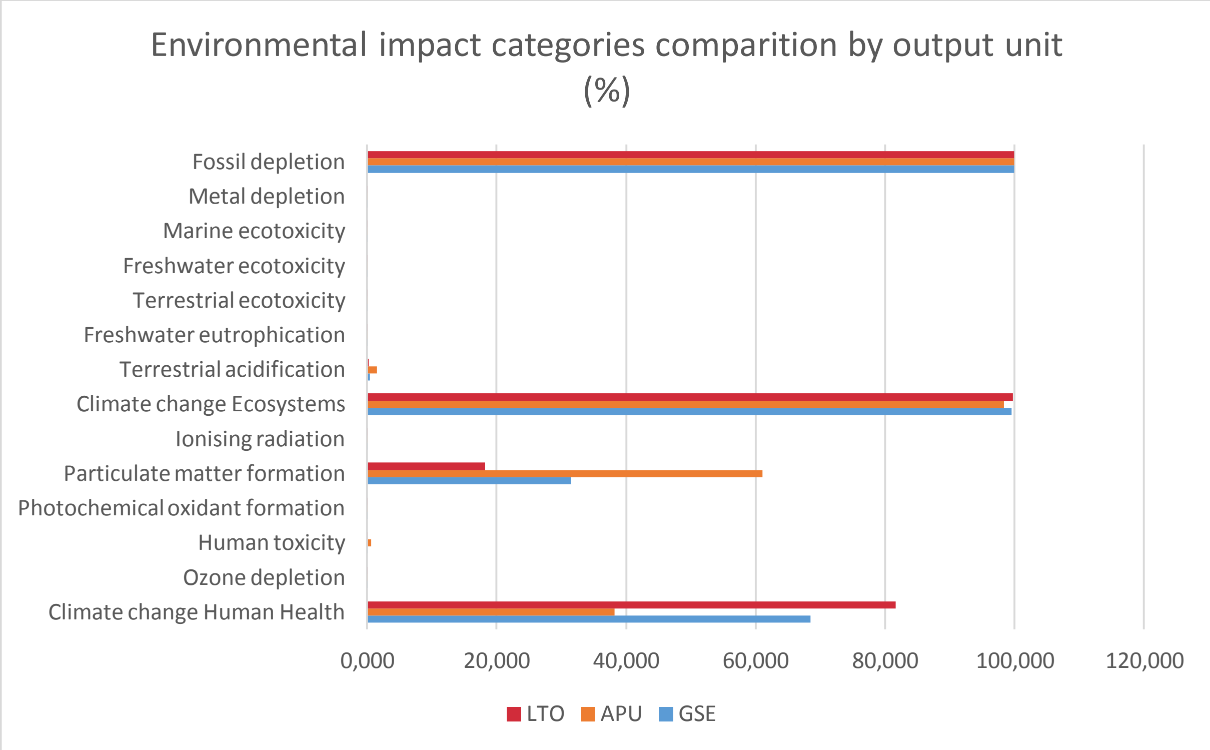


Figure 40: Environmental impact categories contribution comparison
Source: Own

- Climate change human health and particulate matter formation (average of 62.7% and 37%, respectively), represents a 99.7% of the impact categories measured in DALY's.

- Climate change ecosystems category impact accumulates a 99.2% of the total categories impacts measured in species per year.

- Fossil depletion accumulates a 99.9% of the total impacts of economic costs, the ones measured in $.

It's shown that the fossil depletion and climate change ecosystems environmental impacts, accumulates a high contribution percentage over the total environmental impact characterizations. In the case of the "particulate matter formation" and "climate change human health" environmental impacts (which are measured in DALY's), the results are different. The LTO and GSE environmental impact for the "climate change humans" is higher than the particulate matter formation and the opposite results are found for the APU's (where the environmental impact is higher on the particulate matter formation category). Moreover, it's shown that the LTO environmental impact over the "particulate matter formation" is fewer than the APU and the GSE.

This fact can be explained due the APU engines are the most inefficient in comparison with the turbofans and the diesel engines. The reason why the GSE have more impact for the particulate matter formation category is due the type of fuel used, being diesel the fuel with longest molecular carbon chains, which doesn't have enough time to be completely burned on the engines, resulting more particulate matter on the exhaust gasses.

When the IPCC 2013 GWP100a impact assessment methodology is used, the results have just one type of unit, the Kg of CO_2 equivalent emitted to the atmosphere.

For the results description, just the main impacts categories of ReCipe methodology (Climate change human health, particulate matter formation, climate change ecosystems and fossil depletion) are used, as well as the IPCC results.

4.2.1 AIRCRAFT ENVIRONMENTAL IMPACT

Environmental impact results by Kg of kerosene consumed during an LTO cycle

Once the processes for each aircraft are analyzed and normalized, the environmental impact for all the LTO cycles performed at LEBL in 2017 is found. First, the environmental impact per Kg of kerosene consumed during an LTO cycle is detailed. As the set of emissions introduced for each aircraft on Simapro where similar, the results for the environmental impact per Kg of kerosene consumed during an LTO cycle are equals for each aircraft type in the categories “climate change human health”, “climate change ecosystems” and “fossil depletion”; being 4.89E-06 DALYs; 2.77E-8 species per year and 0.18$ per each aircraft type; respectively[16].

For the categories “particulate matter formation” and IPCC GW, the results show some variations over the impact quantification per aircraft when 1 kg of kerosene is burned, showed below.

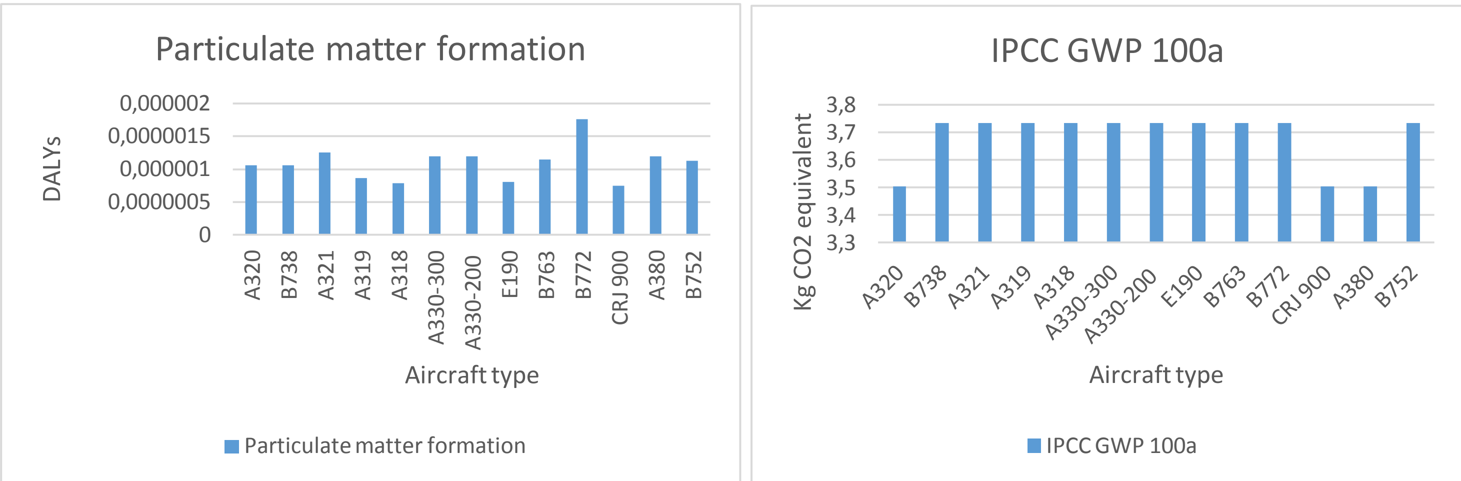


Figure 41: Environmental impact values per kg of fuel consumed, for the “particulate matter formation” and “IPPC GWP” categories according to the aircraft type.
Source: Own

According to the set of emissions introduced, the aircraft that have more environmental impact over the particulate matter formation due the combustion of one Kg of kerosene is the B772, followed by the A321, the A380, the A330, the B763 and the A320. The contribution to the global warming measured in Kg of CO_2 equivalent is equal for the all types of aircrafts (3.73) excepting the A320, the A380 and the CRJ900 which is 3.5 Kg of CO_2 equivalent per Kg of kerosene consumed during an LTO.

[16] See annex 14.11. “Climate change human health”, “climate change ecosystems” and “fossil depletion” impact categories results per kg of fuel consumed.

Environmental impact results per LTO cycle

When the previous results are multiplied by the Kg of kerosene burned per LTO cycle according to the aircraft type, the environmental impact for one LTO cycle is found. Below is showed the environmental impact assessed to one LTO cycle per aircraft type for the environmental impacts measured in DALY's. On the annex[17] are available the figures of the other category impacts, not shown here because have the same trend (according to the aircrafts type impact contribution) than this two showed category impacts, but explained after.

