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Bachelor Thesis

Environmental Information for Aviation Passengers

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Abstract

Purpose – Review of tools that inform passengers about the environmental impact of their flight. Review of tools that allow passengers to compare flying with other means of transportation. Improve already existing tools and develop new ways to determine the environmental impact of passenger transport.
Methodology – Continue work previously done on the ecolabel for aircraft. Study how the scientific community, governmental institutions, passengers, and the general public think about the environmental impact of aviation. Perform a survey that shows how airlines are perceived with respect to their environmental action and how environmental information should be presented to passengers.
Findings – The majority of people are willing to make changes in their travelling behavior in order to make it more environmentally friendly. Taxes or even restrictions would be accepted if fairness and transparency were felt. Passengers would like to be informed with an ecolabel for aircraft. Offsetting carbon emissions would be accepted, if the scheme is explained in detail. The bad reputation of airlines after years of not taking any measures for reducing their absolute environmental impact has made people skeptical about any airline initiative. In the corona pandemic it became apparent that airline associations were never in favor of reducing the number of flights.
Practical Implications – Methods for airline passenger to compare their travel emissions are proposed.
Social Implications – If passengers are able to compare travel options in terms of environmental impact, it will open up a new type of competition among airlines.
Originality – It is the first time that tools are collected and compared to allow airline passengers making an educated choice about their way of travelling regarding its environmental impact.

HAW HAMBURG

DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

Environmental Information for Aviation Passengers

Task for a Bachelor Thesis

Background

The airline Flybe was probably the first to present a label to show the environmental impact of an aircraft. However, this first label had major deficiencies. Tim Hass supervised by Prof. Scholz created in 2015 another proposal for an ecolabel for aircraft. Several other students further improved the label and the calculation method. Work went on to life cycle assessment (LCA) of aircraft. Several airlines offer offsetting schemes for flight emissions. These schemes also estimate equivalent CO2 as a basis to calculate the offsetting price.

Task

Task of this thesis is to provide passengers with information on the environmental impact of their flight compared with other means of transportation. The detailed tasks are:

- Analyze how different means of transport pollute. Understand which phases of the life of a vehicle have to be taken into consideration when studying their environmental impacts.
- Study how the environmental awareness in the aviation passenger sector has evolved over the years. Look at the scientific community, on governmental institutions, airline passengers, and the general public.
- Examine currently existing norms related to aviation pollution. Check, which parameters are limited.
- Analyze aviation emissions offsetting schemes. Look at different agents, countries, and companies.
- Review ecolabels schemes from other industrial sectors.
- Create a method that allows not only to compare aircraft and flights with each other but also to compare travel options including other means of transportation.
- Make a survey to check how environmental initiatives of airlines are perceived. Accomplish this also by reviewing articles on the topic.

The report has to be written in English based on German or international standards on report writing.

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List of Symbols

Symbols

D	Emitted mass
dBA	A weighted decibel
ER	Emissions reductions
FCF	Fuel conversion factor
FOR	Aeroplane operator's total final offsetting requirements
F	Thrust
K	weighting factor
LC	Baseline life cycle emissions values for aviation fuel
LS	Life cycle emissions
m	mass
MS	Total claimed mass
n	number of a given quantity
$\%O$	Per cent Individual in the given year y where $\%O_y = (100\% - \%S_y)$
OE	Aeroplane operator's CO_2 emissions
OGF	Aeroplane operator's Growth Factor
OR	Aeroplane operator's offsetting requirements
R	range
R_x	Absolute reflectance of x
S	seat surface
$\%S$	Per cent sectoral
SE	Total sectoral CO_2 emissions
SGF	Sector's Growth Factor
π	Pressure ratio

Indexes

$()_B$	covered during 2019 and 2020
$()_c$	compliance period c
$()_f$	Corsia elegible fuel
$()_i$	value i
$()_{max}$	maximum value
$()_{min}$	minimum value
$()_p$	emitted pollutant
$()_{pax}$	passengers
$()_s$	stained filter
$()_w$	clean filter
$()_y$	year y
$()_\infty$	total/maximum engine metric

List of Abbreviations

Acronyms

AFC	Aircraft Fuel Consumption
AMC	Acceptable Means of Compliance
C	Correction factor
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CS	Certificate Specificacions
D	Duration correction factor
EASA	European Aviation Safety Agency
EEA	European Economic Area
EES	European Emission Standards
EPNdB	Effective Perceived Noise Level in decibels
EPNL	Effective Perceived Noise Level
ETS	Emission Trading Scheme
EU	European Union
ICAO	International Civil Aviation Organisation
IR	Implementing Rules
ISA	International Standard Atmosphere
LTO	Landing and Take-Off
MPV	Maximum Permitted Value
MTOM	Maximum Take-Off Mass
NMVOC	Non Methane Volatile Organic Compounds
nvPM	non-volatile Particulate Mass
OEM	Original Equipment Manufacturer
PL	Perceived noise level
PM	Particulate Matter
PNLT	Corrected Perceived noise level
PNLTM	Maximum Corrected Perceived noise level
PNLTM	Maximum tone corrected perceived noise level

QCv	Quota Count Value
SAR	Specific Air Range
SN	Smoke Number
SPL	Sound Pressure Level
STGP	Sustainable Global Temperature Potential
TCDSN	Type Certificate Data Sheets for Noise

Terms and Definitions

Climate Change

"Climate change is a long-term change in the average weather patterns that have come to define Earth's local, regional and global climates. [...] Changes observed in Earth's climate since the early 20th century are primarily driven by human activities, particularly fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere, raising Earth's average surface temperature. These human-produced temperature increases are commonly referred to as global warming. (NASA, 2020)"

Global Warming

"Global warming is the long-term heating of Earth's climate system observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere. The term is frequently used interchangeably with the term climate change, though the latter refers to both human- and naturally produced warming and the effects it has on our planet. (NASA, 2020)"

Greenhouse Effect

"A warming of Earth's surface and troposphere (the lowest layer of the atmosphere) caused by the presence of water vapour, carbon dioxide, methane, and certain other gases in the air. Of those gases, known as greenhouse gases, water vapour has the largest effect. (Enciclopaedia Britannica, n.d.)"

Pollution

"The term 'pollution' is widely used and almost as widely misunderstood. A number of definitions of the term are examined and alternatives suggested. Certain natural phenomena causing deterioration in the quality of water, air, or soil may be similar in their effects to some of man's activities, but only the latter are normally subject to man's control. It is suggested that the term 'pollution' be restricted to certain human activities. (Russell, 1974)."

Survey

"An examination of opinions, behaviour, etc., made by asking people questions. (Cambridge Dictionary, n.d.[d])"

Systematic

"Scheme that uses an organized method that is often detailed. (Cambridge Dictionary, n.d.[e])"

The last definition was slightly adapted from the source where it was extracted to be contextualised it in this thesis. Terms such as tool, informative tool or whole tool will be used as synonyms: any construction that refers to a big group of smaller tools that through a methodical use serve an bigger purpose.

Tool

"Something that helps you to do a particular activity. (Cambridge Dictionary, n.d.[f])"

Type certificate

"A type certificate signifies the airworthiness of a particular category of aircraft, according to its manufacturing design ('type'). It confirms that the aircraft is manufactured according to an approved design, and that the design ensures compliance with airworthiness requirements. (Wikipedia, n.d.[c])"

1 Introduction

1.1 Motivation

As it will be seen more deeply along the development of the thesis, in general terms the environmental awareness is growing more and more with the passing of the years. From being a topic widely unknown by the majority population to becoming the center of political and citizen movements big changes must have taken place. If the industry and technology have been one of the most affected sectors, aviation and airlines could not be an exception. With the beginning of the industrial revolution and the increase of exploitation of fossil fuels the releasement of pollutants into the atmosphere rapidly enlarged. In the early times of this era the effects this pollutants had did not suppose a big concern. Air and water pollution happen daily without much inconvenience. As the consequences these effects had started to be known measures to tackle it started to appear. It was not until the end of the last century that the international community finally decided to take action on it, but airlines and aviation in general broke free from having to change much of its usual behaviour towards the environment. However, during the last decade everything started to change: the environmental issue started to worry not just scientists, but the public opinion as well. Political and citizen movements started demanding immediate action on climate change and environmental pollution, and since aviation lived most of its life without doing much on the topic, it became an easy target for those who wanted a greener future. With these claims, airlines and manufacturers began a race for implementing measures to make the sector more environmentally-friendly and what is more important, prove this to users.

In this framework of demonstrating the improvements of air transport the necessity of comparing aircraft and airlines is born. Some airlines want to differentiate themselves from others with worse environmental practices, but by doing that most of the times use self-claimed statistics. For pursuing this a standard scheme where all airlines parameters are computed transparently and with trustworthy means is necessary: this is where the ecolabel appears. However, one realises that although working in the aeronautic field, airplanes might not always be the most environmental solution for travelling. It has to be accepted that sometimes other transports should be used if the environment wants to be protected, at least with the current aircraft technology. This is why the necessity of designing a tool that not only allows to compare aircraft between each other, but with other transport means, appeared.

A very wide perspective in the passenger transport sector needs to be actively pursued for answering the every time more louder claim for not only a greener future but for a more transparent and informed one.

1.2 Title Terminology

Environmental

Strictly the term environmental means referred to the environment. However, in the context of this work a more specific can be found. At (Collins Dictionary, n.d.[a]) is defined as follows:

> *"Environmental means concerned with the protection of the natural world of land, sea, air, plants, and animals."*

If the meaning of "related to the environment" is taken, it should be understood what is the environment. This is why the following definition is presented. According to (Cambridge Dictionary, n.d.[a]) the word environment can be defined as follows:

> *"The air, water, and land in or on which people, animals, and plants live."*

Know it is understood that environmental is referred to topics related to the environment in the context of being concerned about its protection.

Information

The word information is used on a daily basis. Although its meaning is not supposed to present any problem, its definition will be shown anyway. At (Collins Dictionary, n.d.[b]) the definition can be read:

> *"Information about someone or something consists of facts about them."*

At the same page another definition slightly different is also provided:

> *"Information consists of the facts and figures that are stored and used by a computer program".*

Since in this thesis in order to inform about facts about the environment will be necessary to previously store data for being able to provide accurate figures, the last definition closes the whole meaning that will be given to this word.

Aviation

Aviation is a very generic word with a wide meaning. This can be seen by reading how it is defined at (Wikipedia, 2020b):

> *"Aviation is the activities surrounding mechanical flight and the aircraft industry."*

Aviation really implies everything that has to do with flying, designing, operating and maintaining an aircraft. This involves a big industry which obviously will not be completely analysed in this thesis. It has to be specified which sector is the one that will be targeted.

Passenger

In order to understand what aviation means, the term passenger has to be understood, for finally explaining which specific sector of the aviation sector is targeted. According to (Cambridge Dictionary, n.d.[c]) the term can be defined as follows:

> *"A person who is travelling in a vehicle but is not driving it, flying it, or working on it."*

It can be concluded that as the information will be provided to people that travel by flying, the aviation sector in which the topic of the thesis will be focused will be the one in charge of making this transport of people possible: the airlines.

1.3 Objectives

This thesis presents informative tools that allow the passenger to be best informed about the options that has to travel from one point to another regarding the environmental impacts of the journey. These tools consist on the aggregation of various smaller applications, such as websites or the Ecolabel. A creation of a new informative systematic like this is needed to allow the passenger to compare all their travelling options in a structured manner. The functioning of the online tools is explained through the presentation of exemplifying calculations and comparisons. When introducing the Ecolabel, a modified version is considered to be used since it is analysed in order to implement possible changes that could improve its operativity. Finally, a research is done on how passengers perceive these informative tools, which include among other the ecolabel or the carbon offset mechanisms, via the spread of a survey.

1.4 Structure

This work consists of 9 chapters. The structure of the thesis is as follows:

Chapter 2 In this chapter the pollution types are reviewed. Moreover, how transport means participate in this pollution forms is also examined. For finally understanding the relationship between vehicles and pollutants, the life cycle assessment is analysed.

Chapter 3	A study can be found of how the environmental awareness in the aviation sector evolved through the years. This is analysed from two points of view: the one of governmental institutions via international environmental agreements and the one from the general population via surveys that cover the public opinion. To link both perspectives, citizen and political movements on the matter are examined.
Chapter 4	In this chapter the normative that tackles the environmental impacts of aviation is reviewed. ICAO and EASA are chosen as the main sources of information.
Chapter 5	The concept of carbon offsetting is presented. Two offsetting mechanisms are studied: how companies offset their emissions in the framework of emissions trading schemes, and how passengers are given the possibility to offset the emissions of their journey.
Chapter 6	This chapter focuses exclusively on the concept of the ecolabel. Its origin is discussed. The existing ecolabels of the aviation sector are analysed to understand the existing work, as well as similar schemes of other vehicles. Finally, after studying possible improvable aspects, a new design that solves the inconsistencies is shown.
Chapter 7	The informative tools that allow the passenger to make a better educated decision about their travelling options are presented. After examining the flaws of the current informative tool, formed at the moment just by the ecolabel, two new systematics are proposed.
Chapter 8	In this chapter the perception of the environmentally friendly initiatives by the public opinion is reviewed. This is performed by reviewing existing literature and by analysing the results of a specific survey for the thesis.
Chapter 9	This chapter provides the conclusion of the thesis and recommendations for future work on the topic.

2 Fundamentals of Environmental Impacts ofthe Transport Sector

The main goal of this thesis is to inform the passenger about the environmental impact their flight causes. Until now, the methods that try to show the aviation pollution focus exclusively on aircraft. They compare how much different aircraft models pollute, or even how much a certain flight route pollutes in comparison with another. Although there are other transport means options available, such as trains or cars, they are not considered. It is important to recognise, that environmentally speaking it might be more responsible to consider other transports apart from planes. Since during this thesis a method that not only compares aircraft, but other vehicles as well, will be developed, a clear image of what taking a certain transport means is needed. This is why it will be provided a brief description of not only the pollution airplanes generate, but the one coming from cars, trains and ships will be explained as well. This is necessary to deeply understand the comparison tools that will be later shown.

2.1 Classification of Environmental Impacts

In each section the several impacts a vehicle causes to the environment will be disclosed. Firstly, the different types of pollution overall will be explained to be able to identify the most relevant ones for each transport sector. It is important to point out that not only human actions are the cause of the environment pollution. For example, soil erosion helps to increment the air and water pollution in certain situations. However, when describing each pollution type, only artificial sources will be presented. At (Skye, n.d.) the following pollution types are described

Air Pollution

Air pollution is described as any contamination of the atmosphere that causes a disturbance of its natural composition. This contamination is usually generated by particulate matter, such as carbon dioxide or dust, and various types of vapours. Vehicles exhaust is one of the most important sources of air pollution. Manufacturing exhaust, as well as forest fires and building construction or demolition are other main artificial sources of air pollution. Apart from being the responsible for many health problems, as asthma, which can lead to death, air pollution increase smog, rain acidity and the greenhouse effect.

Water Pollution

Water pollution is said to be the contamination of any form of water, such as oceans, rivers, lakes or other type of reservoirs due to chemicals, bacterias or particulate matter that degrade its purity. Improper waste disposal, organic material decay in water supplies, as well as leaching of soil pollution, are one of the most relevant water pollutants. Water pollution leads to the decrease of availability of water for human consume and crop irrigation. Moreover, it can harm any type of living being, both animals and plants, that depend on the corresponding water supply, which can lead to human damages subsequently.

Noise Pollution

Noise pollution is defined as any kind of noise with an undesirable level of intensity that disrupts the living of the population of the area. It is caused mostly by transport means. Airports, railroads and road traffic are usually responsible for the majority of noise pollution in living areas due to its constant character through time. However, manufacturing plants, construction or demolitions of buildings and leisure activities such as concerts or clubs are responsible as well for this kind of pollution. Although some effects of noise pollution can be temporarily, such as hearing loss after an intense and short noise, the majority and most worrying are not. Wildlife disturbance and living standards degradation, mostly due to sleep problems, are very common effects of noise pollution.

Visual Pollution

Visual pollution is said to be the existence of an element in an environment that heavily disrupts its visual homogeneity. It is mostly caused by the construction of big infrastructures, such as power lines, billboards or abandoned buildings. Although it is the pollution type that has the less severe effects on human health, it can heavily hazard the community identity of the area, which can end up causing several economic impacts. However, it does affect wildlife, as it often invades the natural environment.

Light Pollution

Light pollution is said to be the over illumination of an area. It could be considered an specific type of visual pollution. The sources of this over illumination usually come from big cities. Sky glow, which is the diffuse illumination of the night sky due to the city activity, big billboards and entertainment nighttime events. Apart from preventing the stars observation, it can degrade the quality of sleep of the residents of the affected area, which can lead to more serious health problems.

Thermal Pollution

Thermal pollution is characterized as an imbalance of the thermal cycle of the Earth caused by an excessive amount of heat released in to the environment, which leads to long-term effects. These effects are usually confined to areas near the source of heat, but they can have as well a wider geographical impact. Some of the sources that generate this are power plants, uncontrolled urban expansion, deforestation, loss of water reservoirs that work as moderating temperature sources and the emission of air polluting particles, which trap heat. Climate change is the most notorious effect of this kind of pollution, which leads to secondary effects that affect the whole wild and human life.

Soil Pollution

Soil pollution is said to be any kind of contamination that prevents the natural growth of the land. Improper waste management, abuse of inorganic pesticides, mining or deforestation usually cause this type of pollution. Soil pollution is often linked to water and visual pollution. It can imbalance and even eradicate its wildlife, as ell as erosion, which can lead to desertification.

Radioactive Pollution

Radioactive pollution is said to be the physical pollution of living organisms and their environment due to radioactive substances that were released during the handling of radioactive material. This can come from nuclear explosions, both from weapons and nuclear centrals accidents, uranium mining or radioactive waste disposals. Some of the effects of this type of pollution are birth defects, cancer or sterilization. It contributes enormously to water, air and soil pollution.

As it was stated initially, not all the previously described pollution types apply to the transport sector. Some of them, such as radioactive pollution, do not apply to any transport mean. Others, such as water pollution, are only relevant in case of ships. This is why each transport form might present some variations in respect to others. Nonetheless, speaking in general terms, air, noise and visual pollution will be the central topics of the following explanations. Thermal, light and soil pollution, which can be considered consequences of the later, will appear when necessary. It is important to remind as well that although this thesis aims to crate tools that allow passengers to compare their transport options, its central topic is aviation. This means that all the pollutants that surround aviation will be obviously the most relevant ones. If all transport means were willing to be treated with the same relevance level, a much deeper study should be made where people from other transport fields should be working as well.

2.2 Contribution of Vehicles to Environmental Impacts

Arrived at that point it is clear which types of pollutants exist. Therefore, it will be explained now how these transports exactly contribute to the environment pollution. As this thesis is centered on aviation, it is important to understand the aircraft pollution. The previous thesis that covered this topic were centered exclusively on aircraft environmental impacts, but as they will be compared to other means of transport it is important to have a global perspective. How aircraft, trains, ships and cars affect the environment will be briefly described. The same points that were presented at section 2.1 will be used. It is highly probable that different transport means share the same type of pollutants. Given the case its effects will be explained at the end when analysing the similarities and differences of the vehicles, in order to avoid reiteration. The particularities of each case will be explained as they appear. It will have to be understood also in which phases of the life of these transports will be considered and why, but due to the relevance of this matter, this will be presented in a separate point after the current one.

2.2.1 Aircraft

The environmental impacts of aviation will be now analysed. The current normative that regulates the aviation pollution, which methods are planned to be applied to overcome these impacts and how has this pollution evolved and will evolve through the years will be later on introduced. It is important to understand that although contributing to the environmental contamination, there are mechanisms thought for diminishing the damages it causes. Nevertheless, this section will focus exclusively on how aircraft harm the environment.

Climate Change Contribution

This category unites both thermal and air pollution, which are the main consequences of air travel. However, not all the agents that pollute the atmosphere participate in climate change, just some of them. This is why the next point will be used to present the air pollutant compounds that do not participate in the warming effect. As a form of transport that involves combustion, carbon dioxide and other greenhouse gases are released to the atmosphere. This implies, on the one hand, a contribution to the detriment of the air quality (air pollution) and an increase of the climate change (a type of thermal pollution). This is why both types will apply at the same time for most of compounds.

- **Carbon dioxide:** The most significant aircraft emissions during flight that contribute to climate change are from CO_2. The level of emitted particles is the same regardless the flight altitude. In (ATAG, 2020) is said that 915 million tonnes of carbon dioxide are produced yearly because of flights, which accounts for a 2% of the worldwide carbon dioxide production. However, it is stated as well that just 3 litres of jet fuel per 100 passenger kilometres is consumed in new aircraft such as the new Airbus A380 or Boeing 787. In (Wikipedia, 2020d) is stated that from British Airways sources, 100 gram of carbon dioxide per passenger kilometre are emitted when flying large jet airlines.

- **Oxides of nitrogen:** The emissions of NO_x, when released around the tropopause, tend to form ozone (O_3) in the upper troposphere. When oxides of nitrogen are emitted in high altitudes (such as 10km) great concentrations of O_3 are achieved. Unlike surface NO_x emissions, that are poorer in O_3 and have mostly local effects due to its concentration, tropospheric emissions tend to have global effects due to the level of mixture it gets. NO_x emissions end up having contrary effect. On the one hand, because of the formation of ozone, a warming effect is achieved. On the other hand, this compound reduces the level of methane in the atmosphere. Methane is a greenhouse gas, which in consequent, results in a cooling effect. However, since the formation of O_3 is still greater than the reduction of the methane, the net result is an atmosphere warming. Between 31 and 21 g/kg fuel burned of oxides of nitrogen are said to be emitted in an average flight (Turgut, 2017).

- **Water vapor:** The combustion of hydrocarbons with oxygen has as one of the results water vapor. Since kerosene is burned during flights, vapor gas is released, and as it is a greenhouse gas, it contributes to the climate change. When water vapor is released at high altitudes it condenses into droplets forming contrails, which basically are visible clouds line-shaped. They are thought to have a global warming effect, although it is weaker than the one that carbon dioxide and oxides of nitrogen present. Moreover, when water is released in the stratosphere, O_3 is depleted, which offsets its effect. This is the second contribution that has a water vapor, which in this case results into a cooling instead of a warming one.

- **Particulates:** During the flight, particles such as soot and sulfate are released. While soot absorbs heat, and consequently, has a warming effect, sulfate particles in suspension cool the atmosphere through the reflection of radiation. Moreover, these particles affect the way clouds are formed, not only the natural, but the ones coming from water vapor condensing into trains, which obviously play their role in climate change. Furthermore, as it happened with water vapor, sulfur depletes ozone, which reduces its effect.

Air Pollution

As it was stated before, the same substances that contribute to the climate change, which could be counted as thermal pollution, detriment the air quality as well. However, on the one hand, exceptions could be found as well, as water vapor, and on the other hand, there are substances that pollute the atmosphere but do not increase their temperature. The latter will be described now.

- **Particulates:** During the flight phases that take place near the surface, such as taxi, takeoff, climb, descent and landing ultrafine particles are emitted. Since these particles are emanated mostly near the ground have great impacts on the air quality of cities. During takeoff on order of 10^{15}–10^{17} particles are emitted per kilogram of fuel burned. When it comes to non-volatile particles, the number of emitted ones are on order of $10^{14} - 10^{16}$ per kilogram fuel burned (Wikipedia, 2020d).

- **Lead emissions:** Large aircraft use unleaded kerosene. However, aircraft with spark-ignited internal-combustion engines use leaded fuels (known as aviation gasoline or avgas). Although containing a low amount of lead, when emitted to the air very serios health consequences are faced. If inhaled or ingested, the nervous system, red blood cells and the cardiovascular and immune systems can be harmed.

Although being the five last elements the most important species that impact the environment when released during combustion, there are still other compounds that result from the combustion that takes place inside of engines. Methane (CH_4), carbon monoxide (CO), sulphur oxides (SO_x) and non-methane volatile organic compounds. Carbon monoxide if inhaled blocks oxygen from vital organs, and sulfur dioxide can end up forming particles when reacts in the atmosphere, which suppose a big hazard to people with respiratory problems. The following image synthesizes very well the products of fuel combustion:

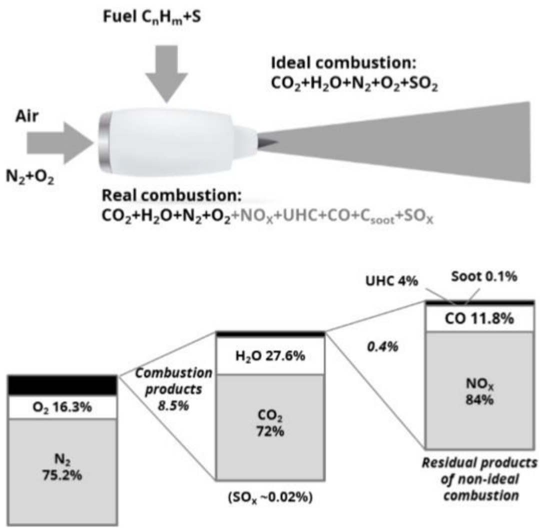


Figure 2.1 Result of the aircraft fuel combustion. Extracted from (Winther et al., 2019)

Water Pollution

The majority of water pollution that aviation can potentially generate comes from the use of certain substances during on-ground operations. Deicing chemicals are widely used in airports that suffer from very cold climates, and its spill could arrive to nearby water streams if not treated carefully. However, as it was previously said, the whole infrastructure that is required inside every transport sector will not be explained, just the performance of the travel itself. Having clear that the use of fluids on ground are the biggest source of potential water pollution, the fluids that aircraft uses for its internal operation can pollute too. They obviously do not appear in the same quantity as an deicing fluid when it is rushed over an aircraft, but still jet fuel and lubricants if spilled and not collected, could end up polluting nearby water sources.

Noise Pollution

Aircraft produce very loud sounds that can be very harmful for the health. It is important to know that there are three main sound sources.

- **Mechanical noise:** coming from the rotation of engine parts, especially fan blades. From all the last three sources of sound, the ones generated by the engine are the main source of sound in an aircraft. The turbulences generated when fuel leaves the the engine are an important source of noise too.

- **Aerodynamic noise:** coming from the airflow around the aircraft surfaces. This is very noticeable when the aircraft flies near the surface but still at very high speeds. According to (Wikipedia, 2020a) there are two type of airframe noises. On the one hand, bluff body noise, caused by the separated flow around the aircraft body, which rolls up into ring vortices to break down into turbulances later. On the other hand, edge noise, caused by the propagation of pressure fluctuations through the aircraft body; this fluctuations of pressure appear when turbulent flow passes the end of a surface or gaps of the structure.

- **Aircraft systems noise:** coming from various systems that are used during flight. For instance, pressurization or power generation subsystems, such as the Auxiliary Power Unit (APU).

As it could have been imagined, sleep disturbance is one of the main problems caused by aircraft noise. Hearing problems, the aggravation of heart diseases and the increment of stress are other consequences. The disturbance of day to day life activities is what excessive sound levels causes. It has been usually said that the reason of the big annoyance of this sounds is the place where it comes from. The noise of aircraft is obviusly heard from above our head. This is a position where humans have zero control. This vulnerability is what generates the fear and alarm state. Apart from the noise pollution the aircraft generates where it flies, there is a small "noise pollution" inside the aircraft itself. The sound it generates can disturb some passengers, but its effect is nowhere near the one that a whole airport makes.

Radioactive Pollution

Finally one could talk about radiation pollution. However, this is similar to the case of the inside-the-aircraft noise pollution. Aircraft themselves do not generate radioactive pollutants, but due to the heights where they fly, can exposure passengers to radiation. According to (Wikipedia, 2020d), being at 12 km high results in a exposure of cosmic ray 10 times greater than being at sea level. This is something to take into consideration but should not be thought as a strict pollution way.

The following parts will talk about other means of transport apart form airplanes and their contribution to the environment pollution. As the central topic of this thesis is aviation, they might not cover their environmental impact as deeply as it was done in the past section. However, they will set the base for future comparisons.

2.2.2 Trains

When travelling long distances trains and planes are probably the two most chosen means of transport. Considering this, trains come across as a very strong alternative to airplanes. This is why it is important to understand what are the differences between these two transport in terms of environmental impact. As it was done with the environmentals impacts of aviation, the several pollution ways will be divided using the categories introduced in Section 2.1.

Climate Change and Air Pollution

The thing that has to be taken into account is that, unlike aircraft, whose propulsion form includes always combustion, in the case of trains two types can be found: electric trains and diesel trains. This makes the environmental impacts of this transport form something that really depends on the train. Consequently, this difference will have to be born in mind. Moreover, although air pollution could be thought as the most obvious difference between diesel and electric trains there are more than this, as it will be seen later.

- **Electric trains:** as it could be expected, the environmental impact of electric trains when it comes to climate change is almost zero. Because of their electric motors, they have no direct carbon emissions. Even counting indirect effects, electric trains according to (Hickman, 2012), where a press note from the UK government was cited, electric trains end up emitting between 20% and 35% less carbon per passenger mile than a diesel train. At (Wikipedia, 2020l) can be seen how the majority of high speed trains (which are one of the major planes alternatives) are electric. This presents long distance railway transport as a very green form of transport.

- **Diesel trains:** unlike electric trains, and as any other type of transport that involves combustion, diesel trains have a big role in climate change due to its emissions. This type of transport, although having its particularities, in term of climate change effects has the ones that any other type of transport powered by a diesel. The exhaust gases are mainly composed of carbon dioxide (CO_2), water vapor (H_2O), oxigen (O_2) and nitrogen (N_2). According to (Blackburn, 2007), light trains emit an average of 0.2 kg of carbon dioxide per passenger kilometer, while heavy trains produce an average of 0.7 kg of carbon dioxide per passenger kilometer. The effect that these products have on climate change has been explained before. These products are the result of an ideal combustion, but it has to be born in mind that real combustion are far from ideals. Non burnt hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter have to be added to the previous list. According to (Majewski Adddy, 2012), these products of a non-ideal combustion represent approximately one percent of the total emitted species. Metals or other compounds, such as dioxins and furans can appear as well, in low concentrations, but with a very high toxicity.

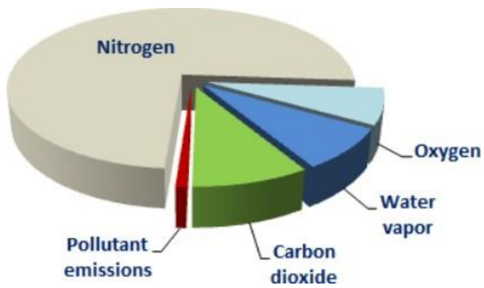


Figure 2.2 Concentration of pollutant emissions in diesel exhaust gas. Extracted from (Majewski Adddy, 2012)

If this photo is compared to Figure 2.1, the percentages of the different released substances can be clearly stated as very similar. This is why although being from different fuels of different engines and of different transports, they are still talking about the same phenomenon: combustion. Later on, when speaking about gasoline, this will be confirmed as well.

Noise Pollution

As it has been already commented, noise pollution implies the disturbance of the life in a residential area due to a noise source. In case of railway transport this has a very strong relevance. Since train stations are placed inside cities, and most of the times in very central locations, during considerably long parts of their journey trains travel inside the cities. This increments the noise pollution in comparison with other means of transport, whose noise does not come from a so near source. Several studies have been conducted studying this. (Trombetta Zannin et al., 2014) is an example of that. In this study an assessment of noise caused by railway traffic in a large Latin American city was performed. This works perfectly to understand what exactly the noise sources in a train are. Two categories were created in order to describe the train noise: a train circulating and a train blowing its horn. Therefore, these two things can be presented as the train noise sources. Not only the noise that comes from the friction of the train while moving over the railways and its respective vibration, or the operation of its internal systems, but the blowing of the horn when approaching a crossing are responsible for very loud emissions.

2.2.3 Ships

Unlike trains, which are always presented as a more environmental-friendly alternative for airplanes, shipping, as aviation, is considered a very polluting form of transport. The impact that shipping has on the environment will be seen now.

Climate Change and Air Pollution

Since ships propulse themselves through the combustion of diesel, the contribution of this transport form to the climate change is clear. The fuel oil they use has a big sulfur content. Therefore, after the combustion sulfur dioxide, nitrogen oxide, particulate matter, carbon monoxide, carbon dioxide and hydrocarbons are produced. These gases help the deterioration of the ozone layer as well as causing adverse health effects. According to (Wikipedia, 2020e) this is generated by the concentration of particulate matter, haze, acid deposition, eutrophication and nitrification of water. Air quality in general suffers a great damage. This pollution becomes more noticeable when ships are docked at port. The cities where ships stop suffer from a worse localized air pollution. Shipping is a big responsible for both climate change and air pollution.