For all the impact categories and for one LTO cycle, the main aircraft contributors are the A380, B772 and the A330-300 and A330-200.

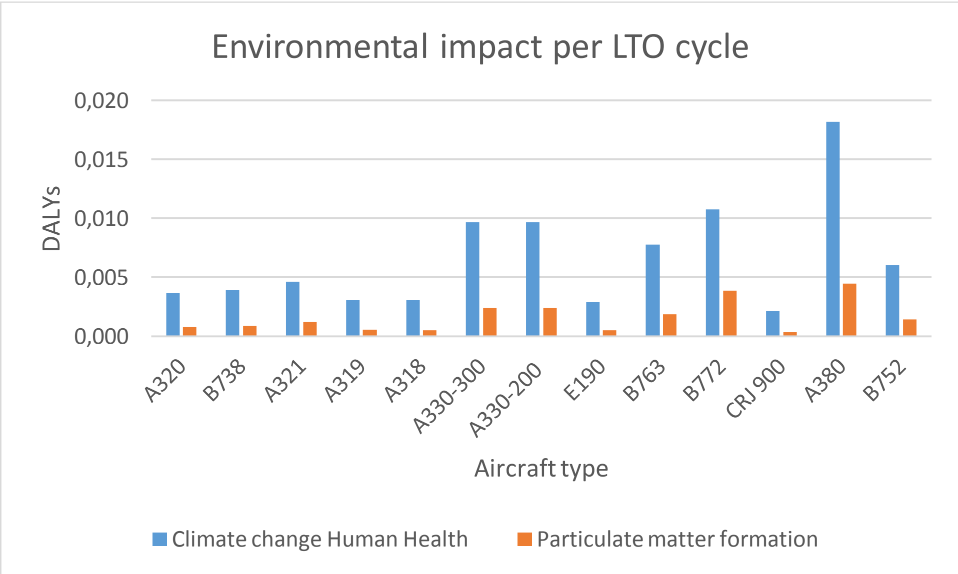


Figure 42: Environmental impact assessed to one LTO cycle per aircraft type
Source: Own

For the Climate change ecosystems impact category, the results show a range of values between 1E-5 (CRJ900) and 1E-4 (A380) measured in species lost per year. For the metal depletion, the range values expressed in $ varies from 80 to 700; and for the Global warming potential the range values in Kg of CO_2 equivalent varies from 1,500 to 13,000.

The results show that for one LTO cycle, the environmental impact is higher for the long haul aircrafts (A380, B772 and A330), followed by the B763, the B752 (tail) and the rest of aircrafts. Notice that for one LTO cycle, an A380 produce four times more impact than the A320 and almost two times more than the A330.

[17] See annex 4.12. "Climate change ecosystems", "fossil depletion" and IPCC GWP impact categories results per one LTO cycle and aircraft type

Environmental impact results for all LTO cycles in 2017

Once the previous results are normalized according to all LTOs cycles performed at LEBL, the results shows that the A320 followed by the B738W, the A321 and the characterization of the tail (B752) are the main contributors of the environmental impacts for all LTO cycles performed at LEBL. Due the magnitudes of the different units of the environmental impact categories are different, below is presented a table containing in ascendant order the name of the aircraft type which has more contribution over the environmental impacts.

Aircraft's contribution to the environmental impacts

Ranking	Climate change Human Health (DALYS)	Particulate matter formation (DALYs)	Climate change Ecosystems (Species/year)	Fossil depletion ($)	IPCC GWP 100[a] (Kg CO2 eq)
1	A320	A320	A320	A320	A320
2	B738W	B738W	B738W	B738W	B738W
3	A321	A321	A321	A321	A321
4	Tail	Tail	Tail	Tail	Tail
5	A319	A319	A319	A319	A319
6	A333	A333	A333	A333	A333
7	A380	A380	A380	A380	A332
8	A332	B772	A332	A332	A380
9	B763	A332	B763	B763	B763
10	B772	B763	B772	B772	B772
11	A318	A318	A318	A318	A318
12	E190	E190	E190	E190	E190
13	CRJ900	CRJ900	CRJ900	CRJ900	CRJ900

Table 69: Aircraft's contribution to the environmental impacts
Source: Own

The total LTO environmental impacts are detailed in the table below.

Total LTOs environmental impacts in 2017

	Climate change Human Health (DALYS)	Particulate matter formation (DALYs)	Climate change Ecosystems (Species/year)	Fossil depletion ($)	IPCC GWP 100[a] (Kg CO_2 eq)
A320	265.2	57.3	1.5	1.0E+07	1.9E+08
B738W	152.2	32.9	0.86	5.8E+06	1.2E+08
A321	92.6	23.7	0.52	3.5E+06	7.1E+07
A319	30.1	5.3	0.17	1.1E+06	2.3E+07
A318	7.9	1.3	0.04	3.0E+05	6.0E+06
A333	14.5	3.5	0.08	5.5E+05	1.1E+07
A332	12.7	3.1	0.07	4.8E+05	9.7E+06
E190	2.9	0.5	0.02	1.1E+05	2.2E+06
B763	10	2.3	0.06	3.8E+05	7.6E+06
B772	8.9	3.2	0.05	3.4E+05	6.8E+06
CRJ900	1.6	0.2	0.01	6.0E+04	1.1E+06
A380	13.1	3.2	0.07	5.0E+05	9.4E+06
Tail	39.1	9	0.22	1.5E+06	3.0E+07
Total	650.8	145.7	3.7	2.5E+07	4.8E+08

Table 70: Total LTOs environmental impacts in 2017
Source: Own

The total DALY impact rises to 796. This means that the world's population will lose 796 years of fully health, because the illnesses or early deaths caused by the climate change and particulate matter formation.

Because of 2017 LTO cycle emissions, 3.7 species will be extinguished, the cost associated to the extraction of fossil resources rises until 25 million dollars and the tons of CO_2 equivalent emitted are 500,000.

4.2.2 HANDLING VEHICLES ENVIRONMENTAL IMPACT

As commented before, the main impact categories for the GSE are Climate change human health, particulate matter formation, climate change ecosystems, fossil depletion and global warming potential.

Below are presented the environmental impact results when normalized[18].

TOTAL HANDLING ENVIRONMENTAL IMPACT 2017 BY vehicle

Vehicles	Climate change Human Health	Particulate matter formation	Climate change Ecosystems	Fossil depletion	IPCC GWP 100a
Follow Me Car	2.23	0.47	1.3E-02	3.4E+04	1.6E+06
Coordinator	0.42	0.09	2.4E-03	6.5E+03	3.0E+05
Maintenance	0.82	0.17	4.6E-03	6.5E+03	5.9E+05
Karts	0.9	0.19	5.1E-03	1.4E+04	6.4E+05
Water Service	0.68	0.37	3.8E-03	1.1E+04	4.8E+05
Catering	1.1	0.54	5.7E-03	1.5E+04	7.2E+05
Refueling	1.76	0.95	1.0E-02	3.1E+04	1.3E+06
Cleaning	0.81	0.44	4.6E-03	1.2E+04	5.8E+05
Cargo Tapes	1.75	0.9	9.9E-03	9.2E+04	1.3E+06
Stair Trucks	0.51	0.27	2.9E-03	1.5E+04	3.7E+05
Buses	0.61	0.33	3.5E-03	1.2E+04	4.4E+05
Conditioning Air	0.52	0.32	3.0E-03	6.8E+03	3.7E+05
TUGS LH	0.16	0.1	9.0E-04	1.4E+03	1.1E+05
TUGS SH	1.07	0.64	6.1E-03	2.2E+04	7.6E+05
GPU short haul Remote	0.56	0.56	3.2E-03	1.7E+04	4.0E+05

Table 71: Handling vehicles environmental impact in 2017
Source: Own

For the “Climate change human health”, “climate change ecosystems” and “Global warming potential” impact categories, the main vehicles contributors are, by ascendant order: the follow me car, refueling truck, cargo tapes and the tugs. These categories have the same impact distribution in percentage by vehicle, showed below.

[18] See annex 4.13. Environmental impact results according to the functional unit (impacts per kWh consumed by vehicle) and for all the category impacts.