Noise Pollution

So far, noise pollution has been defined as the disturbance of the life quality of a certain area. Although this might be true for the majority of transports it is pretty clear than in case of ships this might be a little bit different. It is obvious that the strong sound of ship horns can be annoying if heard, but this is mostly an isolated sound. Docks are usually placed far from residential areas, and ship horns, although being loud do not tend to be excessively long lasting in time. In case of ships, the ones that suffer from noise pollution are animals. There are two type of sounds that ships emit and that harm the wildlife. On the one hand, there is the constant underlying sound of the ship sailing. This includes all the noise its internal machinery emits, as well as the the movement of the propellers through the water. On the other hand, there is the sonar, whose emitted waves can be heard by some animals. The problem of this type of pollution is that the sound is propagated in water, a medium where waves can travel long distances. This sound interference ends up disturbing the orientation, communication and feeding of some species that rely on sound. Even physical damage can happen if acute sounds are heard.

Water Pollution

As it could has been imagined, water pollution is one of the main pollution form that shipping presents. This is logic, since out of all the transport means, ships are the ones that actually are in the water itself. The ways in which ships pollute the water they sail, according to (Wikipedia, 2020e) are the following:

- **Ballast water:** ballast water is water that ships take on in the costal waters of one port which are discharged afterwards in the waters of a following port of a different region. This water is taken after loading cargo and discharged after unloading it. The problem with that is the contamination that the water suffers where the unloading happens. Biological materials from one environment are released in a second one. This invasion of non-native species can damage the ecosystems, which can derive in human health problems.

- **Ship presence:** although not seeming a very sophisticated problem, the presence of ships in the waters they sail ends up counting as another form of pollution. This pollution appears in form of animals collisions. Big marine mammals are the most affected by this situation. According to (Wikipedia, 2020e), a ship traveling at 15 kn has a 79% chance of being lethal to a whale. However, not only mortality is a consequence of strikes, as serious injuries can happen too.

- **Wastewater:** in some cases, water that has been used for several purposes on board ends up being thrown to the see. This water can be classified in two categories. On the first hand, greywater. Greywater is wastewater from sinks, showers, galleys, laundry and other cleaning activities. On the other hand, blackwater. Blackwater is water that comes from toilets and other medical facilities, which makes it very likely of having a high content of bacterias, harmful nutrients such as nitrogen and phosphorus or other pathogens.

- **Solid waste:** solid waste becomes a part of the water pollution problem when is thrown to the water. Although solid waste can be non hazardous to the nature, it can as well be. If it enters the waters and becomes marine debris, marine organisms and costal communities can be in danger. According to (Wikipedia, 2020e) 75% of the solid waste is incinerated on board, which reduces the hazard when is discharged at sea. However, its treatment for a later recycling on port is always the best option.

- **Oil spills:** one of the pollution forms most associated with shipping. Although this does not occur in a regular basis, as it could happen with some of the previous cases, when oils spills happen their effects are devastating as they last for years in the sediment. They are very toxic to marine life due to their components, polycyclic aromatic hydrocarbons ($PAHs$)

2.2.4 Cars and Similars

Finally, the pollution associated with cars and similar vehicles, such as buses, will be explained. Although for very long distance travels cars might not be the first option to substitute airplanes, the truth is that they can never be completely discarded. Moreover, with the possibility of travelling using other road transports, buses, cars and variants have to be considered as another alternative to aviation. When describing the environmental impacts of these transports cars will be used an example, but it could be easily extrapolated to other road transports. Following the same scheme of the past sections, the pollution types first introduced at section 2.1 will be described. Before starting, it should be remembered that cars engines can work with either gasoline or diesel. Given the case, it would be differentiated if a pollution form changes its causes and consequences if the car is running on gasoline or diesel.

Climate Change and Air Pollution

Although gasoline and diesel consequences to climate change are mostly the same, there are some slightly differences. Firstly, the gasoline explanation will take place and then, the differences diesel presents will be exposed.

– **Gasoline vehicles:** As it has been already explained for other transports that are impulsed through combustion, the releasement of greenhouse gases and some pollutant species to the atmosphere are contributing heavily on climate change and air pollution. Not only the combustion process, but the abrasion of tires or brakes produce several air pollutants. According to (Rothengatter, 2019), the emitted species are carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC), aromatic hydrocarbons (PAH), water vapour and particulate matter of different sizes. Several trace elements due to the impurities in fuel or in the engine have to be considered as well, although being emitted in fewer quantities.

  On the other hand, the directly emitted substances are not the solely responsible for pollution, but the ones created by secondary reactions with the environment. Examples of this are ozone (O_3), nitrates and sulfates. Although the creation of ozone could be thought as a positive thing, the reality is that when this happens at ground level it is not (on the contrary of it it was formed on the upper atmosphere): when volatile organic compounds are released, they react with nitrogen oxiddes in the presence of sunlight, which forms the ozone. Ozone ends up being one of the main ingredients of smog.

  Comparing with other means of transport, it can be seen how the products are the same that other transports that involve combustion emit, although there can be slightly differences and different emitted quantities. The effect that these substances have on the environment has been already explained when they first appear in the aviation section. In case of cars and other types of road transport the impact on the environment and population communities depend a lot on the topography, the areas that roads cross and how the human structure is settled. According to the same study, respiratory, cardio-pulmonary, cerebrovascular, carcinogenic and asthmatic problems can appear as a consequence to the exposure.

The previous health problems have been already commented in the other transports that included them. However, the difference with others, such as planes or ships, is that big part of the pollution takes part inside the city, which generates a local air contamination. Several cities around Europe have reacted setting limits to the concentration of certain substances, such as NO_x or O_3.

The contribution to climate change is obviously one of the main problems that road transport has. Vehicles emit greenhouse gases, such as carbon dioxide, that contribute to climate change. According to (Union of Concerned Scientists, 2018), over one-fifth of the total global warming pollution of the United Stats comes from emissions from cars, trucks and buses. The mechanisms through which this happens have been slightly explained, but will be reminded later when summing up the most worrying substances that the different transports share.

– **Diesel vehicles:** one of the most noticeable differences that diesel engines have in comparison to gasoline ones is the operation with an excess of air. Due to this fact, the carbon monoxide emissions are lower. However they can not be neglected.

The following table collects reference values of the emissions that gasoline and diesel engines emit. As it can be seen, both are very similar.

Table 2.1 Exhaust gases of gasoline and diesel engines. Adapted from (Good Earthling, 2016)

Combustion-engine exhaust gases	**% of total**	
Compound	**Petrol**	**Diesel**
Nitrogen	71	67
Carbon dioxide	14	12
Water vapor	13	11
Oxygen		10
Trace elements	<0.6	0.3
Nitrogen oxides	<0.25	<0.15
Carbon monoxide	1-2	<0.045
Particulate matter		<0.045
Hydrocarbons	<0.25	<0.03
Sulphur dioxide	possible traces	<0.03

Noise Pollution

In case of cars (and similar vehicles such as buses, etc.) noise pollution comes in shape of roadway nose. Roadway nose is defined by (Wikipedia, 2020n) as the collective sound energy emanating from motor vehicles. According to this article, roadway noise contributes more to environmental noise exposure than any other source in the United States. In this article it is explained that this pollution appears due to the following phenomenons.

- **Speed:** sound energy is said to double for each increment of ten miles an hour of the vehicle velocity. This aerodynamic noise overcomes the other noise sources of the vehicle except at low speeds, where braking and acceleration noises take the lead. This can be increased with the vehicle shape. For instance, high trucks with rectangular contours present a greater drag, which increments the sound.

- **Mechanisms:** the internal mechanisms of vehicles produce sound as they move. Brakes are one clear example, but internal machinery in general produces sound. Probably the engine is one of the most heard components of cars. All in all makes internal noises reach high levels. According to (Wikipedia, 2020n), motorists, who can perceive better the internal noises of their vehicles, have registered 65 dBA[1].

- **Pavement and tires:** the interaction between these two element plays a very important role when it comes to making sound. The material of the road can make the sound levels vary up to 4 dB. The material of tires can make vary the sound intensity even more: 10 dBA variations in noise can be found.

- **The surroundings:** although it might not be a noise source alone, it might help to increment the existing sound. Geometry of the surrounding terrains or the wind activity of the location can generate sound diffraction, reflection or refraction, making the perception of the sound different.

2.3 Relevance of Vehicles Life Phases in Environmental Impacts

It is highly important to take into account that the transport sector does not only pollute when the vehicle performs the trip: the construction and maintenance of the machine, as well as the required infrastructures for its operation pollute as well. Nevertheless, only the pollution coming from the action of moving from one point to another will be analysed now. This responds to two reasons. On the one hand, it falls out from the scope of the project: to consider the whole surrounding operations needed for the vehicles functioning would represent an excessive deviation from the main topic. On the other hand, it has been proved for various vehicles that the carbon emissions produced during the operation phase notoriously exceeds the ones that take place during previous phases, such as the development and design; this was proved at

[1] dBA's are a variant from dB's where an "A weighting" is applied. This "A weighting" aims to adapt the noise level of instrument-measured sounds to the capacities of the human ear, which is not very sensitive to low frequencies.

(Johanning; Scholz, 2014)[2]

The percentages that each phase of the life on an aircraft represent can be seen at Figure 2.3. Maybe train comes as an exception for these two points, since the majority of them are powered by electric energy. Nevertheless, it is important to remind that this project is aviation-focused, which makes every other transport mean appear as a tool for comparison. Because aviation meets the criteria of having a greater carbon footprint while on operation, the comparison with the rest of transports will take place under this point of view.

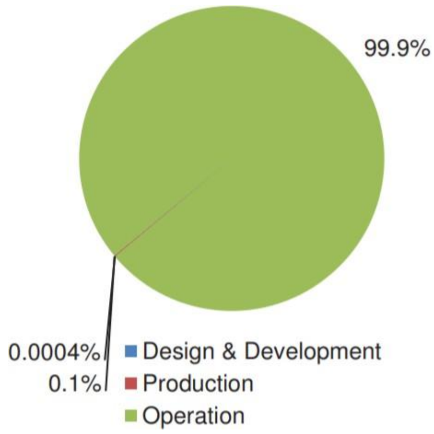


Figure 2.3 Environmental impact of an Airbus A320-200. Extracted from (Johanning; Scholz, 2014)

It was not only proved in aircraft, but in cars as well, as it was revealed in (Weiss et al., 2000). The study showed that 75% of the carbon emissions from a car come from the fuel burn. 19% of this carbon emissions are generated by the production and transport of the fuel it uses. The lasting 6% comes from the manufacture. This numbers show us how important the carbon emission is for the operation of a fuel-powered vehicle. It is important bear in mind that these numbers are not aimed to be taken strictly. For instance, in (Ingram, 2014) is said that according to Volkswagen, the emissions generated by driving of one of its average cars constitutes a 68%, while the manufacturing process accounts for a 22%. As it can be seen, the numbers differ (probably due to the temporal difference between both studies). However, what is important to see is that these emissions clearly represent the biggest part of the carbon footprint of a car. The later percentages were obtained by performing an LCA, a Life Cycle Assessment. Before continuing developing this section it is necessary to to understand what this method consists on.

However, a brief clarification before jumping into the LCA definition should be made: it is important to make the reader understand why the last paragraphs have been exclusively focused on carbon dioxide. Carbon dioxide is not the only pollutant that the transport sector emits, but it is one of the most important ones. Therefore, when a pollutant agent had to be chosen to exemplify how much more weight the operational phase has in comparison with the construction one, carbon dioxide was perfect due to its relevance.

[2]It was shown that emissions during an aircraft operation phase have a much greater impact that the ones during the previous ones. This is due to the nature of an aircraft design, which is thought to operate intensively during long periods of time. This ends up making up for the majority of the environmental impact.

2.3.1 The Life Cycle Assessment

According to (Curran, 2008), the Life Cycle Assessment is described as:

> *Life cycle assessment is a cradle-to-grave or cradle-to-cradle analysis technique to assess environmental impacts associated with all the stages of a product's life, which is from raw material extraction through materials processing, manufacture, distribution, and use.*

As the definition says, this method allows to know how a product makes an impact in the environment. This impact analysis is performed through making an inventory of the energy and materials that are required during the chain of value of the product. Thanks to this inventory, not only the actual emissions to the environment are calculated, but the potential environmental impacts too. This procedure is described by the International Organisation for Standardisation (ISO) in (British Standards, n.d.). This level of official recognition shows why it is so widely used to improve the environmental character of many products in many industries.

There are many types of LCA's regarding its goal and scope, how the inventory is managed, how the impact assessment is performed and its final interpretation. Consequently, several uses and analysis of the obtained data can be found. Moreover, apart from the classic cradle to grave and cradle to cradle analysis [3], variations of the method can be found. These variations come from changing the points of the chain value of the product where the analysis begins and ends. Examples are cradle to gate (from the resource extraction to the factory), gate to gate (analysing just one added-value process that takes place inside the factory) or well to wheel (used mainly for transport fuels and vehicles, goes from the fuel production to the conversion from fuel to energy that happens inside the vehicle).

In particular, the method used by (Johanning; Scholz, 2014) to calculate the carbon emissions percentages is called ReCiPe. ReCiPe is a method used for the impact assessment in a LCA. Its main goal is to extract a limited number of environmental impact scores from the ones that conform the initial long list of inventory. These impact scores are indicators of how much these elements of the inventory affect the environment. There are two levels of indicators: the first level consists of 18, called midpoints, and the second presents 3, the endpoints. Midpoints focus on single environmental problems and endpoints show the environmental impact that results from the sum of indicators that come from upper levels. The objective of adding indicators to conform newer levels is to ease its interpretation. However this comes at the cost of a higher degree of uncertainty. A representation of these points can be seen at the following picture. It is easy to see how the rightmost column has a fewer number of elements compared to the leftmost one.

[3] Cradle is how the beginning of the creation of the product is called, and grave, its end. The use of this terms help to emphasize the meaning of the LCA process.

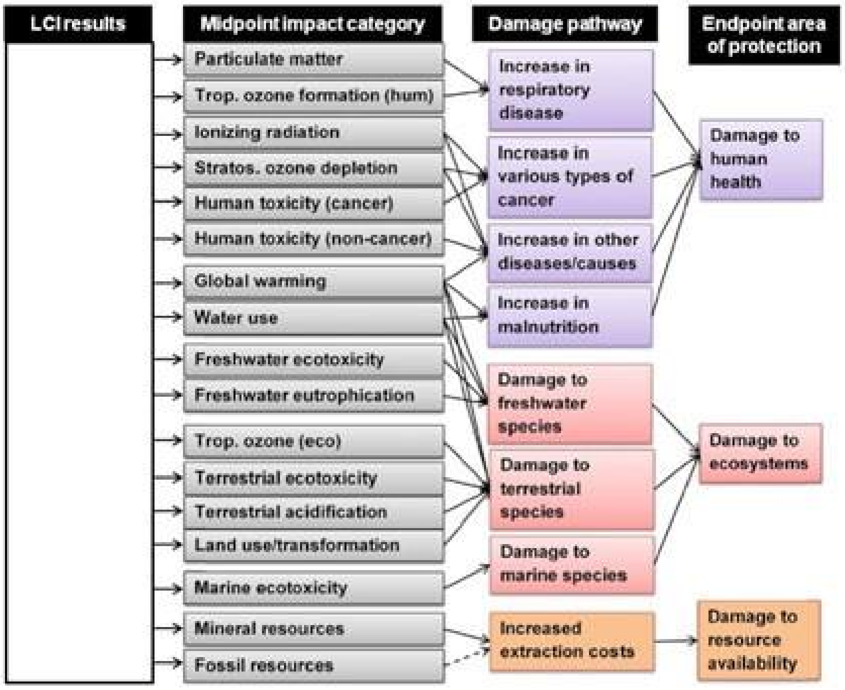


Figure 2.4 Example of the scheme of impact categories of the ReCiPe method. Extracted from (Golsteijn, 2017)

Now that it has been made clear what the LCA consists on, it has been understood why a certain phase of the life of a vehicle is chosen to evaluate the environmental impacts of a transport mean and why in the framework of this phase an specific metric is decided to be used.

This section has been very useful to set the basis for what it comes next. Once the environmental impacts in which all the vehicles participate are known, further studies can be performed. From now on everything will revolve round these pollutants: its evolution through the years, how they are tackled by governments, companies and the scientific community, how they are seen by the public opinion and which methods can be used to inform the passengers about their effects. Everything will be seen with the objective to achieve a global perspective.

3 Evolution of the Environmental Awareness in Passenger Aviation

In this section the evolution of the how the environmental awareness has grown in the passenger aviation sector. It is important to keep in mind that the topic of this thesis has a reason for being because of the great environmental awareness that has risen in the recent years. It is clear that since the industrial revolution the use of fossil fuels has been increasing year after year, which has come together with so many consequences, such as climate change and pollution of many ecosystems. Once people started to realise these effects, a sense of global consciousness began to appear gradually, as well as many political and citizen movements that tried to make a difference. The sum of all of these actions lead to the current situation, where aviation is questioned and initiatives such as the Ecolabel are created. In order to deeply understand the reason to be of this thesis, a review of the most important environmental events that lead to the necessity for an Ecolabel will be reviewed.

3.1 Evolution from the Institutional Perspective

Firstly, the evolution of the environmental awareness in the passenger aviation sector will be studied from an institutional point of view. The scientific community has pushed since a very long time for actions to counteract climate change and other environmental damages, but governments similar institutions have not always listened to their advise. How this has changed through the years will be studied through international agreements, which are the best examples of reaching a major agreement in something.

3.1.1 Generic International Agreements

There was a point where nations from all over the world realised that burning fossil fuels was not free of consequences. Air pollution and climate change were two of their main impacts. With the comprehension that the emission of certain gases, called greenhouse gases, a global warming was occurring, it was agreed that counteractions had to be taken. This is where states started to gather and commit to establish certain limits to their pollution levels. The Kyoto protocol is an example of this and probably the first one with a major relevance.

The Kyoto Protocol

The Kyoto Protocol, according to (United Nations, 2020), is an international agreement about environmental practices. It was adopted on 11 December 1997. It obligated countries to limit and reduce the emissions of greenhouse gases. It focus mainly on industrialised developed countries.

This protocol has several mechanisms for ensuring its implementation. The most important ones are the following:

- **Emissions trading system:** This system functions in a similar way to the ones that will be explained at Section 5.1 (where it will be explained in more detail)f. The emissions that can be released into the atmosphere are limited. Nonetheless, the members of the protocol are allowed to trade the right for realising these emissions if they have an excess or a deficit. However, not only the possibility of emitting more can be traded. When activities such as reforestation or the investment in clean development mechanisms are performed, countries are reducing and removing emissions. Because of these certified activities they receive units that can be exchanged in the system or traded with other members.

- **Monitoring emissions system:** The protocol establishes according to (United Nations, 2020) a monitoring, review, verification and compliance system. In order to make sure that the members of the protocol meet their goals, a rigorous monitoring has to take place. The emissions are registered and reported by the countries to the United Nations responsible parts. Moreover, countries can receive help if they have problems to reach their emissions goals.

Overall, the Kyoto Protocol can be described as the operational part of the United Nations Framework Convention on Climate Change, which was a convention that took place on 1994. It was one of the first times that was promoted the international cooperation for the sake of human safety. Although in that moment there were not as many scientific evidences for climate change as there are today, the convention kept its intentions despite the uncertainty.

The Paris Agreement

According to (Wikpedia, 2020), the Paris Agreement is another international compromise for taking care of environmental matters within the United Nations Framework Convention on Climate Change, the same frame where the Kyoto Protocol was located. It was signed in 2016 and pursues to reduce the greenhouse gas emissions and deal with the technological and financial adaptations that need to be made in consequence. This means that it is intended to help economically towards a development based on low greenhouse emissions. It is also known that although monetary and technical changes are made to fight for a more environmentally-friendly world, the already existing adverse impacts of the climate change can end up threatening things such as food production, which has to be avoided at all costs. The agreement plans to fight that so as basic things such as the previously commented food production do not see compromised. Furthermore, probably the most important and well-known goal of this agreement is to keep the increase in global temperature below 2^oC above pre-industrial levels. Although this intention is though for long-term, for even further perspectives, the real ambition is to keep this increase below 1.5^oC.

Although the two international agreements that have been briefly described are one of the most well-known ones they are not the only ones that have been made in the recent years. Conventions have been constantly held in order to direct the human evolution towards a sustainable one. The following image shows some of the most important environmental summits and their achievements:

Figure 3.1 Main climate summits and their achievements. Extracted from (Iberdrola, n.d.)

At this point the most generic international agreements have been reviewed presenting their most important goals. However, as it has been said, they are generic: they affect all industries and not just specifically aviation. Even though it is important to know them, since they show the increasing environmentally awareness that has appeared in the recent years (this progress is seen clearly in the Figure 3.1, in the following points more aviation-focused topics will be reviewed. Now that it has been made clear that evolving sustainably has been a topic with a great importance in the international agenda, how aviation has experienced that and how the public opinion has seen its adaptation or not towards more environmentally-friendly methods will be analysed.

3.1.2 Aviation-Specific International Agreements

It is clear that although the agreements described in the last section had a generic character, they have to include points where the specific measures for each industrial sector are described. Moreover, agreements different from the generic ones, made by aviation-specific institutions or summits exist as well. This step, towards a more-aviation-centered explanation will be taken now before entering deeply in the public opinion about aviation and environment. Although seeing the citizen and political movements might be more representative of the real opinion, governmental campaigns are also important to understand, since they a reflect from the technical experts opinion about environmental matters.

The Paris Agreement in the Aviation Sector

There is no need to say that the objectives of the part of the Paris Agreement that covers the aviation sector are the same of the whole compromise, but adapted for the needs of this specific sector.

According to (Transport And Environment, 2016), aviation is responsible for a 4.9% of the global warming caused by human activities. At the previous Section 3.1.1 it was seen how the international community agreed on the need of taking care of the environmental issue. Considering this, the last provided data for aviation global warming and the following graphic of aviation pollution, it will be understood later why the public opinion towards aviation started to be in such a certain way.

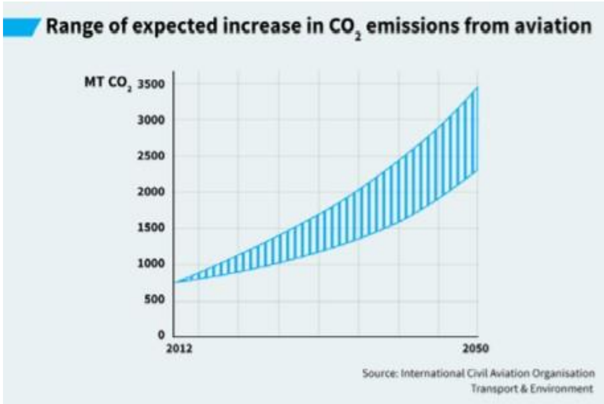


Figure 3.2 Range of expected increase in CO_2 emissions from aviation. Extracted from (Transport And Environment, 2016)

One of the things that the Paris Agreement had to deal with was the special situation where aviation stands. The fact of being a sector that is experiencing a very rapid growth, added to not having to pay any taxes, which on the one hand increases its demand but on the other hand does not motivate the airlines to buy newer and more efficient aircraft, makes it a very delicate sector when it comes to the environment.

Another point that aggravated the impacts on the environment of the aviation sector has been the lack of explicit references of the international agreements towards the sector. According to (Transport And Environment, 2016) the fact that the Paris Agreement made no explicit reference to emissions from international aviation, just set a long-term goal where all implied parts where trust, but not obligated, to cooperate. Because of that, no explicit actions were taken by ICAO in 2016, when the agreement was signed, and were postponed for 2020. These measures will be seen in more detail in Section 5.1. This has been moreover added to the fact that the Kyoto Protocol did not include neither international aviation in the emissions inventories because ICAO was asked to work individually with its members, which eventually end up in a delay of almost two decades of greenhouse emissions fighting. However, according to (Transport And Environment, 2016), ICAO said that aviation emissions were expected to grow up by to a 300% if no action was taken, which together with the Paris Agreement, has make this time impossible a further delay in fighting against carbon emissions to happen. Nonetheless, as it has been already said, the ICAO mechanisms to fight against it will be exposed in Section 5.1. Finally, it is important to remark that aviation has not been the only sector to fall in this error, according to (United Nations, 2016), the shipping case is very similar, with a perspective of a 250% increase of emissions by 2050 if no action is taken. This is not in any case a consolation for aviation, but a fact to realise that there is a lot of work to do in the international transportation sector.

The IATA Environmental Assessment

The International Air Transport Association (IATA) is a trade association of the world-wide airlines that focus on working on an economic regulation of the aviation industry, improving the safety of the sector and making it more efficient. Moreover, working for reducing the environmental impacts of the sector has been another objective of the association.

According to (IATA, n.d.[b]), there are three targets with which IATA wants to diminish the amount of carbon dioxide emissions. These targets are the following:

- Improve fuel efficiency a 1.5% each year from 2009 to 2020.
- Set a cap on aviation carbon dioxide emissions to aim for a carbon neutral growth from 2020.
- Get to make the carbon dioxide emissions in 2050 a 50% smaller compared to the ones in 2005.

In order to achieve these goals, a series of actions were defined. The one that becomes more interesting for this section is the so called IATA Environmental Assessment, a program which according to (IATA, n.d.[a]) aims to improve the environmental management of airlines via independent evaluation and assessments. Other measures that are being taken regarding the environment issue are the promotion of sustainable aviation fuels; the design of a carbon offset program; the creation of FRED+, a platform that helps to report carbon emissions to the CORSIA system [4], that has linked another IATA program, called Aviation Carbon Exchange; and finally the improvement of industry practices regarding Aircraft Decommissioning. The first ones, that are the ones linked to the environmental impacts that interest the most for the scope of this thesis, will be explained later in the development of other sections, such as Section 5.1. This is why this point will be centered in the IATA Environmental Assessment. It has to be remarked that this program is voluntarily, airlines are not forced to join it.

According to (IATA, 2015), in 2015 IATA announced proudly that two airlines completed two stages of the program. It will be more deeply reviewed later. The Stage 2 of the program is thought to happen 3 years after the entering of the given airline in the program. This means that the program might be thought to have been created around the early 2010’s. This is completely logical, since as in (IATA, 2015) is said, the environmental objectives previously described were set in 2009. The stages of the assessment program can be seen in the following picture:

[4]This system is fully explained at Section 5.1.

Figure 3.3 Stages of the IATA Environmental Assessment program. Extracted from (IATA, n.d.[a])

Furthermore, the chronological order in which these stages are implemented can be seen in the following picture:

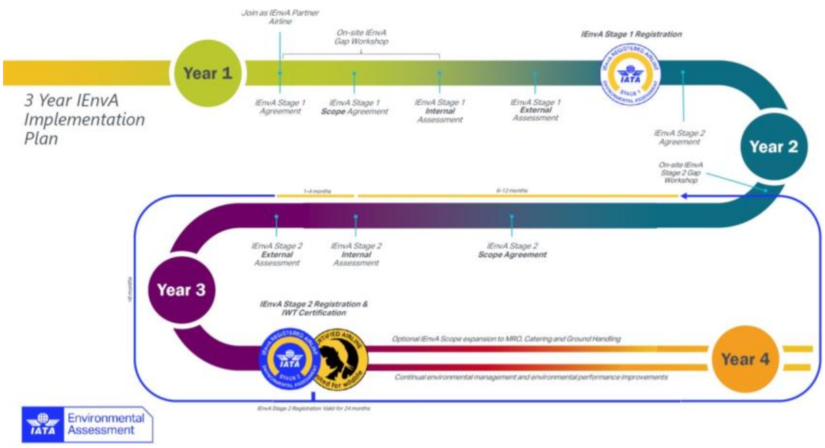


Figure 3.4 Range of expected increase in CO_2 emissions from aviation. Extracted from (Transport And Environment, 2016)

This program has been going on since its creation and some airlines have been joining it since then. It is clear that it has not been remained unchanged sine its beginnings. In 2018 was created the Environmental Assessment Program Plan, which intended to improve the coordination between all the interested parts: IATA, the Environmental Assessment developers and the airlines.

Which has to be kept in mind after this point, is not only the contents of the programs, but mostly the year when it appeared and its motivations. Considering when the Kyoto Protocol was released, which did not put any pressure in aviation, and when the Paris Agreement started to ask for a higher effort from aviation, it can be seen how IATA actions started approximately at the same time. This need of external pressure for making environmental changes that the industry has presented will allow to understand in the following points why the public opinion has been in such a way.

3.2 Evolution from the Passenger Perspective

It has been said repeatedly during this section that its objective is to study the reasons that have lead to feel the necessity for carrying a study such as the one of this thesis. Analysing which international treatments have been born and when this happened allows to understand the importance the topic has among the governments and other official institutions: the fact that communities of experts started to think that an issue is relevant enough to create normative that targets it is a good indicator that shows a strong change of mentality. However, a change of mentality in scientific communities does not necessarily imply a change of mentality of the public opinion. It is important to realise that most of the times experts say something which strongly disagrees with the public opinion due to the restrictions it implies. This is why it can not be assumed that the scientific environmentally awareness that international agreements imply, also means a public opinion awareness about the environment. This is why this part of the section will be focused exclusively on studying how the environmental impacts that aviation causes are seen by the general population. For doing that, three articles will be reviewed. These articles were written in different years, with a sufficient big gap time to understand the evolution of the public opinion.

It is important to remark that the first article will be focused generally in the public opinion of air pollution, while the second and the third more specifically in the public opinion of air pollution and climate change in the aviation sector. The first study was carried out in a time where it was too early to discuss the concrete impacts of aviation in the environment, however, as the air pollution is directly linked to the airline sector conclusions can be extracted very accurately.

3.2.1 Public Attitudes Towards Air Pollution in 1967

The aim of this article (Gill et al., 2007) is to present the findings of a study that was carried out in 1967 in the US to understand the attitudes that the population showed towards air pollution. This research was performed to plan the implementation by the American government of topic related measures. Although it is not directly linked with aviation, since the airline sector is one of the most air polluting sectors, it will be valid enough to understand the public opinion several decades ago. The findings of the article will be now summarised:

- During the early years of the 1960 decade several surveys were performed in different cities, such as Buffalo, Los Angeles, St. Louis or Nashville. In all of them, approximately between a 30% and a 50% of the interviewees affirmed that air pollution was a hazardous problem for their community.

- The bigger the city where the survey was done was, a larger number of people was worried about air pollution. Rural areas as it was expected were less disturbed about this topic.
- The article concluded that overall, for the population, during that time, air pollution was as serious as alcoholism, less worrying than unemployment but more than car accidents.
- It was also found that most of them considered that health was affected by this type of pollution. Families with young children were the most concerned sector of population.
- Moreover, the majority of respondents agreed on the fact that the government had to take care of the topic and control the air pollution.
- However, most of the participants felt a big sensation of incompetence regarding this. They exposed that they did not complain because they felt that there was nothing they could do to solve the problem as individuals.

Although no firm conclusion can be extracted before reviewing the other two articles, it is expected to find that with the years the environmental awareness of the population grows. Finding that less than half of the interviewees are worried about air pollution is surprising if thought from the current perspective. However, it is important to remember that from 1960 to 2020 there is a 60 years difference. A jump of nearly 50 years will be taken to analyse the following article. This jump is not excessively big, as it has been seen that not even with the Kyoto Protocol aviation was the target of the environmental consciousness: it was not until the Paris Agreement that the perspective started to change.

3.2.2 Public Attitudes Towards Aviation Environmental Impacts in 2007

The aim of this article (Gill et al., 2007) is to study the public opinion towards the environmental impacts of aviation. For doing that, a previous analysis is performed of the context where the airline sector and the environmental awareness located. This is highly needed because the survey directly asks for specific topics that are contextualised in this previous study. Similar to the first article, conclusions are extracted to understand what measures could be taken to target the problem. The findings of the study will be now summarised. It has to be remarked that in this case the study took place in the UK. However, given the fact that the US and the UK are well developed countries, a comparison could be made without much inconvenience.

Context

By the time the article was written the aviation emissions were responsible of a 13% of the climate impact in the UK with a perspective of rising up to a 50% by 2050 if no actions were taken. The following graph helps to visually understand this prediction. It shows the evolution of passengers in civil English airports between 1953 and 2005; it is easy to project how much the sector will have grown by 2050.