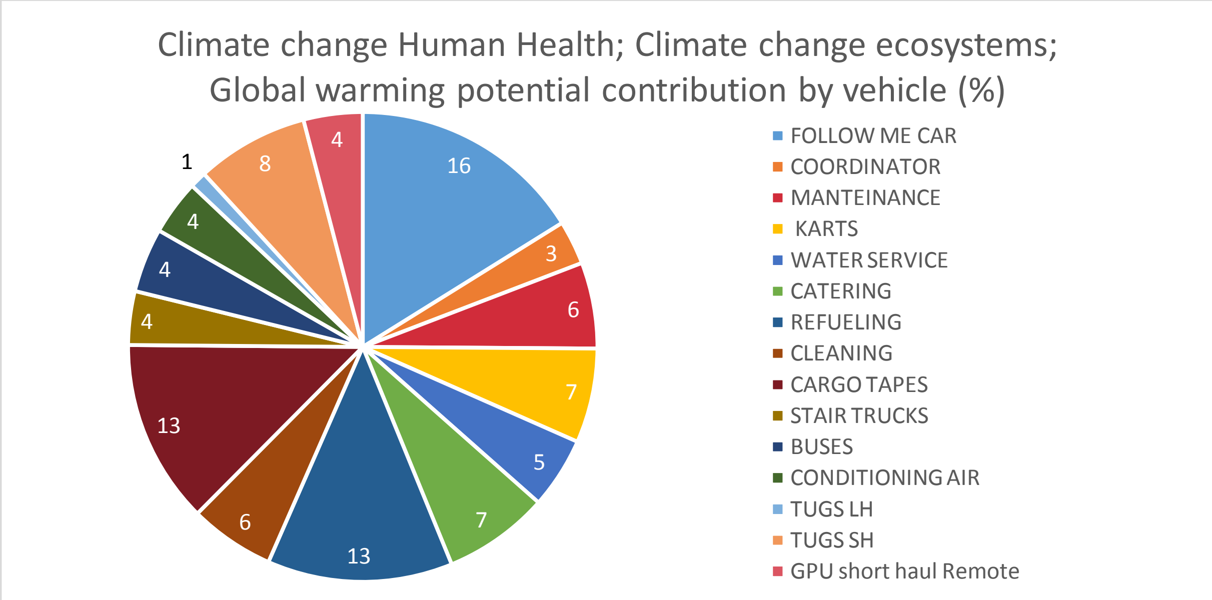


Figure 43: Climate change Human Health; Climate change ecosystems and Global warming potential impact categories contribution by vehicle (%)
Source: Own

For the “particulate matter formation” category impact, the vehicles that have more impact assessed for attending all the LTO cycles performed at LEBL are the Refueling, the cargo tapes, the tugs and the GPU. Below is presented a figure containing the percentage contribution per vehicle over this impact category.

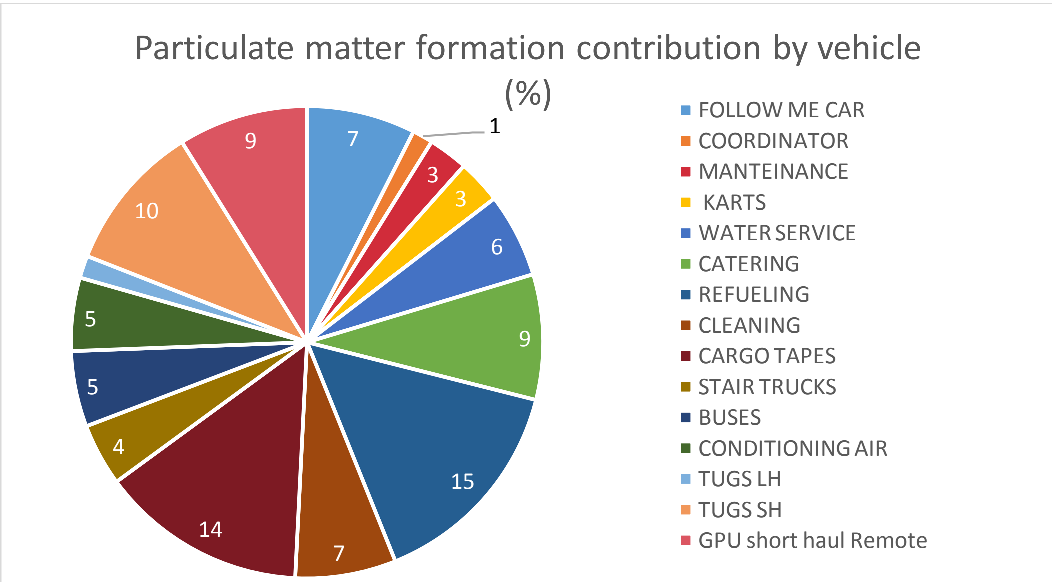


Figure 44: Particulate matter formation contribution by vehicle (%)
Source: Own

For the fossil depletion, the main impact contributor are the cargo tapes, the follow me car, the refueling trucks and the tugs.

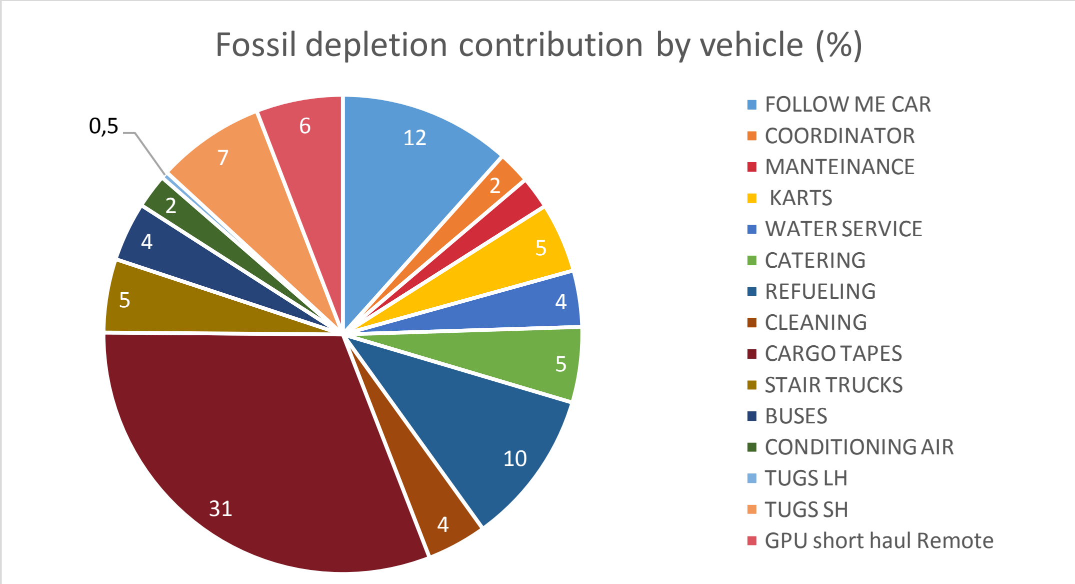


Figure 45: Fossil depletion contribution by vehicle (%)
Source: Own

The results show that the heavy-duty vehicles are the main contributors of the total environmental impact, excepting the follow me car. This vehicle, due their travels are longer than the rest of GSE, is the main impact source for the categories related with the climate change. The other light duty vehicles travel less distance in comparison with the follow me car, so their contribution to the total impact is fewer. Instead, for the particulate matter formation, the main contributors to this impact category are the heavy-duty vehicles.

It's possible to determine that the heavy-duty vehicles are the most impacting vehicles on the airport due the typology of their engines, but it's needed to consider the impact assessed to the follow me car.

Focusing on the environmental impacts distribution per terminal, the results shows that a 56% of the impacts are related to the handling activities on T1, meanwhile for T2A and T2B the percentage contribution to the impact are a 5% and 38% respectively. In comparison with the aircraft sharing by terminal (70, 4 and 26%, respectively), it's possible to see how in the T2 the environmental impact is higher than the percentage of incoming aircrafts to the terminal. The opposite happens for T1, where a 70% of the flights generate the 56% of the total impacts. This is due the distances traveled for the GSE (from the service points to the stands) are higher for the T2 than the T1.

4.2.3 AUXILIARY POWER UNIT

The auxiliary power unit results are based on the same environmental impact categories. Below are presented the quantification of the impacts due the usage of the APU in all terminals.

APU TOTAL IMPACT 2017

DALYs		Species per year	$	Kg CO2 eq
Climate change Human Health	Particulate matter formation	Climate change Ecosystems	Fossil depletion	IPCC GWP 100a
1.41	2.25	8E-03	5.4E+05	1E+06

Table 72: APU total environmental impact in 2017
Source: Own

The total APU's contribution to the airport environmental impact, in comparison with the GSE vehicles, is fewer in all the main categories excepting the "fossil depletion", which is 3 times higher. This fact can be attributed to the high fuel flow requirement by APU's.

It's needed to consider that for the rest of impact categories (not the main ones), the APU's impact results are higher than the GSE vehicles in the following categories: Ozone depletion, Human toxicity, Ionising radiation, Freshwater eutrophication, Terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and metal depletion[19].

According to the APU's impact per terminal, a 59% of the impacts are produced on the T1, and a 7% and 34% to T2A and T2B, respectively.

4.2.4 ENERGETIC MIX

The following results are the environmental impact assessed to the production of 1 kWh of energy in Spain according to the 2016 electrical mix. Three new impact categories have appeared (Agricultural land occupation, urban land occupation and Natural land transformation) due the wind power mix contribution. This energy source requires wide terrains to produce the energy, and the environmental impact related of this lands occupation and transformation is quantified. Moreover, the total impact when the results are normalized is presented, according to the energy consumed by each electric vehicle in 2017 (table 45).

The wind power and co-generation energy sources are the only contributors to "metal depletion" category impact.