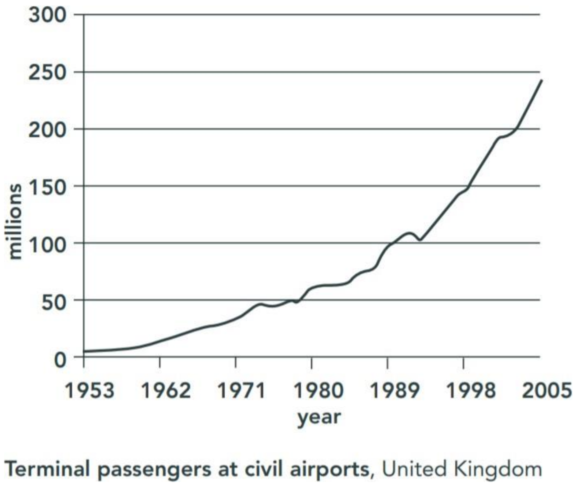


Figure 3.5 Graphic that shows the evolution of terminal passengers at civil airports of the UK. Extracted from (Gill et al., 2007)

Another graphic that is very representative of the current and future problem and why it should be tackled is the one that represents the growth of global carbon emissions before the industrial revolution until now.

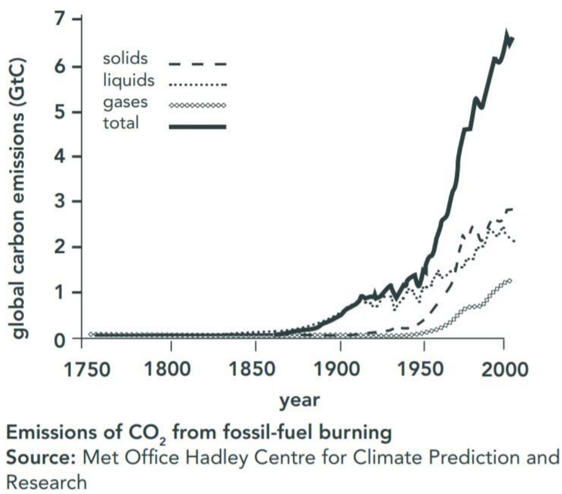


Figure 3.6 Graphic that shows the evolution worldwide of the emissions of CO_2. Extracted from (Gill et al., 2007)

By looking at the last picture it is logical to understand why the international community is so worried about reducing the carbon dioxide emissions in the following decades.

Focusing on aviation, according to the article, a 5.5% of the carbon emissions of the UK were caused by the aviation sector. The following graphic shows a prediction of how the aviation carbon dioxide emissions will evolve in the following years:

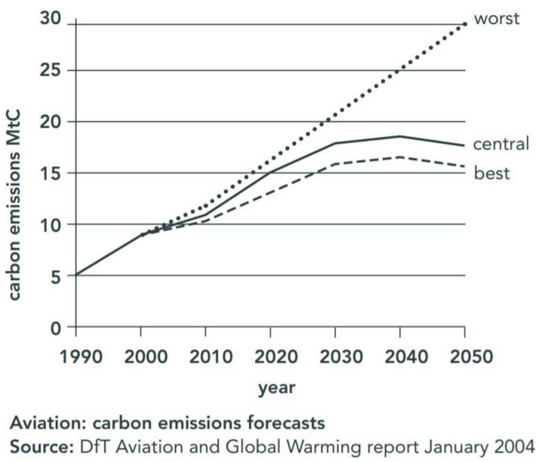


Figure 3.7 Graphic that shows prediction of worldwide emissions of CO_2. Extracted from (Gill et al., 2007)

The best case scenario comes from taking into consideration the technical improvements the sector has lived, due to more efficient engines, airframes and traffic management. According to the article, Rolls Royce estimated that a reduction of 21% of carbon emissions was achieved between 1990 and 2000. Moreover, the Advisory Council for Aeronautics Research in Europe expects a emissions reduction of 50% in the following years due to the previously commented technical factors. The problem, however, is that not only carbon dioxide is emitted by aviation: airplanes contribute in the climate change with the emission of various greenhouse gases.

To sum up, it can be seen how the context was characterised by increasing emissions, increasing airline transport demand and an uncertain improvement of the efficiency of aircraft. This puts aviation in a difficult position regarding the environmental issue.

Public Opinion

Once the context of the relationship between the aviation and the environment that was known by the time the article was written is understood, it is possible to start revising which was the public opinion towards this topic. The conclusions extracted will be know summarised. Before starting to review the public opinion in full depth a brief comparison with the last article should be made. In the previous one it was seen how when it was asked if air pollution was a topic that relevantly worried the interviewed, no even half of them considered it worrying. However, when asked now, nearly half of the people considered it the most serious threat to the well being of the world. Passing from a 30% (on average) that consider air pollution a danger from their community to a 45% that consider climate change the most serious danger to the world is a big step. Although the first data was obtained from the US and the second one from the UK, being both two well developed countries the results can be compared without much inconvenience.

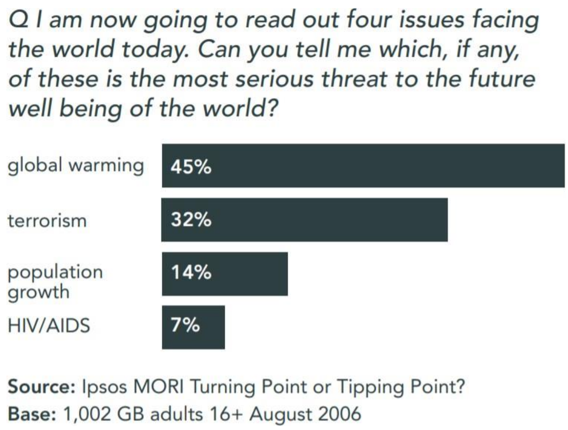


Figure 3.8 Graphic that shows the answers to the question about the most worrying world topics. Extracted from (Gill et al., 2007)

– A general sensation of willingness by the public for taking action in the climate change is felt. This happens despite the uncertainty of the knowledge on the matter and the likeliness of having to make personal sacrifices.

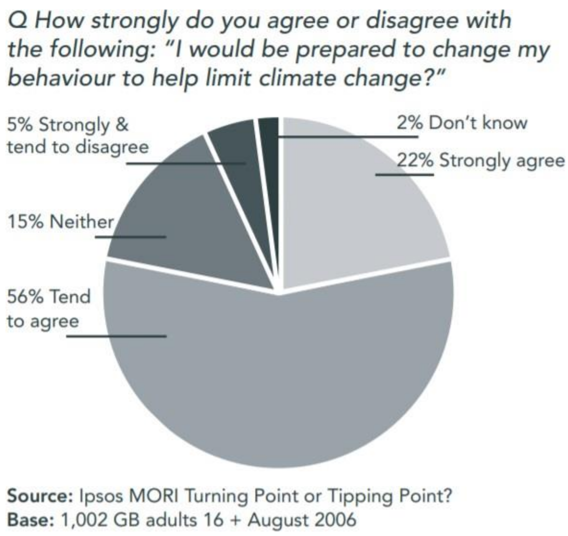


Figure 3.9 Graphic that shows the answers to the question about the willingness for changing the environmental habits. Extracted from (Gill et al., 2007)

– There was a strong view that the government had to assume the worst possible scenario and act in consequence.
– A feeling of concern towards aviation emissions was felt and its consequence need for action by part of the governments. However, not all the measures were accepted equally by the public opinion.
– A taxes increase was generally not welcome by the population, just if a sense of fairness was felt; this means that just the right people pay. Moreover, it was also thought that the sector should compensate their own environmental impacts by paying for what they pollute.

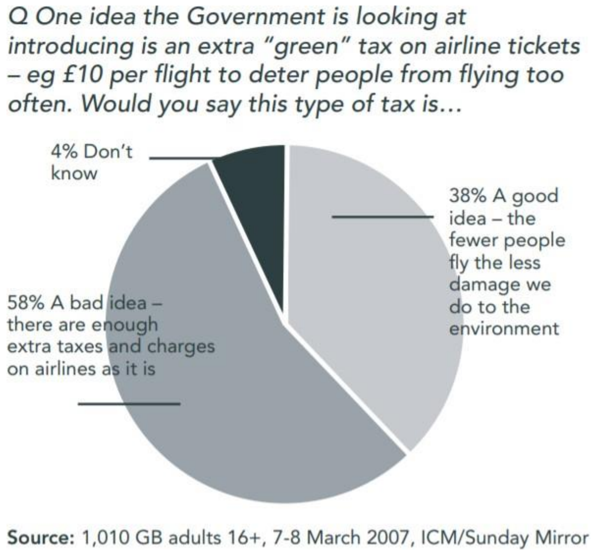


Figure 3.10 Graphic that shows the answers to the question about the willingness for accepting an environmental tax. Extracted from (Gill et al., 2007)

- It was thought that a considerably high level of acceptance could exist towards a limitation of flying. The question of it this should happen or not happens in the frame of considering a limitation of the aviation growth as a possible solution for its part of the climate change.
- As it has been said before, fairness is a key concept that is repeated several times: it was felt that if taxes are set the poorest classes will receive the consequences.
- Finally, it was seen how the public is open for being persuaded about fighting aviation and its impacts. Counting the share of population that might accept being convinced about restricting aviation, and the one that was already aware of its environmental damages.

3.2.3 Public Attitudes Towards Aviation Environmental Impacts in 2019

The aim of this article (Murray, 2019) is to understand the different public attitudes to air travel and climate change and explore the factors that affect the given support towards reducing air travel. According to the article, this was achieved by pulling 1750 British Adults in November 2018. Several conclusions were obtained from this study, and now they will be summarised. The statistics of some of the conclusions will be presented in form of graphs as it has been made.

- The majority of the interviewees agreed on that the government should do more to tackle the environmental damage caused by air travel.

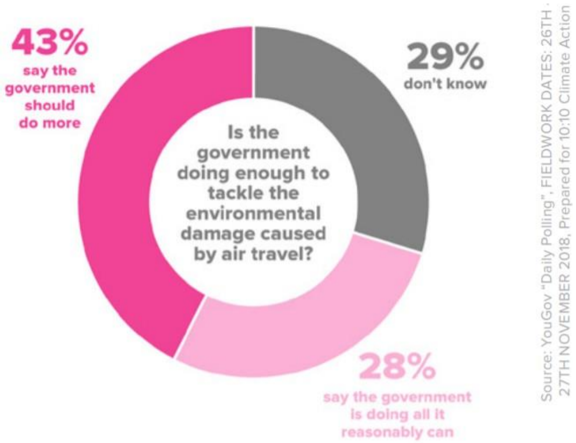


Figure 3.11 Graphic with statistics for: Is the government doing enough to tackle the environmental damage caused by air travel?. Extracted from (Groot, 1967)

- On the one hand, when asked, half of the surveyed said that they would be willing to reduce how much they flight to protect the environment.
- On the other hand, frequent flyers were much less willing to reduce how much they flight compared to no-usual passengers
- As it could have been expected, passengers concerned about the environment were more supportive of limiting air travel. Moreover, they were in favour of this limitation happened not only in a policy level (an external governmental restriction, for example) but also in a personal one (reducing how often they flight without no external prohibition).
- The ones that agreed on this aviation limitation it was because their were aware of the pollution that aviation produced. However, it was proved that a large majority of the interviewees were unaware of the harms that air travelling was doing to the environment.

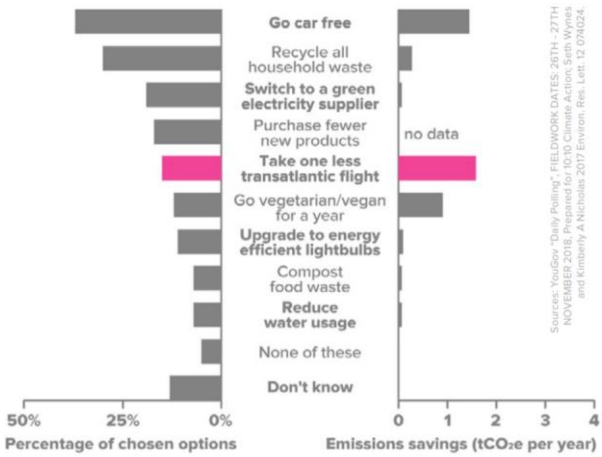


Figure 3.12 Graphic with statistics for: 2 Which changes would make the biggest impact on reducing someone's carbon footprint in a year? (Participants asked to choose up to two options from list). Extracted from (Groot, 1967)

- Among the different types of fees that could be applied to make people more aware of how much they flight, a levy that tackled frequent flyers was considered the most fair tax.

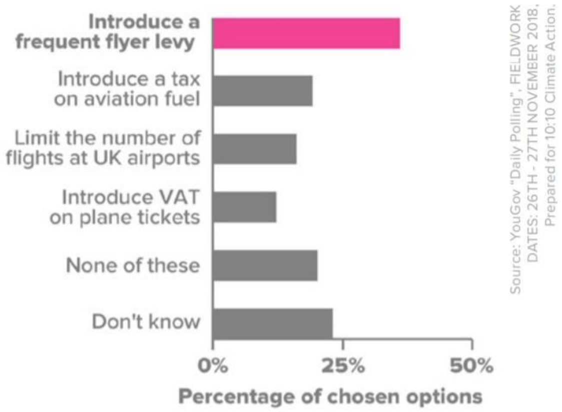


Figure 3.13 Graphic with statistics for: Which policy changes would help tackle environmental damage caused by air travel? (Participants asked to choose up to two options from list). Extracted from (Groot, 1967)

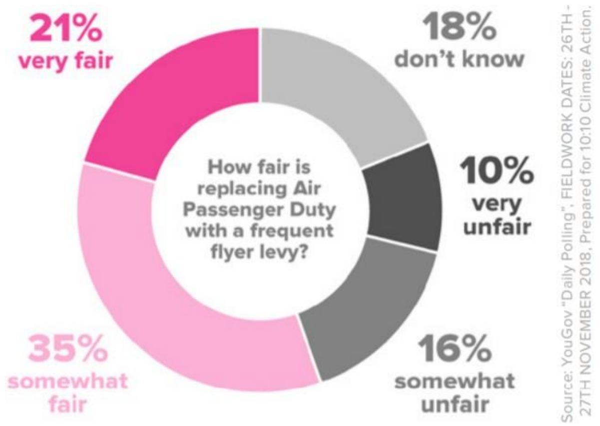


Figure 3.14 Graphic with statistics for: 4 How fair is replacing Air Passenger Duty with a frequent flyer levy?. Extracted from (Groot, 1967)

It has to be understood why these conclusions were obtain and not others. Other areas have had the possibility to become more environmentally competitive by introducing low-carbon technologies, but this has not been possible in the air transport. Although some changes have been introduced to improve its efficiency, such as synthetic fuels, new airframe designs or electric technologies, the gains it has produced are very modest compared to the growth of the sector. According to the article, IATA said that globally the sector was growing at a rate of 3.5%, and for example, in the UK, the number of passengers increased by 15% in the last five years, which caused an increase of aviation emissions of 1.2% in 2016. This extremely rapid growth of the sector has been accompanied with an emissions growth.

In the recent years the sector has experienced a big growth due to different factors. Firstly, the improvement of the overall life quality of the occidental world that has made leisure be an important part in life of population. After the second world war, with the growth of the American economy and the beginning of the globalisation the occidental world started to see how the living standards of the population rose. Travelling started to change from a luxury to a more achievable leisure activity, which started to open air travel to a bigger public. With the appearance of budget airlines this opening process became even bigger. Furthermore, considering that this happened during generation where the living standards were considerably higher, travelling became a very affordable activity. Internet had also an important role in this process, since thanks to its costs in advertisements and local rents were diminished, which together with a bigger diffusion capacity, made the competence in the sector fierce. The prices of flight tickets decreased and the demand rose, which lead to the current situation.

Since the pollution has not been able to be stopped by technological improvements the necessity of diminishing them by varied policies has appeared. The problem is that despite the fact that the majority of people agrees on reducing how much their fly, the majority of flights right now are being used by a minority of population, which do not agree that strongly.

The conclusion that has to be extracted from this extract is that a necessity among the population has risen to take care of the environment as the airline sector grows and its environmental impacts. However, not all the passengers have reacted in the same way in front of the measures that are being taken to tackle this situation. It has to be understood that these policies are still new and under development and it is normal that some passengers have doubts towardsit.

Arrived to this point, the reader has been able to see how among not only the international community, but the public opinion in general, a sense of environmental awareness has risen rapidly. Aviation, as an industry that strongly relies on the use of fossil fuels for obvious reasons, has been target of measures to reduce its pollution levels. Moreover, it has been the public opinion which has started to see it as a sector with a strong necessity of change in order to fit the new environmental standards, as it was able to understand with the last two articles. However, although they have been very educating, showing the reader the public attitudes toward the environmental impacts of aviation, they are not enough to fully understand the position where aviation ends up lying. It is true that the general thoughts of the population about this topic have been studied, but there have been a series of important events whose sum through the years has build the whole structure of thought. This is why, in order to finish this section, concrete events will be now studied. This will add the only lacking perspective to fully understand the picture that this section is trying to analyse.

3.3 Current Overall Perspective

The perspective of the environmental awareness of the aviation sector has evolved differently over the years depending on the analysed perspective. However, in the current times, all have merged into a common idea of awareness for the environment. A series of important happenings have happened due to this current paradigma, and they will be reviewed now in order to fully understand how the perception of the aviation and the pollution it generates is being shaped nowadays. Most of them will be pretty recent, but this should not be any surprise: in the previous section it was seen how the Kyoto Protocol did not refer directly to the airline industry, and when it was mentioned during the Paris Agreement, it happened with not much concretism. If the sector has been able to postpone its environmental measures until the most recent times, it is normal that during this time, not much opposition against its practices was found.

Apart from the information extracted from surveys, interviews and other analysis there are other events that can allow to understand how the perception of aviation and environment has changed through the years. With the review of the international agreements that tried to tackle this issue and the analysis of the three articles that tried to understand how the topic was perceived by the main population a general perspective has achieved. However, it has to be taken into account that there are some particular events that have had a special relevance in the recent years. The growth of importance of aviation and environment has been very rapid in the recent years. This is why it is logical to think that some of the most important events have also been the most recent. All of them are strongly connected.

3.3.1 Citizen Responses

Fridays for Future

One of the most recent actions that has had a very important role in the environmental awareness scene has been the movement called “Fridays for future”. Although it did not appear specifically for fighting aviation, due to its promotion of the emissions reduction it is without any doubts linked to the flying transport sector. According to (Fridays for Future, 2020) it begain in August 2018 when Greta Thunberg, being 15 year old, started a school strike for defending the implantation of measures to fight climate change. She started it alone and other students started to join her. They sat outside of the Swedish Parliament every school day for three weeks demanding action on the climate issue. After that, they decided to continue striking every Friday until the Swedish policies provided action guidelines that enabled to achieve the objectives stated in the Paris agreement: keep the temperature rise under $2^{o}C$. It was one of the first times that youth started to take such decisive actions in the climate crisis. “Fridays for future” started to gain more and more relevance as other students worldwide joined the initiative and began strikes and demonstrations on the same topic. The goal was the same, but this time, focused on the corresponding part of the world where the actions took place: force politicians to, following scientific guidelines, take measures to limit emissions and keep the global warming under control as the Paris agreement stated.

Flightshaming

It is not strange that if a young movement began fighting for climate change, the aviation was one of its targets. Being one of the most polluting industries, with a small level of introduction of electrical technologies and without much progress, avoiding for example implanting measures in the times of the Kyoto Protocol, the fact that a high degree of pressure appeared was not strange. In the framework of Fridays for future a concept called “Flightshaming” started to be heard. According to (The Guardian, 2020b) the term was born in 2018 in Sweden together with other initiatives such as as the twitter hashtag #stayontheground. Greta Thunberg, the previously introduced Swedish activist, was one of the personalities more firm in terms of promoting flying avoidance.

In (MARTÍN, 2020) it was stated that the number of commercial passengers flying in Sweden drop a 4%. This is a good example of how strong and persuasive this movement was. Although it can not be said that this flight shaming is something completely established it is true that the idea of travelling by plane implies an unnecessary luxury compared to other more environmental option has began to gain more and more relevance. However, as it has been seen in the previous section, not all passengers are willing to voluntarily stop flying. This is why the idea to start introducing taxes or other type of restrictions has risen recently. Again, in the previous section it was seen how some passengers agreed on this, but not all, and the ones who did was always if it was applied in a fair way.

Figure 3.15 Image of Greta Thunberg campaigning with other students in Fridays for Future. Extracted from (Huber, 2019)

3.3.2 Institutional Responses

Several methods have been presented for making people more conscious about how much they flight and the impact it has. Implementing taxes for, on the first hand, reducing the demand and on the other hand, using this extra money to invest in measures to compensate the emissions, has been one possible idea. Other, although more extreme, has been limiting how much a person is able to flight in one year. Both options will be now briefly described, as they are the ultimate consequences of all the accumulation of campaigns and movements about the climate change and aviation.

Flying Taxes

On the one hand, regarding flight taxes, an initiative called Frequent Flyer Levy (Freeride, 2020) has appeared to regulate the way flying taxes are applied. It argues that currently, frequent flyers are taxed the same as the rest of the people that fly way less. They propose taxing passengers according to how often they fly. For example, they want to shift taxes from casual holidays to wealthy frequent travellers and make the sector pay a fair share of taxes. Moreover, as it has been slightly introduced with other initiatives, promote other forms of travelling more environmentally responsible in order to be able to compete with airlines has also been stated as one of its objectives. According to (Freeride, 2020) a 70% of flights are taken by 15% of the population: this is one of the main reasoning for demanding the previously.

Flying Restrictions

On the other hand, banning flying has been another thought alternative. Some countries have already began seriously considering it. This is explained in many articles, such as in (Boon, 2019), where it is remarked that the main reason is the environmental advantage it implies. According to (The Blue Swan Daily, 2018), The Standing Committee on Energy and the Environment's Chairman have proposed to limit to 10 the number of flights that Norwegian citizens are able to take per year. However, it is just an an idea and how specifically it should be implemented is still unclear. Norway has not been the only one to think about it. According to (The Connexion, 2020), also the French government is considering banning domestic flights of low-cost airlines if a train journey of less than two and a half hours exists for the same route. This would impulse railway companies to create new routes if they did not exist, because the measure ensures a shift of passengers from planes to trains. The interesting part about this is that not only governments are making these restrictive proposals, some airlines too. An examples is KLM, that partnering up with NS Dutch Railways and French-Belgian high-speed train operator Thalys wants to replace flights between Amsterdam Airport Schiphol and Brussels. The airline says that this is an initiative inside its framework of promoting responsibly travelling. Despite the fact that this is a positive initiative, it can not be remembered that this change will not be made if an economical interest was behind. According to the same page, this flight route is very expensive, which can have lead to see a partnering with a railway company as a more beneficial solution. Airlines tend to do several marketing strategies to make them appear more environmentally friendly, something that is becoming more frequent over the years.

3.3.3 Companies Responses

Greenswashing

As it was introduced before with the environmentally marketing strategies, a brief comment has to be said about the evolution of the environmental consciousness. Although it is true that airlines and other members of the sector have to do a big work to improve their environmental practices, this has not to be confused by greenwashing, a more and more common practice that has appeared lately. It consists on, by using marketing strategies, promoting a false perception of a product, making the consumer think it is more environmentally respectful that it really is. This is performed in the benefit of the company. It is usually done by investing money to wash the reputation of a product, instead of improving their practices. The used strategies are varied, they go from changing the name of appearance of a product to launch advertising campaigns that claim arguably false statements.

Ryanair has been accused of this, because of the statements about being one of the less polluting airlines, as well as Finnair, that claims that when flying to Asia, passing through Finnland saves fuel despite the doubts of aviation experts. Because of the great pressure that companies are living to improve their environmental practices, this not very honest way of acting has become more and more popular as an easy response. This is why consumers of institutions have to be aware and eradicate it.

Having already finished this section it is possible to understand how the evolution that aviation has lived through the years: from being in its peak, with people hardly worrying about air pollution and starting to fly more and more to some years where if its technology does not rapidly improve the flying efficiency, taxes, bans and other restrictions are going to be applied with a great acceptance of the public opinion. As this thesis is being written during the coronavirus pandemic, where flight restrictions are happening due to the virus, it is important to consider possible links with the environmental topic. No conclusions can be extracted yet, but in the following years it will have to be seen how the already imposed flights restrictions for health issues disappear as time goes by, or end up being normalised and the environmental campaign takes advantage of this. With this section the reader has been able to understand how is possible that a very pollution aviation went from giving no environmental justifications about their acts, to be in the spotlight and appear the necessity to write a thesis like this.

By focusing these points solely on institutional limitations, the reader can get the false impression that the only restrictions the sector has are mainly focused on setting emission caps, but this is not true. Al thought they are very well-known due to the growing relevance this topic has, aviation institutions provide limitations as well. They differ considerably from the past institutional limitations, which set goals and objectives; these are technical limitations that aim to restrict several metrics. In order to not forget that there is an important technical point of view also present, the next sections will focus on these type of restrictions.

4 Environmental Restrictions in Passenger Aviation

Now that the environmental impacts of aviation have been seen it is important to understand what the industry is doing to address this situation. In this section, the normative that regulates the pollution levels of several categories, such as noise or emissions, will be summed up. It is necessary to understand what are the technical limitations that the industry imposes to the aircraft builders. It is important to remark than the objective of this section is to make the reader understand that there are limitations in several metrics. However, the origin of formulas used to define these limitations are not the most relevant thing. It is important to know that they exist, but as they will not be used again, just a brief comment will be made.

There are two sources of information where environmental normative can be found, and in some cases they are linked. Both are developed by two of the main institutions responsible for aviation regulations. The first source is the one conformed by the Certification Specifications, developed by the EASA; the second one, the Annexes of the ICAO. This section will follow a similar scheme to the past one. Considering the three main types of pollution: air pollution, contribution to the climate change and noise pollution, the normative for each one of them will be explained. However, before starting to specify these normative, a brief introduction to the documents and the institutions that will be used will be done.

It is important to remark that IATA is another well known aviation organisation with several regulations regarding the environmental protection. However, IATA is an airline organisation, while EASA and ICAO are organisation that regulate the aviation sector as a whole. Taking this into account and the fact that IATA was already mentioned in the previous Section 3.1.2, this section will be focused just on normative of EASA and ICAO.

4.1 Sources of Information

4.1.1 The Annexes of ICAO

ICAO is an acronym that stands for International Civil Aviation Organisations. It was created in 1947 and functions as specialized agency of the United Nations. According to (ICAO, n.d.) the mission of the agency is to serve as a global forum of States for international civil aviation. It develops policies and standards, conducts compliance audits, studies and analysis, assists and builds capacity in the field of aviation through cooperation of state members and other stakeholders. It has 193 state members. The tasks it pretends to accomplish are the following:

- Improve operational safety
- Increase capacity and efficiency of air navigation
- Strengthen aviation security and facilitation
- Promote economic development of air transport
- Promote and improve the environmental protection

As it was said before, the Annexes are the ICAO documents that will be reviewed to understand the currently environmental limitations that the normative fixes. The Annexes, as its own name says, are annexes of another document, which is the Convention on International Civil Aviation, also known as the Chicago Convention. This document establishes the international regulations of all the matters related with aviation and its safe and sustainable operation, such as the management of airspace or aircraft. The Chicago Convention has a total of 96 articles divided in 4 parts and 19 Annexes. The Annex that will be reviewed to understand the environmental normative it contains is the Annex 16. It is composed by four volumes, which are the followings:

- Volume 1: aircraft noise
- Volume 2: aircraft engine emissions
- Volume 3: CO_2 certification requirements
- Volume 4: carbon offsetting and reduction scheme for international aviation (CORSIA)

As it can be seen, this covers the types of pollution that have been explained in the last section. The topic of the last volume will be more connected to the one of the next section, where the carbon offsetting schemes where airlines and other companies participate will be explained.

4.1.2 The Certification Specifications of EASA

EASA is an acronym that stands for European Aviation Safety Agency. It was legally established in 2002 and began its fully operability in 2003. According to the institution, as it is stated in its website (EASA, 2020b), the mission of the agency covers the following points:

- Ensure the highest common level of safety protection for EU citizen.
- Ensure the highest common level of environmental protection.
- Single regulatory and certification process among Member States.
- Facilitate the internal aviation single market and create a level playing field.
- Work with other international aviation organisations and regulators.

Considering the last points of the objectives that EASA has, the tasks that it is entitled to do are the following:

- Draft implementing rules in all fields pertinent to the EASA mission.
- Certify and approve products and organisations, in fields where EASA has exclusive competence, such as airworthiness.
- Provide oversight and support to Member States in fields where EASA has shared competence, such as air operations, air traffic and management.
- Promote the use of European and worldwide standards.
- Cooperate with international actors in order to achieve the highest safety level for EU citizens globally, such as EU safety list, third Country Operators authorisations.

As it can be seen, the EASA is responsible for the protection of the EU citizens and the environment through the application of several regulations, certifications and the supervising of the state members. Currently the agency has 32 states member.

The part of its functions that it is necessary to understand for this thesis is mostly the certification part, and specifically, the Certifcate Specifications (CSs). According to (EASA, n.d.[b]), the Certification Specifications are defined as follows:

> *Certification Specifications (CS) are non-binding technical standards adopted by the EASA to meet the essential requirements of the Basic Regulation. CSs are used to establish the certification basis. Should an aerodrome operator not meet the recommendation of the CS, they may propose an Equivalent Level of Safety (ELOS) that demonstrates how they meet the intent of the CS. As part of an agreed CB, the CS become binding on an individual basis to the applicant.*

Since some of the safety requirements stated by the EASA are related to the pollution levels, these documents will be useful to understand which limitations do aircraft face. Amongst the several Certification Specifications, the ones that will be analysed are the following ones:

- CS-E Engines.
- CS-25 Large aeroplanes.
- CS-34 Aircraft Engine Emissions and Fuel Venting.
- CS-36 Aircraft noise
- CS-CO2 Certification Specifications, Acceptable Means of Compliance and Guidance Material for Aeroplane CO2 Emissions.

Later, a deeper look into each of these documents will be performed analysing which pollution imitations do they assess. Each CS presents several versions: an initial one, called first issue, and other ones called amendments. Each amendment is a posterior version of the first one with some changes. The most recent version (the last amendment) will be the one that will be analysed. Each CS is divided in several subparts, and each subpart in several points with a number that differentiates it.

In the descriptions of some CS, Acceptable Means of Compliance (AMC) might appear as well. This is why it is important to know its meaning. According to (EASA, n.d.[b]) is the one that follows:

> *Acceptable Means of Compliance (AMC) are non-binding. The AMC serves as a means by which the requirements contained in the Basic Regulation, and the IR, can be met. However, applicants may decide to show compliance with the requirements using other means. Both NAAs and organisations may propose alternative means of compliance. 'Alternative Means of Compliance' are those that propose an alternative to an existing AMC. Those Alternative Means of Compliance proposals must be accompanied by evidence of their ability to meet the intent of the IR. Use of an existing AMC gives the user the benefit of compliance with the IR.*

Since in this definition the term IR can be read (which refers to Implementing Rules), its definition will be presented as well:

> *Implementing Rules (IR) are binding in their entirety and used to specify a high and uniform level of safety and uniform conformity and compliance. The IRs are adopted by the European Commission in the form of Regulations.*

4.2 Normative

Now that the sources of normative that will be used have been decided, the actual limitations that the normative set will be defined. Three categories will be defined, according to the same structure that has been followed so far.

4.2.1 Air Pollution

According to CS-E 1020 subpart F (EASA, 2018) it must be demonstrated that the Engine complies with the emission specifications of CS 34.2 (EASA, 2019b), which states that the engine must comply with the applicable emission requirements defined under 21.B.85(c). This past reference belongs to a section from another EASA document, the Easy Access Rules for Airworthiness and Environmental Certification (Regulation EU no 748/2012) (EASA, n.d.[a]). This section, called Designation of applicable environmental protection requirements and certification specifications for a type-certificate or restricted type-certificate, redirects to the Annex 16, Volume 2, Part 3, Chapter 2, 3 and 4 of the Chicago Convention. Both Chapter 2 and 3 cover turbojet and turbofan engines, but the first one is intended for propulsion only at subsonic speeds and the second one for supersonic speeds; since passenger jets travel at transsonic speeds, the Chapter 3 will be neglected. Smoke and gaseous emissions are covered in the Chapter 2, and non-volatile particulate emissions in Chapter 4.

Smoke

After setting the conditions where the test of the engine emission have to take place a final result is achieved. The used magnitude is called Regulatory Smoke Number. The Smoke Number is calculated using a reflectometer that reads the absolute reflectance of the stained filter (R_S) and the absolute reflectance of clean filter material (R_W). It is defined as follows:

$$SN = 100(1 - \frac{R_S}{R_W}) \quad (4.1)$$

Using the rated thrust (F_∞), the maximum take-off thrust approved at ISA sea level conditions, the limitation of the Smoke Number is established as follows:

$$RegulatorySN = min((83.6)F_\infty^{-0.274}, 50) \quad (4.2)$$

It is important to understand that despite the the procedures to obtain these variables, and others that will appear in other normative, it does not mean that they are automatically obtained. They have a procedure behind them, which can be found in the Appendixes, but if falls out of the scope of this thesis. In this section the objective is just to prove that there are actual limitations to the pollutants presented before and have a brief look at its more important values.