[19] See annex 4.14. Enviornmental impact categories results for the APUs

Environmental impact assessed to the production of energy

Environmental impact category	Unit	Impact per kWh	Total impact*
Climate change Human Health	DALY	4.12E-07	5.59E-02
Ozone depletion		6.58E-11	8.92E-06
Human toxicity		1.32E-08	1.79E-03
Photochemical oxidant formation		3.15E-11	4.27E-06
Particulate matter formation		8.47E-08	1.15E-02
Ionising radiation		1.08E-11	1.46E-06
Climate change Ecosystems	Species/yr	2.33E-09	3.16E-04
Terrestrial acidification		7.47E-12	1.01E-06
Freshwater eutrophication		2.65E-13	3.59E-08
Terrestrial ecotoxicity		3.69E-12	5.00E-07
Freshwater ecotoxicity		2.85E-13	3.86E-08
Marine ecotoxicity		5.82E-14	7.89E-09
Agricultural land occupation		7.12E-11	9.65E-06
Urban land occupation		2.06E-12	2.79E-07
Natural land transformation		5.62E-12	7.62E-07
Metal depletion	$	7.56E-05	1.03E+01
Fossil depletion		1.21E-02	1.64E+03
IPCC GWP 100a	kg CO_2 eq	3.06E-01	4.15E+04

Table 73: Environmental impact assessed to the production of 1 kWh. *According to the total kWh consumed per electric vehicle (table 45)
Source: Own

The category impact with more contribution to the total impact for producing one kWh of energy are the Climate Change Human Health, representing an 80% of the of the categories measured in DALY's, the Climate change ecosystems (accumulating a 96% of the impact categories measured in species per year) and the fossil depletion (99.3%). Below are presented the percentage contribution for the impact categories measured in DALY's. The distribution for the rest of impact categories according to the unit (species per year and $), are not showed here because, as explained above, just one environmental impact represents the totality of these groups of impact.

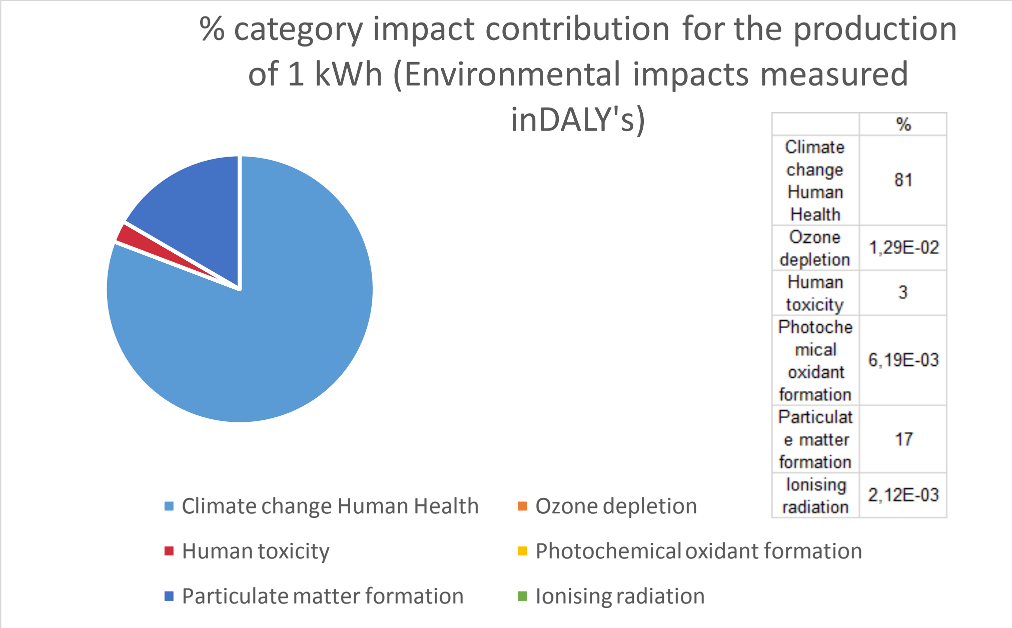


Figure 46: Environmental impacts (DALY's category impact) contribution for the production of 1 kWh.
Source: Own

Comparing the environmental impacts generated due engine combustion for producing one kWh of energy with the ones related to the electrical production of one kWh, the results are the following ones, given for the main impact categories and the vehicles chosen in the scenario to be changed from diesel to electric (50 % of the follow me, coordinator, baggage karts and buses).

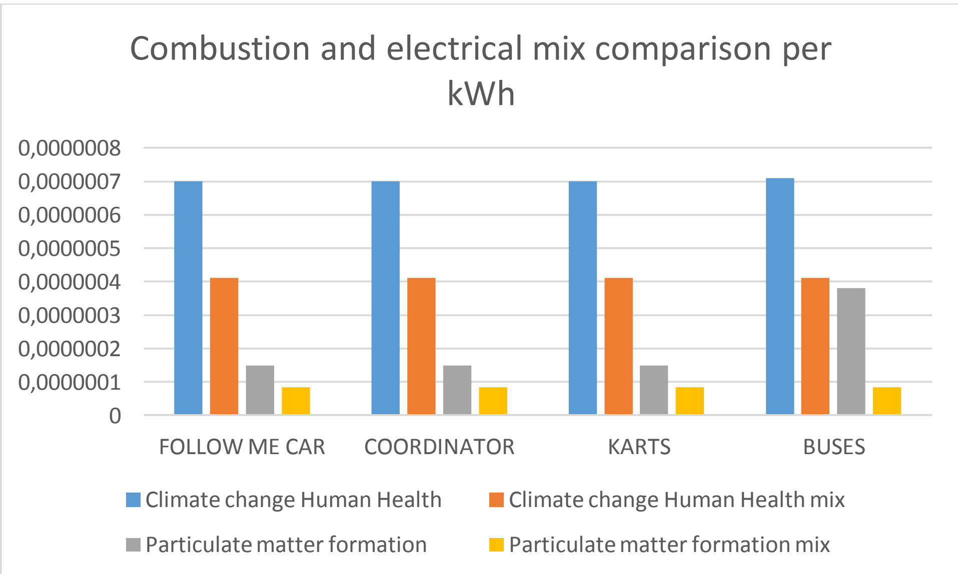


Figure 47: Combustion and electrical mix comparison per kWh.
Source: Own

For the impact categories measured in DALYs, the comparison between the combustion engine and the electric production of 1 kWh shows that the environmental impact is fewer for the electric production in a 41% and 43% for the categories “Climate change human health” and “particulate matter formation”, respectively), as it’s shown above.

For the impact category of “climate change ecosystems”, the electrical mix is again a 41% lesser than the combustion engines, and for “IPCC global warming”, the electricity generation generates a 38% less impact in comparison with the combustion engines.

According to the “Fossil depletion” impact category, is shown that the electricity production is higher (11%) than the combustion engine’s production of one kWh. However, the higher efficiency of the electric vehicles and their decreased consumption values per kilometer, turns lesser the total environmental impact related to the “fossil depletion” when electric vehicles are used.

In this figure is clearly seen the differences between the heavy and light duty vehicles, as the reduction of the particulate matter formation impact for the buses is a 77% lesser.

Below is presented a table containing the environmental impact comparison between the diesel and electric engines per one kWh.

Environmental impact comparison per one kWh (GSE vehicles and the electric mix)					
Environmental impact per kWh	Climate change Human Health	Particulate matter formation	Climate change Ecosystems	Fossil depletion	IPCC GWP 100a
Electric mix	4.12E-07	8.47E-08	2.33E-09	1.21E-02	3.06E-01
Follow me (diesel)	7.01E-07	1.49E-07	3.97E-09	1.08E-02	5.01E-01
Coordinator (diesel	7.01E-07	1.49E-07	3.97E-09	1.08E-02	5.01E-01
Karts (diesel)	7.01E-07	1.49E-07	3.97E-09	1.08E-02	5.01E-01
Bus (diesel)	7.09E-07	3.81E-07	4.02E-09	1.36E-02	5.07E-01

Table 74: Environmental impact comparison per one kWh (GSE vehicles and the electric mix)
Source: Own

Having into account all the environmental impact assessed to the electric vehicles for 2017 handling activities, the contribution per vehicle is the same for each environmental impact, showed on the next figure.