Gaseous Emissions

For gaseous emissions the metrics are defined using two magnitudes: the rated thrust (F_∞) and the mass of the pollutant emitted during the landing and take-off cycle (D_P). The procedures to arrive at these magnitudes are presented at the AMC of the CS-34, which redirects to the Appendixes of the Volume 2 of the Annex 16 of the Chicago Convention. However, as it was stated before a deeper look into these procedures will not be taken, since it does not belong to the scope of this project. Bearing this in mind, the following conditions are imposed:

- **Hydrocarbons (HC):**

$$\frac{D_P}{F_\infty} = 19.6\ g/kN \tag{4.3}$$

- **Carbon monoxide (CO):**

$$\frac{D_P}{F_\infty} = 118\ g/kN \tag{4.4}$$

On the other hand, it has to be borne in mind that this Annex 16 volume is not the only one that has carbon dioxide restrictions in its normative. The third volume of the Annex 16, Environmental Protection is focused on CO_2 Certification Requirement. This is why more environmental constrains can be found. As it has been said en every point, a big part of the contents of the Annexes are definitions of the specific situations where certain tests should be performed and the computation of different variables. All of this in order to arrive at the final restriction. In this case, the restriction is the only thing of interest. There is not just one restriction, but many regarding the MTOM of the aircraft. The following list collects some the maximum permitted CO_2 emissions evaluation metric values for the different aircraft configurations. It has to be taken into account that there are several combinations depending on the MTOM of the aeroplane and the year of the submission of some important documents, such as its Type Certificate. The important thing to realize is that in some cases the Maximum permitted value is a fixed value and in other cases it is not. In order to exemplify this, three examples will be shown. The restrictions are chosen since they ask for the same temporal conditions of the Certificate of Airworthiness and Type Design, which allows its comparison. The maximum permitted values (MPV) are the following:

Aeroplanes with MTOM less than or equal to 60000 kg

$$MPV = 10^{(-2.57535+(0.609766log10(MTOM))+(-0.0191302(log10(MTOM))^2))} \tag{4.5}$$

Aeroplanes with MTOM between 60000 kg and 70107 kg

$$MPV = 0.797 \tag{4.6}$$

Aeroplanes with a MTOM greater than 70107 kg

$$MPV = 10^{(-1.39353+(-0.020517log10(MTOM))+(0.0593831(log10(MTOM))^2))} \quad (4.7)$$

The temporal specifications these restrictions apply to can be seen at the point 2.1 of (ICAO, 2017b) are the following:

> ***d*** *derived versions of non-CO_2-certified subsonic jet aeroplanes of greater than 5 700 kg maximum certificated take-off mass for which the application for certification of the change in type design was submitted on or after 1 January 2023.*
>
> ***e*** *derived versions of non-CO_2 certified propeller-driven aeroplanes of greater than 8 618 kg maximum certificated take-off mass for which the application for certification of the change in type design was submitted on or after 1 January 2023.*
>
> ***f*** *individual non-CO_2-certified subsonic jet aeroplanes of greater than 5 700 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028.*
>
> ***g*** *ndividual non-CO_2-certified propeller-driven aeroplanes of greater than 8 618 kg maximum certificated take-off mass for which a certificate of airworthiness was first issued on or after 1 January 2028.*

– **Oxides of nitrogen (NO_x):**

In case of this last compound there is no unique restriction. Depending the year when the engine was manufactured, its pressure ratio (π_∞) and its maximum rated thrust the formula that computes the $\frac{D_P}{F_\infty}$ relation changes. There are a total of 17 different combinations. To see all it is advised to consult the Section 2.3.2 of (ICAO, 2017a). Nevertheless, a general expression with four parameters (a, b c and d) will be given. In each of the 17 cases, the variable have different values:

$$\frac{D_P}{F_\infty} = a + b\pi_\infty + cF_\infty + d\pi_\infty F_\infty \; g/kN \quad (4.8)$$

Non-volatile Particulate Matter Emissions

For limiting the amount of non-volatile particulate mater emitted by the engine another expression that involves the maximum rated thrust (F_∞) is used. For all the metrics the measurement of the magnitudes has to take place in specific conditions that are defined in each section.

In the Chapter 4 of the Annex the following equation for the regulatory limit concentration of non-volatile particulate mass is presented:

$$Concentration\ of\ nvPM_{mass} = 10^{(3+2.9F_{\infty}^{-0.274})}\ \frac{\mu g}{m^3} \qquad (4.9)$$

In Section 4.1.2 five different types of CS were mentioned. Not considering the one about aircraft noise, all except the first one and the last one, CS-25 and CS-CO_2 respectively, have been mentioned. In case of the first CS none of their requirements is linked with atmospheric emissions: every time that some of its points speak about carbon dioxide or other compounds is always in the context of the materials that are used inside the cockpit so to avoid health problems for the passengers. If a look is taken to this last one, its points redirect to sections of other documents, such as the Annex 16 or the Easy Rules for Airworthiness and Environmental Certification that have already been seen.

However, on the other hand, in the Section 4.1.1 was seen how there were four different Annexes of the Chicago Convention whose review was interesting. So far, just the first three of the list. The last one, whose topic is the carbon offsetting and its reduction scheme, will be treated in a different section due to its importance. Although it is linked with emissions, the importance that offsetting is starting to gain, not only for airlines, but also for individuals or other industry sectors makes it worth to write a whole section just about it. Taken this into account, this part can be concluded.

4.2.2 Noise Pollution

In order to analyse the normative relative to the noise levels of aircraft, two CS will be looked at. Firstly, the CS that deals exclusively with aircraft Noise, CS-36, will be studied, and then, the CS about large aeroplanes, CS-25 will, be reviewed as well. Probably with the first one almost all the information could be obtained, but a brief look will be taken at the second one too. At the CS-36 (EASA, 2019a) can be seen how it is said that the aircraft must comply with the applicable noise requirements defined at the point 21.B.85(a) of (EASA, n.d.[a]). The topic of this point is the designation of applicable environmental protection elements and certification specifications. As it happened with restrictions of emissions, the document redirects the reader to the Annex 16, but this time its first volume (EASA, 2017). Since this thesis is focused on passenger aviation, subsonic jet aeroplanes are the type of aircraft that have to be looked at. This is why chapters 2, 3 and 4 will be reviewed, as the text suggests. In this case a situation similar to the one found with oxides of nitrogen restrictions is found. Each of these chapters corresponds to different subsonic jet aeroplanes depending on when its Type Certificate was submitted. As an example of the methodology that the Annex follows, the restrictions of the Chapter 3 will be the ones used. Restrictions of the first chapter are applied to aircraft whose Type Certificate was submitted before 6 October 1977; the second one, to the ones whose Type Certificate was submitted between 6 October 1977 and 1 January 2006; the third one, to the ones whose Type Certificate was submitted after 1 January 2006. As the vast majority of airplanes that are used nowadays can be found on the second group (Take as an example one of the most common aircraft in passengers aviation, Airbus A320, whose first flight was in 1987), this will be the one to be analysed.

Once again, as it happened with the section of emission restrictions, the Annex 16 contains the whole instructions that set the adequate conditions in which the tests have to be made and how to compute some necessary parameters. However, just the actual restrictions will be looked at. Before continuing it is important to explain the unit in which the restrictions express the maximum sound level. Instead of using decibels (dB), the Annex 16 uses effective perceived noise in decibels (EPNdB). In order to obtain them, a procedure has to be followed to convert a sound measured in dBs into EPNdBs. However, qualitatively it is important to know that is a magnitude that measures relative noisiness of the of a pass-by event of an individual aircraft; it integrates the duration of its event, which tends to be 10 seconds. As it will be seen, takeoff, overflight and landing are the analysed phases. The maximum noise levels that are stated in the point 3.4 of (EASA, 2017) are divided regarding the flight phase they refer to and are the followings:

At the Lateral Full-Power Reference Noise Measurement Point

103 EPNdB with maximum TOF of 400000 kg. Then it decreases linearly with the logarithm of the mass down to 94 PNdB until 35000gkg.

At Flyover Reference Noise Measurement Point

– **Aeroplanes with two engines or less:** 101 EPNdB for aeroplanes with maximum MTOM of 385000kg. Then it decreases linearly with the logarithm of the mass at the rate of 4 EPNdB per halving mass down to 89 EPNdB.
– **Aeroplanes with three engines:** the same as in the last point, but with 104 EPNdBB for aeroplanes with MTOM of 385000 kg and over.
– **Aeroplanes with four engines or more:** the same as in the first point, but with 106 EPNdB for aeroplanes with MTOM of 385000 kg and over.

At Approach Reference Noise Measurement Point

105 EPNdB for aeroplanes with MTOM of 280000 kg or over, and decreasing lenearly with the logarithm of the mass down to 98 EPNdB at 35000 kg.

The normative considers the possibility of some of the past restrictions being surpassed at some points. However, even this more room for more noise has its own restrictions. In the point 3.5 of (EASA, 2017) the following trade-offs when noise levels are exceeded are stated:

– The sum of excesses shall not be greater than 3 EPNdB.
– Any excess at any single point shall not be greater than 2 EPNdB
– Any excesses shall be offset by corresponding reductions at the other point or points.

Once again, it could be thought that the CS-25 (EASA, 2020a) was not mentioned because it does not contain anything related to this section, however, this is not the case. In the CS for Large Aeroplanes there are restrictions for two type of sounds: on the one hand, to interior cockpit noises, which are not related with the noise pollution that this section is about; on the other hand, the noise the aircraft emits to the environment.

Regarding the last type, all the references that are made about possible restrictions redirect the reader to the CS for Noise (EASA, 2019a). This CS has been already reviewed and how it ends up leading to the Annex 16 (EASA, 2017). This is why this section could be concluded as the brief review of the noise normative has been completed.

It is important to take into account that the limitations that have been presented during this chapter will not be seen in the same exact way in further explanations: some of the same metrics will appear probably in later tools, such as in the Ecolabel, but it is very likely that they do not refer to the same contexts or use the same units. As it has been commented several times, the results of this restrictions are not thought to be taken strictly for comparison purposes, but for qualitatively ones: after reading this chapter, the reader has to have clear that although aircraft pollute the environment, there are restrictions that try to limit these environmental impacts, despite the fact that they are not the only ones that can be used, as it will be seen later.

These past restrictions, together with the environmental caps and goals seen previously, lead to a situation where airlines have to do something to tackle their pollution levels. In this framework is where the same institutions that set these limitations realise that a dynamic system to make them able to reach their goals has to be used, since it is always better encouraging to do something that solely imposing it. This is where the offsetting schemes are born, methodologies that allow airlines to reach their emission goals with flexibility and that impulse the sector competitiveness.

5 Offsetting Strategies of Carbon Emissions

Despite being an air pollution topic, the offsetting strategies needed to have its own section because of its relevance. This is why this new section is created instead of being a subpart of Section 4.2.1. According to (Cambridge Dictionary, n.d.[b]), the definition of offset is the following:

> *"To balance one influence against an opposing influence, so that there is no great difference as a result"*

Understanding that the offsetting strategy happens in the context of reducing carbon dioxide emissions, it is logical to think that something has to be done in order to compensate these emissions. Before going deeper into what the industry defines as offsetting, it is interesting to see the general definition. When searching in the Cambridge Dictionary the definition of offsetting (Cambridge Dictionary, n.d.[b]), apart from the general meaning, a specific explanation for an environmental context is found. This shows how meaningful this concept is. (Cambridge Dictionary, n.d.[b]) defines offset in an environmental context as follows:

> *"To pay for things that will reduce carbon dioxide in order to reduce the damage caused by carbon dioxide that you produce"*

Now that the general concept of offsetting has been understood, a more detailed analysis of what offsetting means for the aviation industry will be performed. In the case of 4.2.1 offsetting was linked with actions that airlines as companies had to perform, however, this concept does not apply only to corporations: it has derived into an action that passengers as individuals can carry out. First of all, the offsetting actions linked to the companies of the aviation sector itself will be explained, and then, the offsetting that passengers can perform.

5.1 Offsetting as a Company

The fourth volume of the Annex 16 (ICAO, 2018) has as a title "Carbon Offsetting and Reduction Scheme for International Aviation", also known as CORSIA. Its purpose is to develop measures that involve the integration of alternative fuels and the application of an offsetting to the airlines. Its implementation will begin on 2021. However, before starting to expand this topic it is necessary to understand that carbon offsets strategies appeared way before this application to the aviation industry. Before going deeper into the CORSIA, a look at the European Union Emission Trading Scheme will be taken, which was the first large greenhouse gas emissions grading scheme in the world.

5.1.1 The European Union Emission Trading Scheme (EU ETS)

As its own name says, this system takes place in Europe and it started in 2005. All countries that conform the European Union, plus Iceland, Liechtenstein and Norway belong to this system. According to (Wikipedia, 2020g), more than 11000 heavy energy-using installations, which include power stations and industrial plants, plus airlines form part of this emission limit scheme. This results in a coverage of around 45% of the EU's greenhouse gas emissions. According to the same webpage of the European Comission, the objectives in mid term of the project, are the followings:

- Make the emissions covered by the system in 2020 be 21% lower than in 2005.
- Make the emissions covered by the system in 2030 be 43% lower than in 2005.

The principle under which this system works is very simple. It uses a cap and trade approach. This was slightly introduced with the Kyoto Protocol at Section 3.1.1 but now it will be explained in more detail. An emission cap is set, which means that globally the installations associated to the system have a maximum amount of greenhouse gases they can emit. As time goes by, the cap is reduced, which makes the total amount of emissions ultimately fall, as the companies as a whole are allowed to emit less every time. This is why the system is said to follow a cap principle. The trade part is because of how the companies can work under the cap. Certain allowances are given to the companies: ones for free, others through auctions. This allowances give them permission to emit a certain amount of pollutants.

It is important to remind that the total amount of given allowances remains always under the cap. Yearly, the companies must demonstrate to have enough allowances to cover all the emissions they produced. If a company is short of them has to get the extra allowances it needs buying them from another company with a allowances-surplus. On the contrary, strong fees are applied. However, these companies with an excess of allowances do not obligatorily need to sell them to others, as they can keep it for future needs. The aim of the European Comission is promote the use in less carbon and the investment in clean low-carbon technologies combining this with a robust carbon price. This is achieved since companies see themselves forced to pay for polluting, which pushes them to manage more efficiently their emissions or use other types of technologies that not imply carbon.

Although the general idea of the system has been covered, some details are necessary to be understood. First of all, even being the most notorious, not only carbon dioxide emissions are monitored, nitrous oxide (N_2O) and perfluorocarbons (PFCs) are controlled as well. Secondly, its compulsory or not character has not been discussed yet. The use of this trading system is mandatory for all the installations that emit the lastly commented gases. When it comes about other sectors, the mandatory or not character of the trading system depends on several factors. As it is stated in (Wikipedia, 2020g) there are the following exceptions:

- In some sectors installations under a certain size are excluded to participate in this program.
- Certain installations can be excluded as well if measures coming from the governments are performed. This measures should imply a cutting of their emissions by an equivalent amount.

– Only flights between airports of the European Economic are obliged to participate in the program. This will remain until 32 December 2023.

This strategy has been divided in four phases that organize the steps the scheme needs to follow between 2005 and 2030. Those strategies are widely explained at (European Commission, n.d.[c]) and (Wikipedia, 2020g). A brief summary of every one of them will be made:

Phase 1 (2005-2007)

During this phase the only emissions that were covered were the carbon dioxide ones coming from power generators and energy-intensive industries. The allowances were given for free and the penalty for an emission excess consisted on 40EUR per carbon dioxide emitted tone. It was a phase focused on setting the needed infrastructure to carry out this system.

Phase 2 (2008-2012)

This phase coincided with the first commitment period of the Kyoto Protocol. The Kyoto protocol is an international agreement whose objective is reducing the greenhouse effect gases. It is hold in the United Nations Framework Convention on Climate Change. The main differences of this phase in respect to the last one are several. Firstly, a lower cap of 6.5% less allowances than 2005 was set. The nitrous oxide was included in the targeted gaseous emissions. Moreover, the penalty for an emission excess was raised up to 100EUR per emitted tone. The possibility for businesses of buying international credit of allowances was given until a total amount of 1.4 billion tones of carbon dioxide equivalence. The emission cap was national. Finally, the aviation sector entered in the scheme on 1 January 2012.
The following image represents the evolution of the trading volumes in EU emissions allowances (in millions) between 2005 and 2012. As a reference, according to (European Commission, n.d.[c]), the 7.9 billion allowances traded in 2012 were worth 56 billion euros.