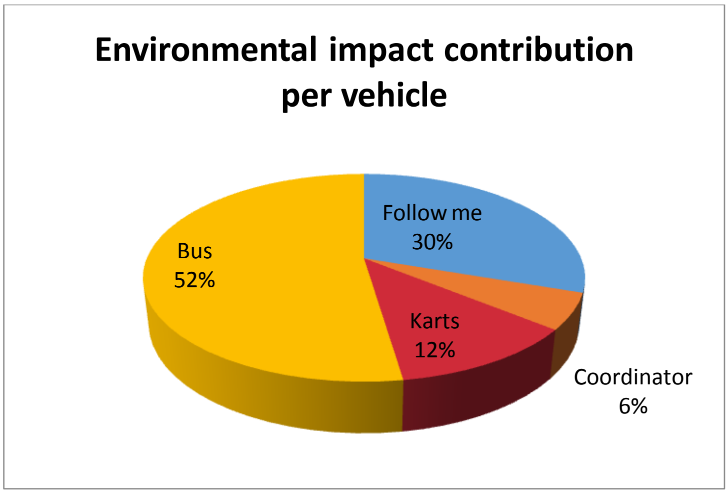


Figure 48: Environmental impact contribution per vehicle
Source: Own

4.2.5 GSE ENVIRONMENTAL IMPACT SUMMARY RESULTS

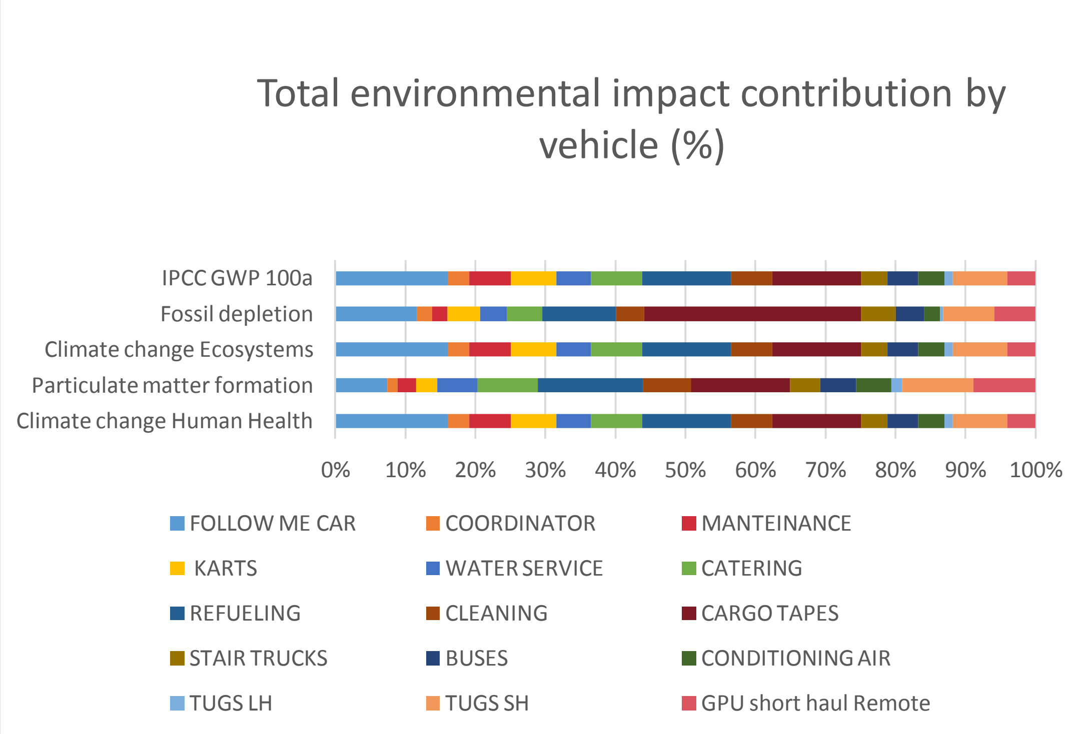


Figure 49: GSE environmental impact contribution summary.
Source: Own

4.3 MIVES RESULTS

In this chapter are going to be presented the sustainability comparison results between both scenarios as well as the sensitivity analysis results.

Below are presented the results for the first approach (equal weights for the requirements and a minimum satisfaction value of +20%). It's shown on the graphics that the total scenario weighting is higher for the S2 than the S1, with values of 0.506 and 0.436, respectively. This reflects that, in terms of sustainability, the scenario 2 is better making worth the economical effort of substituting the 50% of the diesel vehicles to electric ones. Tough is seen how there isn't a notorious difference between both scenarios (14% higher for S2).

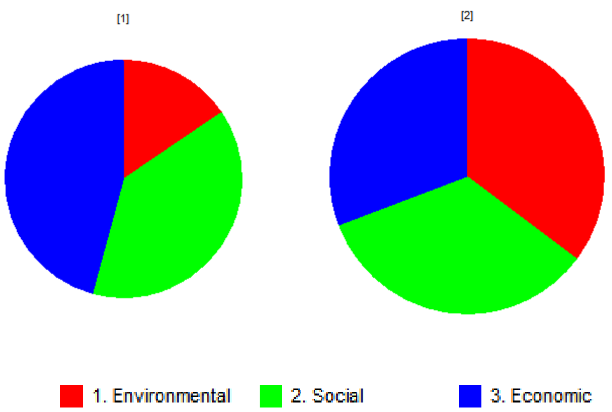


Figure 50: Final scenario weighting
Source: Own

Requirement contribution on the final weight

Results	Final weight (S1)	% (S1)	Final weight (S2)	% (S2)
Environmental	0.07	16	0.17	35
Social	0.168	38	0.17	34
Economic	0.2	46	0.16	31

Table 75: Requirement contribution on the final weight
Source: Own

It's shown that the economic and social requirements decrease their percentage weight contribution to the sustainability on S2 (4.5 and 16% respectively), while the environmental one increases a 20% for the S2. In terms of weight, just the economic requirement has less weight assessed on the S2 in comparison with the other two requirements, which have increased weights values on the second scenario.

In the case of the social requirement, the weights for each scenario are very similar, but higher for the S2, showing that the environmental perception criterion compensates the security perception criterion decrease.

Globally, the weight increase of the environmental and social requirements compensates the decreasing values of the economic requirement.

Thus, when an equally weighting is set for the requirements, the results for both scenarios are close each other, but higher on S2. This makes more interesting the upcoming sensitivity analysis.

Looking at results per indicator, all the environmental ones are higher on the S2; being the climate change over ecosystems and the fossil depletion the highest weighted indicators inside the environmental requirement. Moreover, these two indicators are the ones that increases more their weight on S2, with a 7% and a 6%, in comparison with the other three indicators (climate change human health, particulate change formation and GWP), which values on S2 increases in a 3%, 2% and 2%, respectively.

As commented, the social requirement shows an increase on S2 for the emissions impact perception and acoustic impact perception indictors (1% and 4% in weight, respectively), but compensates the decreasing value for the security perception indicator on the S2 (which decays a 10% in comparison with S1).

As expected, the results for the economic indicators (investment, parking remodeling and VPN) have decreased on S2 in a 16%, 6% and 4%, respectively, while the maintenance and use indicators gains 4% and 6%, respectively, on the total scenario weighting.

The following figures show the graphical weighting distribution per scenario and indicator and the corresponding weight percentage associated.

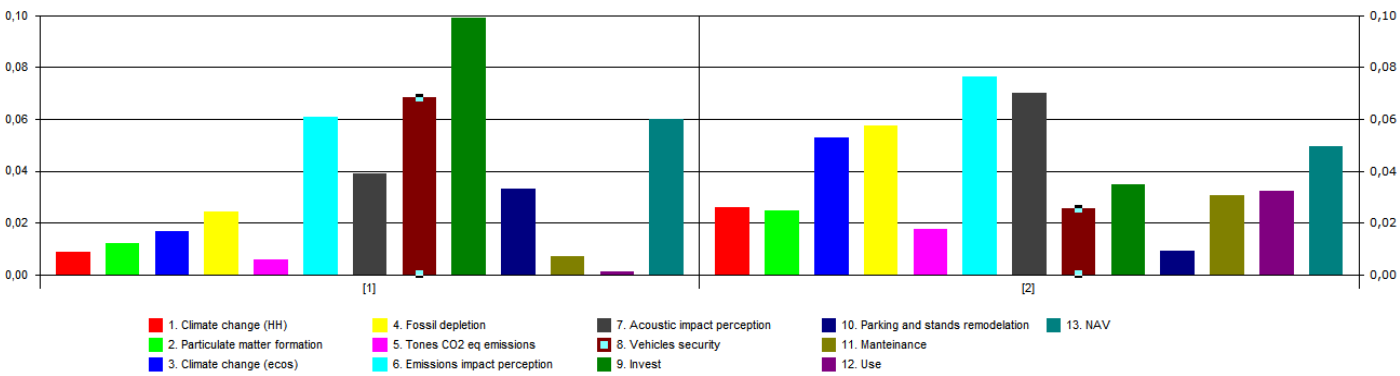


Figure 51: Indicators weighting comparison for S1 and S2
Source: Own

Indicators weighting comparison for S1 and S2

Requirements	Indicators	S1 Weights	S2 Weights	% S1	% S2	S2 % difference (S2 – S1)
Environmental	CC HH	0.009	0.026	2	5	3
	PM form	0.012	0.025	3	5	2
	CC ES	0.017	0.053	3	10	7
	Fossil D.	0.024	0.057	5	11	6
	GWP	0.006	0.017	1	3	2
Social	Environ. P.	0.061	0.076	14	15	1
	Acoustic P.	0.039	0.07	9	13	4
	Security P	0.068	0.026	16	6	-10
Economic	Investment	0.099	0.035	23	7	-16
	P. Remodeling	0.033	0.009	8	2	-6
	Maintenance	0.007	0.031	1	6	5
	Use	0.001	0.032	1	7	6
	NPV	0.06	0.049	14	10	-4

Table 76: Indicators weighting comparison for S1 and S2
Source: Own

4.3.1 SENSITIVITY ANALYSIS RESULTS

The sensitivity analysis has been carried on using different minimum satisfaction values for the valor functions (see MIVES methodology). This parameter is set as 5, 10, 30 and 40%, instead of the 20% used.

So, here below are presented the results for each requirement according to the parameter set.

Sensitivity analysis results (I)

Requirement	Scenario	5%	10%	20%	30%	40%
Environmental	S1	0.01	0.03	0.07	0.11	0.14
	S2	0.11	0.14	0.18	0.21	0.23
Social	S1	0.17	0.17	0.17	0.17	0.17
	S2	0.17	0.17	0.17	0.17	0.17
Economic	S1	0.19	0.20	0.20	0.21	0.22
	S2	0.14	0.14	0.16	0.17	0.18
Total	S1	0.37	0.39	0.44	0.48	0.52
	S2	0.42	0.45	0.51	0.55	0.58

Table 77: Sensitivity analysis weighting results
Source: Own

The final scenario weighting per each parameter shows always higher weights for S2 than S1. Also, the analysis results indicate that the lower the parameter set is, the less weight is assessed (to the environmental and economic requirement) over the total weight scenario and vice versa. This explains that the total scenarios weight rises when higher parameters are chosen. This occurs because when the minimum satisfaction values are close to the scenario's indicators values, a tiny weight is assessed to them.

When comparing the differences between the total weights per scenario (S2 minus S1), is shown that the weight differences rises from the parameter 5% to 20%. Then, when using 30% and 40% parameters these differences become smaller.

Sensitivity analysis results (II)

	5%	10%	20%	30%	40%
Total weight difference (S2-S1)	0.05	0.063	0.07	0.067	0.06
% weight difference (S2/S1)	12	13	14	13	10

Table 78: Sensitivity analysis results, differences between the scenarios
Source: Own

This fact is explained later trough the next table, where the differences between the scenarios and requirements are shown. The following numbers reflects how many times is bigger the value of the best scenario than the worst scenario (scenario 2 for the environmental and social requirements and scenario 1 for the economic requirement).

Sensitivity analysis results (III)

	5%	10%	20%	30%	40%
Environmental (S2/S1)	12	5	2,6	2	1,7
Social (S2 / S1)	1.02	1.02	1.02	1.02	1.02
Economic (S1/S2)	1.43	1.37	1.28	1.23	1.2

Table 79: Sensitivity analysis results, differences between the scenarios
Source: Own

So, for the environmental and economic requirements, it's possible to see a decreasing trend when higher parameters are used. This means that when low parameters are used the assessed environmental weight on the S1 is very low (due the data introduced is close to the minimum satisfaction level). Thus, if comparing with S2 where the environmental indictors have much higher values, the correlation between S2 and S1 are higher when using low parameters.

Oppositely, when higher parameters are used, the data introduced for the environmental requirement is farther from the minimum satisfaction value, so more weigh is assessed on S1 and the correlation between S2 and S1 decreases when using high parameters.

The same happens with the economic requirement, being higher the difference between the scenario 1 and scenario 2 when low parameters are used, and vice versa.

So, if low parameters are used, the weighting results over the environmental indicators are bigger (for the S2), but are bigger as well for the economic requirement (for the S1). Thus, in an environmental perspective would be better to set the environmental minimum satisfaction limits to a 5% and the economic ones to a 40%. Thus, the results depend on the weight compensation between the environmental and economic factor.

This reason explains the results of the table 79, where the differences between the weighting of the scenarios is highest for the +20% parameter, meaning that the +20% parameter reflects the most weighting compensation between the environmental and economic factor, thus making the highest weight difference between the scenarios for all the parameters.

Requirement's weighting sensitivity analysis.

For carrying the weighting sensitivity analysis, the parameter +20% is set as the minimum satisfaction values on the valor functions. The maximum satisfaction values set are the same, as well as the scenario's input values.

The weights over the criteria and the indicators haven't been changed; just the requirements weights are modified:

- 60% environmental, 20% social and 20% economic
- 20% environmental, 60% social and 20% economic
- 20% environmental, 20% social and 60% economic
- 40% environmental, 20% social and 40% economic

Now are presented the results according to the weight modification.

Requirement weighting modification results (I)

	60/20/20		20/60/20		20/20/60	
Requirements	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
Environmental	0.12	0.32	0.04	0.11	0.04	0.11
Social	0.10	0.10	0.31	0.31	0.10	0.10
Economic	0.12	0.10	0.12	0.10	0.36	0.28
Total weight	0.34	0.51	0.47	0.51	0.51	0.49

Table 80: Requirement weighting modification results
Source: Own

When the environmental and social requirements are over weighted, the scenario 2 is the alternative having more value, but not when the economic requirement is set as the main weight. Concretely, when a 60% is fixed to the environmental requirement, the results have the maximum difference shown on all results between S2 and S1, having the scenario 2 a 33% more weight than the S1.

When the main weight is assessed to the social requirement, the results of the social requirement for both scenarios are the highest contributors to the final weight, but they barely differ from each other. The contribution of the two other requirements is low. The environmental weight increase for the S2 is higher in proportion than the decrease of the economic one, compensating the results in favor of the S2. Tough, the difference between both scenarios is very close, being the S2 just a 9% higher than the S1, the lowest value shown for all results.

Oppositely, when a main weight is set for the economic requirement, the S1 becomes the more weighted scenario. Tough, both scenario weights are close each other, being the S1 just a 3% more weight than S2.

Requirement weighting modification results (II)			
	60/20/20	20/60/20	20/20/60
Weight differences (S2 -S1)	0.17	0.04	-0.01
% difference	33	9	3

Table 81: Requirement weighting modification results.
Source: Own

When a weighting of 40%, 20% and 40% are set, the results are 0.425 and 0.503 for S1 and S2, respectively, being the S2 a 16% higher in weight than the S1.

40/20/40 weighting results				
Results	**Final weight (S1)**	**% (S1)**	**Final weight (S2)**	**% (S2)**
Environmental	0.08	19	0.21	42
Social	0.10	24	0.10	21
Economic	0.24	57	0.19	38

Table 82: Sensitivity analysis results for a weighting of 40/20/40
Source: Own

4.3.2 SENSITIVITY ANALYSIS RESULTS SUMMARY.

According to the results, and focusing on an environmental perspective, the parameter that offers a best weighting difference between the scenario 2 and 1 (when an equal analysis is made, 34/33/33), is the +20% parameter. But, concretely, the environmental indicators gain more weighting when a +5% parameter is set; as well as the economic indicators.

Once carried all the sensitivity analysis, just when the main weight is set for the economic requirement (20/20/60) the scenario shows as a better alternative than the S2. For the rest of settings, the weight of the scenario 2 is higher than the S1, from a 9% to a 33% higher according to the parameters set.

The social requirement behaves very stable between scenarios using any parameter, due the indicators values compensates each other. For this reason, the sensitivity analysis for the weights 40/20/40 is carried on.

CHAPTER V: DISCUSION

In this chapter is presented the discussion of the obtained results over the engines exhaust gasses emissions quantification and their associated environmental impact, as well as for the sustainability analysis results.

5.1 Aircrafts and LTO cycles

The two models used for the quantification of the aircrafts emissions during their LTO cycles (EEA model and ICAO engines data sheet) show different values for the pollutants measured for both models (NOx, CO and hydrocarbons). Using the ICAO engine data sheet emission factors, the total LTO emissions for the CO and the HC are a 26% higher than the EEA's results model. Oppositely, NOx emissions are a 0.08% higher on the EEA model (thus, equal values).

Using the EEA model, a wide characterization of the pollutants can be performed, and makes more reliable the study in terms of quantification, as this model was developed on 2015 and the Engines data sheets are dated on 2013.

The characterization of the B752 as the representative aircraft for the tail of the study (see chapter 3.2.2) have an impact on the results, being the fourth aircraft with more emissions assessed. Also, the environmental impacts assessed for one LTO cycle are a 33% higher in comparison with the A320 and the B738, and a 50% higher in comparison with the A319 and A318. This means that the choice of a B752 can represent the tail of the study without underestimating their emissions and impacts.

The contribution, in percentage, to the total LTO emissions according to the aircraft type is closely related with the aircraft percentage distribution (% of aircraft types operating at LEBL) but differs for each aircraft. As well, when the environmental impact contribution in percentage is calculated, it differs from the percentage of operating aircrafts at LEBL, shown below.

Gas emission and environmental impact contribution per aircraft					
Aircraft type	LEBL operating aircraft types (%)	Total emissions contribution (%)	Total environmental impact contribution (%)	Emissions variation (%)	Environmental impact variation
A320	46	43.1	39.3	-3	-6.8
B738W	25	21.8	24.0	-2.7	-0.5
A321	13	12.2	14.6	-0.5	1.9
A319	6	5.3	4.7	-0.9	-1.5
A318	2	1.4	1.2	-0.2	-0.4
A333	0.9	2.4	2.3	1.5	1.4
A332	0.8	2.2	2.0	1.4	1.2
E190	0.6	0.6	0.5	0.0	-0.1
B763	0.8	2.3	1.6	1.5	0.8
B772	0.5	1.7	1.4	1.2	0.9
CRJ900	0.5	0.2	0.2	-0.3	-0.3
A380	0.5	1.9	1.9	1.4	1.4
Tail	4	5.0	6.2	0.9	2.1

Table 83: Gas emission and environmental impact contribution per aircraft
Source: Own

It is shown that for the A320, B738, A310, A318, CRJ900 and the E190, the emission and environmental impact contribution is lesser in comparison with their percentage of operation in LEBL. On the other hand, the aircrafts A330-200/300, A380, B763, B772 and the B752 (tail of the study) shows higher values of emission and environmental impact contribution in comparison with their percentage of operations in LEBL. Within the last mentioned aircrafts are shown the long haul aircrafts, allowing to determine that this aircraft type have more contribution over the pollution and environmental impact than the short haul aircrafts.

On the chapter 2.8, a quantification of LEBL's emissions is presented, according to the el Prat Directors Plan (2003). Comparing these values with the ones obtained on the modeling, the results differs each other, mainly for the CO and the HC (where the results of the modeling are a 50% lesser). For the NOx modeling results, it's seen that the value is a 13% lesser and for the Sox, the same value than the Director Plan and the model is found.

These values differences can be explained due the cargo flights and the private flights, performed at LEBL, are not considered on the modeling, as well as the possible schedule delays that increases the amount of gases emitted. Moreover, another factor enhancing the difference is the engines efficiency, which was lesser when the Director Plan was realized and thus the emission factors used should be higher. An example of this fact is the amount of SOx, almost equal for both quantifications, meaning that the past policies and restrictions on the emission of this pollutant are achieved. And so, the restrictions implanted from 2003 to the actuality over the other pollutants, should entail the usage of lower emission factors.

It's possible to say that the aircraft emissions and impact contribution is closely related to the percentage of aircraft types that operates at the airport, but it's needed to consider the ratio of long haul aircrafts, which contribution to the emissions and the environmental impact is higher than the short haul aircrafts.

Emissions comparison

Now are going to be compared the results obtained with the results of the Zurich airport environmental report. At this airport, 134,650 LTO cycles were performed in 2003, and the total NOx emitted by the ground handling vehicles were 110 tons (counting the APU's), corresponding to a 10% of the aircraft NOx emissions, 1,100 tons. For LEBL's results obtained, the NOx emissions of the GSE (and APUs) correspond to a 4% of the emissions generated by the aircrafts (80 and 2,020 tons, respectively).

Through this comparison, it's possible to see that the NOx emissions at Zurich are almost a 50% lower than in Barcelona just having a difference of a 17% on the performed LTO cycles. This difference is notorious, and could be attributed to the aircrafts types that operate on the airports (the LTO performed at Zurich are made, in more proportion than in Barcelona, by lesser polluting aircrafts as the turbo propelled).

Regarding at the table 7, a forecast of the NOx and PM_{10} emissions due the LTO cycles at LEBL (made by the Barcelona city council in 2014) is presented. The forecast for 2017 indicates that 147,401 LTO cycles are going to be performed (10% less than the value established on this model). The NOx and emission forecast for 2018 are 1,629 tons of NOx and 10.85 tons of PM_{10} (24 and 20% less than the results obtained on the model).

Looking on the IPCC global emissions report (figure 9), and comparing it with the LEBL's CO_2 equivalent emissions (LTO cycles), is found that the emissions contribution of the LTO cycles in Barcelona represent a 0.0001% of the global CO_2 emissions. Bearing in mind that the estimation of the total aviation contribution to the global CO_2 emissions is set to a 2%, according to this 2% El Prat airport has a contribution of a 0.05% on the aeronautic sector.

5.2 GSE Vehicles

As explained on the methodology, two sets of emission factors were used for the quantification of the GSE vehicles emissions (the NRVE emission factors for the PM_{10} and the EEA emission factor for the rest of the pollutants). Below is presented a comparison between the two models when the total emissions of 2017 are calculated:

GSE total emissions model comparison (tons)					
Emission factors	Pollutants	T1	T2A	T2B	TOTAL
MJ, EEA	**NOx**	**27.4**	**2.4**	**12.5**	**42.4**
	CH_4	0.1	0.0	0.1	0.2
	VOC	5.8	0.5	2.7	9.0
	CO	**24.8**	**2.2**	**11.5**	**38.5**
	N_20	0.12	0.01	0.06	0.19
	CO_2	2616.2	245.7	1272.1	4134.0
kWh, EU	**CO**	**22.2**	**1.9**	**10.1**	**34.2**
	HC	4.3	0.4	1.9	6.7
	NOx	**24.7**	**2.1**	**10.9**	**37.7**
	PM	1.7	0.4	0.8	2.9

Table 84: GSE total emissions model comparison in tons. These values do not take into account the Ac, GPU and tugs. Source: Own

It's shown how the EEA model has increased emission values than the NRVE for the pollutants modeled. Just the NOx and the CO are the pollutants measured for both models, and the quantification over them is a 12% higher using the EEA model. Thus, it's considered that the usage of the EEA emission factors makes more complete the pollutant characterization and decreases the total emissions underestimation.

Looking on the pollutant emission results obtained per vehicle (figure 34), it is shown that the main pollutants emitted are the CO and the NOx. Moreover, a difference between the Light Duty Vehicles and the Heavy-Duty Vehicles is found: CO is the main pollutant emitted by the LDV and NOx are the main pollutant emitted for the HDV.

The CO_2 emissions of the GSE are conditioned by the emission factors used, which are the same for the HDV and the LDV. Hence, the follow me vehicles turns to the vehicle with more CO_2 emissions within the GSE, a remarkable fact that needs to be considered on the evaluation of the vehicles fleet substitution. Contrary, the HDV (Refueling, cargo tapes and tugs) are the vehicles with more pollutant emissions assessed.

In absolute terms, a 60% of the total emissions are assessed to the HDV and a 40% to the LDV. But, as commented before, due the follow me vehicles have higher travel times, and the CO_2 emission factors are the same for the HDV and the LDV, the follow me vehicle is the main source of emissions (16% of the total GSE emissions), followed by the refueling truck, the cargo tapes and the tugs.

The environmental impact results assessed to the GSE follow the same trend than before. For the environmental impacts related with the CO_2 emissions (Climate change human health and ecosystems and IPCC GW) the follow me vehicle is the main environmental impact contributor, but for the rest of impact categories, the HDV are the most impacting vehicles.

Comparing the emissions between the GSE and the LTO cycles, the contribution of the GSE represents a 1.15% of the total emissions (when the CO_2 emissions are considered), and increases until a 4.4% when just the pollutants are compared.

Total emissions contribution		
	Tons emitted (2017)	%
Total LTO	4.2E+05	98.8
Total GSE	4.9E+03	1,1
total APU	3.7E+01	0,01
Pollutants LTO	3.1E+03	94
Pollutants GSE	1.4E+02	4
Pollutants APU	3.7E+01	1

Table 85: Total emissions contribution
Source: Own

When the environmental impacts categories are analyzed, for the impacts related with the climate change (over humans, ecosystems and IPCC GW) the GSE environmental impact is a 2% in comparison with the LTO cycles impact. But, for the particulate matter category impact the GSE represents a 4% over the LTO cycles.

The GSE impacts are strongly influenced by the type of aircraft attended, as it's shown below, where the GSE environmental impacts for attending one TAP of a short haul and long are compared at T1 and T2.

Environmental impact for one TAP. Short Haul and Long haul aircraft				
	TAP SH T1	TAP LH T1	TAP SH T2	TAP LH T2
Climate change Human Health (DALY)	1E-04	2.2E-04	1.5E-04	2.8E-04
Particulate matter formation (DALY)	4.9E-05	1.1E-04	6.4E-05	1.3E-04
Climate change Ecosystems (sp/year)	5.9E-07	1.3E-06	8.2E-07	1.6E-06
Fossil depletion ($)	1.9	5	2.6	6.1
IPCC GWP 100a (KG CO_2 eq)	75.1	158.4	103.9	200.6

Table 86: Environmental impact for one TAP. Short Haul (SH) and Long haul (LH) aircraft
Source: Own

It's shown that for the long-haul aircrafts the impact assessment is much higher, being the double for both terminals.

GSE vehicles comparison

As explained on the chapter 5.1, the contribution of the GSE and the APUs over the total NOx emitted at Zurich airport is bigger than at LEBL (10 and 4% respectively).

This may indicate that more available handling activities were introduced on the Zurich airport model, as the handling of the cargo flights, the aircraft maintenance procedures during the night and other procedures not related just with the attendance of the passenger flights. Moreover, the differences of the airport performance (taxi distances, type of stands, and availability of electric and air supply) can lead to this difference on the GSE NOx emissions.

Regarding at the total NOx and PM_{10} emissions coming from the road traffic of Barcelona, the values set on the Barcelona's air quality management report (2014) were 4000 and 360 tons. Comparing it with LEBL's GSE emissions, these represent a 2 and 1.6% (for NOx and PM_{10}, respectively) of the road traffic emissions.

Now, comparing the results of the table 7 (the forecast of NOx and PM_{10} emissions), the emission contribution of the GSE and the APU respecting the LTO cycles are a 4% for the NOx and a 18% for the PM_{10}, almost the same values found on this model (3.8% for the NOx and 25% for the particulate matter).

5.3 Emissions and environmental impact

As explained, the emissions and the environmental impact are mainly produced by the aircrafts, but for the particulate matter emissions and their environmental impact, the contribution of the GSE is higher than the other emissions or environmental impacts. For the PM_{10} emissions, a 20% are assessed to the GSE and for the GSE environmental impact "particulate matter formation", the contribution is a 4%. Both contribution values are higher in comparison with the resting environmental impact categories.

It is considered that the emissions estimated for the GSE are lower than in the reality. This is due the handling activities of the cargo flights are not scheduled on "infovuelos" (the web page where the aircraft data was taken). Also, the delay on the TAP that may occur increases the emissions of the GSE, and this factor is not included on the modeling.

Moreover, the model just quantifies the GSE activities for attending the TAPs, but other activities not related just with the TAP are performed by the GSE, as the maintenance procedures of spoiled aircrafts.

5.4 Electric vehicles substitution

When the substitution of the diesel fleet is evaluated in terms of sustainability, it is shown that this alternative is better than the current situation where all the vehicles are diesel. Although, the results obtained doesn't differ too much between both scenarios.

This means that the parameters introduced on MIVES have a significant role on the scenario weighting, and for this reason the sensitivity analysis performed is a crucial step for understanding the sustainability results. As commented on the results chapter, the sensitivity analysis allows to compare the different perspectives and aims that one project can take.

The carried analysis demonstrates that, just when the economic requirement of the scenarios is overweighed in comparison with the environmental and the social ones, the actual scenario barely has higher sustainability values than the purposed scenario. So, for the rest of weighting settings (where the environmental and social requirements are overweighed, and when the social requirement is less weighted in comparison with the other requirements), the sustainability values are higher for the purposed scenario.

When the requirement weighting modification are analyzed (Environmental/Social/Economic), logically the higher weighting difference between the scenarios is found when the environmental requirement is overweighed, followed by the analysis where the requirements are set as 40/20/40, 34/33/33 and 20/60/20.

As commented, the only weighting that makes more sustainable the actual scenario is the 20/20/60, but the final weights differences between both scenarios is the lowest found in the sensitivity analysis results.

Secondly, the parameters modified for the sensitivity analysis (the values of minimum satisfaction), doesn't have a big transcendence on the results, as all of these modifications maintain the purposed scenario with higher sustainability values. Just the total weight differences between the scenarios are affected.

It's possible to say that the better settings, having an environmental perspective, are the parameters +5% for the environmental indicators and +40% for the economic indicators. This configuration allows finding the maximum weight differences on the sustainability values.

Electric vehicles comparison

As explained on the chapter 5.3.1, 53 vehicles and 10 buses were the substitution target for the purposed scenario. In terms of direct emissions, these substitutions would be equivalent to retire a 1.6% of the total daily road traffic of Barcelona, quantified in 16,000 vehicles.

CHAPTER VI: CONCLUSIONS

At LEBL, most of aircrafts are considered short haul aircrafts (mainly A320 and B738). This fact has a strong influence over the emissions contribution, because the difference of kerosene consumption between the long and short haul aircrafts are notorious, as well as their ground handling services requirements. Thus, the characterization of the aircraft types is a key step to begin with the emissions and environmental impacts assessment.

In terms of emissions, the total emissions contribution per each aircraft is closely related to the percentage of aircraft types that operates at the airport. In the case of LEBL, a high difference between the main aircrafts and the rest is found, thus they accumulate the most part of the emissions. But, if the values for the long-haul aircrafts were more compensated, the emission and environmental impact contribution per aircraft type would vary. So, due the LTO cycles performed at LEBL, the aircrafts with more emissions and environmental impacts assessed are the A320, the B738 and the A321, accumulating a 78% of the total emissions and environmental impacts. The total CO_2 emissions for all the aircrafts due all 2017 LTO cycles rises until 0.4 million tons, and the pollutants emissions are quantified in 167,000 tons.

The handling activities deployed to attend the aircrafts during the TAP are as well conditioned by the aircraft type, the distances that the vehicles must travel according to the terminal where they are operating and the type of stand where the aircrafts are attended.

In absolute terms, the HDV (Heavy duty Vehicles) are the most contributors to the total emissions (60%), but the follow me vehicle, a LDV (Light Duty Vehicle) is the main emission source due their longer travels (in comparison with the rest of GSE) and the CO_2 emission factors used (same emission factor for the HDV and the LDV). Therefore, the environmental impacts related with the climate change have, as a main contributor, the follow me vehicles instead of the HDV. The total CO_2 emissions for all the vehicles for attending all 2017 TAPs rises until 4,785 tons, and the pollutants emissions are quantified in 310 tons.

Oppositely, having a look on the pollutant emissions, the HDV are the most pollutant vehicles on the airport, due their type of engine and the activity time associated to them. These vehicles are, by ascendant order: the refueling truck, the tugs, the cargo tapes and the catering vehicle (all considered HDV). After this group of vehicles, the next main contributor to the pollution are the follow me vehicles (considered a Light Duty Vehicle).

Considering the total emissions (CO_2 and pollutants), the main contributors are: Follow me vehicle (19%), refueling truck (16%), cargo tapes (14%) and tugs (9%).

Performing TAPs on T1 or T2 entails different environmental burdens, because the distances between the service points and the stands are farther at the T2 than at the Terminal 1. Also, as the T2 have more remote stands, so more GPU, conditioning air vehicles and buses are needed; but the tug's requirement is lower. Considering all the environmental impacts assessed to the vehicles, a 56% are related with the activities of T1 and a 46% are related to the T2. Comparing this values with the aircraft terminal sharing (70% of the LTO cycles performed on T1), it's possible to conclude that the activities deployed on the terminal 2 generates more environmental impact than in the T1, but doesn't compensate the amount of incoming aircrafts on the T1.

When the emissions and the environmental impact are compared between the LTO cycles and the handling activities, most of these are assessed to the LTO cycles (accumulating a 98% of the total emissions and impacts). However, the emissions and the environmental impact categories have different contributions within them, being the particulate matter formation the environmental impact in which the GSE has more contribution (6%) in comparison with the LTO cycles

The policies over the APU usage restrict the emissions from the APU, which have less contribution to the environmental impact than the GSE (except for the fossil depletion environmental impact), but it's considered a big source of emissions.

To reduce the emissions and the environmental impact of the GSE a big investment is needed for purchasing the electric vehicles, but the economical effort turns worth when social and environmental considerations are evaluated. The sustainability indexes over the raised scenarios are always higher for the purposed scenario, except when the economic requirement is overweighed. For any other weight configuration or parameter adjustment, the environmental and social improvements compensate the investment cost.

When an environmental or social perspective is chosen for the sustainability evaluation of the scenarios, the sustainability indicators are a 33% and 9% higher for the purposed scenario. When an economic perspective is set, the sustainability value for the actual scenario is a 3% higher (being the minimum difference found between both scenarios).

The substitution of the diesel vehicles implies a reduction of a 23% of the total GSE emissions. But, a 14% is the environmental impact reduction for the following impacts: Climate change human health, Climate change Ecosystems and IPCC GW. For the particulate matter formation and the fossil depletion, the reduction is an 8% and 10%, respectively.

CHAPTER VII: FUTURE WORK

The data characterization of the LTO cycles and the handling activities would need to be more exhaustive by using official sources (not using just the public data available), with the aim of quantifying all the LTO cycles performed at LEBL (taking into account the cargo aircrafts and the private flights) and all the extra handling activities performed that are not related with the services provided for attending the passenger's aircrafts.

Any data of possible delays on the LTO cycles or the handling activities have been found for el Prat airport. The delays increase the amount of emissions and environmental impacts; thus, a quantification of the delays could be introduced on the model.

In this project, when the MIVES tool is used, the environmental indicator values are directly related with the LEBL results obtained. These results can be relativized, with the aim of obtaining generalized sustainability results, which does not just belong to LEBL, having the chance of using this sustainability model for other airports.

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