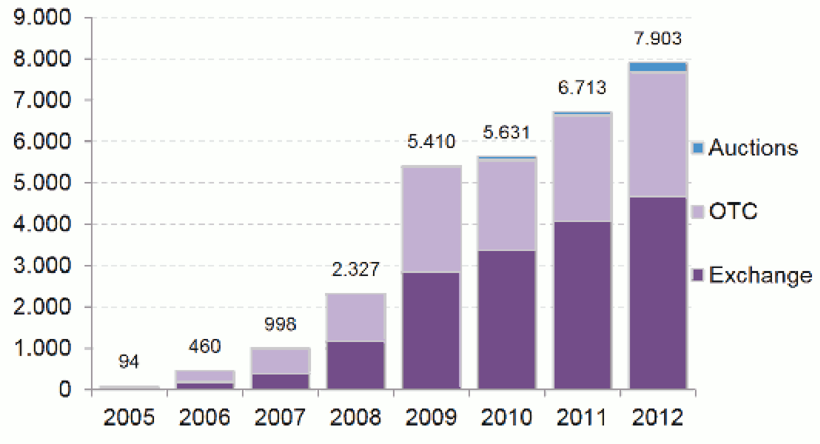


Figure 5.1 Evolution of the million of EU emissions allowances traded. Extracted from (European Commission, n.d.[c])

Phase 3 (2013-2020)

During this phase the nationals emission caps were deleted and substituted by a single European one. The rest of gases that were previously commented were added in the list of gases to set the cap on. Moreover, the method for giving the allowances change from free allocation to auctioning. A set of 300 million allowances was set aside to fund innovative and renewable energy technologies. This encouraged the several industries to not only manage more efficiently their emissions, but to try to invest in carbon-neutral technologies.

Phase 4 (2021-2030)

This phase will be the next one to take place. It plans to reduce in 2021 a 2.2% the allowances. Apart from that, no specific objective is yet determined: it is intended to maintain the free allocation of allowances but ensure the technological progress towards low-carbon methods and the competitiveness of the industry.

5.1.2 Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

Apart from the emission cap that the part of the aviation industry has because of belonging to Europe, there is another mechanism through which an offsetting scheme is applied. The International Civil Aviation Organization (ICAO), has developed a similar system to the one explained in the last section. Its objective is to offset the carbon emissions and promote the use of alternative fuels, always targeting aviation with an international character. It began in October 2016. Its objective is to achieve carbon neutral growth from 2020. The system is thought to be implemented in three phases, beginning in 2021 and making mandatory to participate in 2026. It will be possible to choose from a different variety of biofuels or fossil fuels with some type of more efficient refinery processing. According to (Wikipedia, 2020c), by 2018 more than 70 countries that represented more than 85% of international aviation were participating in CORSIA.

One of its most controversial points has been its approach towards the use of biofuels. On the one hand, according to (Transport and Environment, 2018) (which performed a Lifcycle analysis based on Globiom study from 2016) it has been proved that this can lead to greater emissions than if fossil fuels were used. On the other hand, an overuse of fuels with different kinds of vegetables as main component can easily cause deforestation. Furthermore, it has been highly advised to not allow the airlines perform the emissions offsetting through forest offsetting. Forest offsetting consists on contributing with money to protect a forest region or planting new trees in order to compensate the amount of emitted greenhouse effects. The problems with this type of offsetting are various: on the one hand, they are very difficult to measure, and on the other hand, they have very high chances of not being long-lasting; if the forest disappears, the offsetting effect disappears as well. Other characteristic of CORSIA that has arisen some criticism is the fact that the CORSIA scheme has not set any upper cap of emissions. This means that neither airlines nor countries have a maximum limit of emissions: they just pay as they pollute, which does not help to grow carbon-neutral.

Finally, the fact that just international flights form part of this system lead to think that all in all CORSIA can present more weaknesses than other similar programs, such as the EU ETS. This is clearly reflected in (Schep et al., 2016), where through the comparisons between both schemes the lack of strictness of CORSIA can be seen. The main highlighted differences is that EU ETS establishes an emission cap of 95% of the average emissions between 2004-2006, while CORSIA defines its cap at the 100% of emissions of 2020 and that the mandatory phase of CORSIA will not begin until 2027. What is interesting about the study was how it analysed the impact that other scenarios resulted from the change of scopes of CORSIA and EU ETS could have. Since both systems include the offset of aviation (EU ETS, flights inside EU; CORSIA, international flights), the change of its targets could have interesting results:

- If all the international flights under the EU ETS were included in CORSIA from 2021 onwards, the demand for offsets in CORSIA would remain the same while the demand for allowances in ETS from outsidde aviation would be lower.
- If just flights inside the European Economic Area (EEA+) belonged to EU ETS and the rest were assigned to CORSIA, the reverse situation as the stated in the first point would happen.
- If all the flights shared between the scopes of EU ETS and CORSIA were exempted from CORSIA or 50% of the emissions produced because of EEA flights were exempted from CORSIA the total amount of allowances produced outside the aviation sector would be greater than in the situation of the last point.

Going back to the Section 4.1.1, the last volume of the Annex 16 that was enumerated but not treated in the section, is the one that covers this system. (ICAO, 2018) revolves around CORSIA and how applying it. The document includes its whole mechanism, from definitions of the required conditions, to the necessary tools to monitor the emissions. Among all the points that are treated in this document there are a few that can be remarked for the interest of this project. From (ICAO, 2018) there are some important topics that should be remarked. It is important to highlight that during this section several equations with a great number of different variables will be presented; the meaning of this variables can be found at the list of symbols at the beginning of the document. As it happened with aviation normative, although these formulas will not be used later, they function of a reinforcement of the offsetting philosophy: it is measurable and monitored, not random and qualitative; the reader has to extract this conclusions after seeing that many expressions.

CO_2 Offsetting Requirements

There are several formulas that states shall use to calculate the amount of carbon dioxide emissions that the aeroplane operators are required to offset. Depending on the time period, the formulas change:

– From 1 January 2021 to 31 December 2023

$$OR_y = OE \cdot SGF_y \tag{5.1}$$

,where:

$$SGF_y = \frac{SE_y - SE_{B,y}}{SE_y} \quad (5.2)$$

– From 1 January 2024 to 31 December 2035

$$OR_y = \%S_y \cdot OE_y \cdot SGF_y + \%O_y \cdot OE_y \cdot OGF_y \quad (5.3)$$

,where:

$$OGF_y = \frac{OE_y - OE_{B,y}}{OE_y} \quad (5.4)$$

,and:

$$\%O_y = (100\% - \%S_y) \quad (5.5)$$

,and:

Table 5.1 Overview of CO_2 offsetting requirements on a sectoral and individual basis. Extracted from (ICAO, 2018)

Year of applicability	$\%S_y$	$\%O_y$
1 January 2024 to 31 December 2029	100%	0%
1 January 2030 to 31 December 2032	(100%-$\%O_y$)	A specified percentage of at least 20%
1 January 2033 to 31 December 2035	(100%-$\%O_y$)	A specified percentage of at least 70%

Emissions Reductions from the Use of Corsia Eligible Fuels

There is an expression that computes the emissions reductions that an aeroplane operator can get by using CORSIA eligible fuels. It is computed as follows:

$$ER_y = FCF \cdot \sum_f MS_{f,y} \left(1 - \frac{LS_f}{LC}\right) \quad (5.6)$$

In the last equation, FCF is equal to 3.16 kg CO_2 \ kg fuel for Jet-A fuel and Jet-A1 fuel, and 3.10 kg CO_2 \ kg fuel for AvGas or Jet-B fuel. On the other hand, LC is equal to 89 gCO_2e \ MJ for jet fuel and equal to 95 gCO_2e \MJ for AvGas.

Total Final CO_2 Offsetting Requirements for a Given Compliance Period with Emissions Reductions from the Use of Corsia Eligible Fuels

There is finally one last expression that allows to calculate the amount of CO_2 emissions reqired to be offset after taking into account the emissions reductions obtained by using CORSIA eligible fuels (using the equation of the last point). The expression is stated in (ICAO, 2018) as follows:

$$FOR_c = (OR_{1,c} + OR_{2,c} + OR_{3,c}) - (ER_{1,c} + ER_{2,c} + ER_{3,c}) \quad (5.7)$$

Once it has been seen the mechanism that EU and ICAO use to limit the production of carbon dioxide while encouraging companies and countries to pursue a more sustainable development, the offsetting that will really help for the development of environmental informative tools can start to be analysed. Although offsetting that companies do is interesting and illustrative, this thesis is centered in developing methods to inform passengers about the impacts of their flights. This is why the past formulas and restrictions have been presented without much more depth: because the main focus of this project is the passenger, not the airlines, and the offsetting they can perform will be the one presented now. As it was said when the formulas of environmental limitations were displayed, it is important to know that the offsetting mechanisms are well-thought and with reasons, not random. This is why the reader has to know that there are a series of expressions that set these practices. However, further understanding about thei origin is not needed.

5.2 Offsetting as a Passenger

It has been already seen how offsetting will be becoming in the near future a widely used strategy to counteract pollution effects. Governmental institutions are looking for ways to diminish the consequences of emissions and with offsetting have found an effective solution that works in three ways: companies see themselves pushed to use more efficiently fuel in order to emit less so they can pay less, they start investing in carbon free technologies so they can avoid paying for emitting and, in case none of these first two options happened, as companies have to pay for polluting, the governmental associations can try new measures as they have money to do so. This is the strategies that governments are applying on companies to take advantage of the necessity of using fuel. Private companies are starting to take advantage of this too. As well as they pay for polluting, some airlines are starting to give the chance to passengers to offset the emissions they generate because of flying. The money they collect is usually given to non-profit organisations that fight for climate change. Sometimes, this organisations are the ones that collect the funding themselves. However, not always the carbon offsetting is performed in the same way, every airline does it differently: who recollects the money, who manages it and for what purpose are things that can be done in some many ways. Some of the offsetting methods of the biggest airlines in Europe and in the world according to (Wikipedia, 2020m) and (Wikipedia, 2020i) respectively, plus some others, will be reviewed to understand which strategies can be used.

5.2.1 Comparison of Carbon Offsetting Methods

As it was said before, the comparison of the carbon offsetting methods several airlines use will be now performed. Almost always the possibility of offsetting the emission one produces appears together with an emissions calculator. Both tools will be reviewed at the same time. The reason to analyse these specific airlines is the fact that all present offsetting tools that provide are all different and offer different points of view. Although the title of this section is called "carbon offsetting" it has to be remembered that there might be the case where other emissions can be offsetted as well, such as nitrous oxide in the European Trading Emission Scheme.

Lufthansa

Lufthansa will be the first airline whose offsetting method will be analysed. Since it will be the first offsetting calculator to be reviewed, its functioning will be deeply explained from scratch. After that, the rest of calculators will not be presented in the same level of detail if their working principle is exactly the same: just the main differences will be shown. The service Lufthansa uses is called Compensaid, and in order to describe how it works the process that a passenger that wants to offset its flight will be documented step by step.

The first step consists on choosing the airports of origin and destination. The type flight class can be also chosen between economy, premium economy, business and first. The number of passengers can be decided as well (it allows a minimum of 1 and a maximum of 60). Finally a second flight can be added clicking on the option add a flight leg. In the following image, Figure 5.2 this first screen of options can be seen.

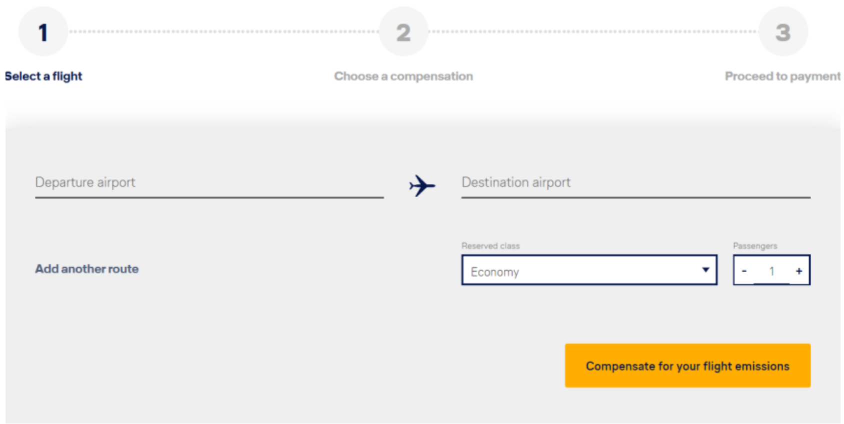


Figure 5.2 First step of Compensaid. Extracted from (Lufthansa, 2020a)

In order to continue this web review the departure and destination airports have to be chosen. A flight between Hamburg and Barcelona will be the chosen one. The offset will be done for one passenger in economy class. When the button "Compensate for your flight emissions" is clicked the following appears:

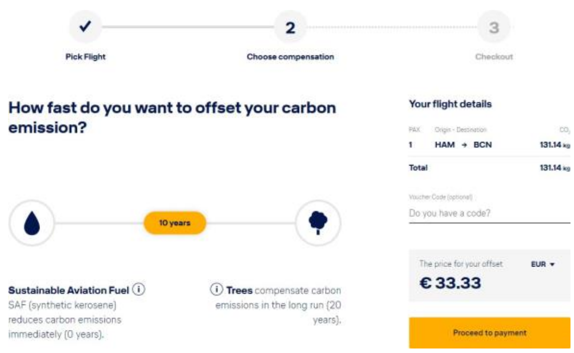


Figure 5.3 Second step of Compensaid. Extracted from (Lufthansa, 2020a)

As it can be seen in the Figure 5.3 the total amount of CO_2 the flight emits appears in the right side of the screen. What is interesting however, is what appears at the bottom part. There is a line that connect two circles, one with a drop and another with a tree. This represents the two ways that Lufthansa offers to compensate for the produced carbon dioxide: investing in Sustainable Aviation fuel (SAS) or in trees replanting. The orange tag placed in the middle of the two figures can be moved along the grey line. Depending on to which extreme the tag is moved the amount of years it marks changes: if it is placed right next to the left side (SAS) it shows 0 years, if it is placed right next to the right side (trees) it shows 20 years, and if it is placed in the middle, 10 years. This amount of years marks how long does it take to have an effect the offset the passengers pays. The price of the offset changes as well with the change of years: in order to take the offset 0 years to have some effect, it costs 64.04*EUR*; 20 years, 2.62*EUR*; and 10 years, 33.33*EUR*. This is due to the type of offset each option focus on. Both options are explained by Lufthansa at (Lufthansa, 2020b) and (Lufthansa, 2020c) respectively.

- **Sustainable Aviation Fuel:** According to (Lufthansa, 2020b) this type of fuel is the first viable alternative to fossil jet fuel. One of its advantages is that it allows to be used in planes without changing much of the current infrastructure. Furthermore, it reduces carbon emissions up to 80% due to the sustainability of its obtaining procedure. The following image synthesizes its procedure.

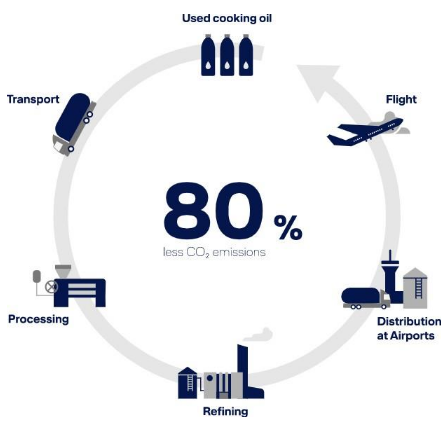


Figure 5.4 Representation of the SAS cycle. Extracted from (Lufthansa, 2020b)

The key to obtain SAS is recycling already burned fuel that comes from sustainable biomass or gases: the emitted carbon is reabsorbed through biomass and transformed into fuel again. According to Lufthansa, if the manufacturing and supplying process was optimized a 100% of carbon neutrality could be achieved. If the passenger decides to offset their emissions, they pay for the price difference between the regular kerosene that this passenger uses and the price of the amount of SAS that would have produced the same amount of CO_2 as the actual burned kerosene. Lufthansa uses the contribution to buy SAF and guarantee its circulation within the next six months: since SAF is said to be approximately three times more expensive that normal fuel, its demand is low and the productions costs tend to rise. This is why the acquisition of more amounts of SAS is needed, since as long as its production is kept in small amounts the levels of efficiency of its productions will be low.

– **Planting trees:** In this case, Lufthantsa partners up with Myclimate (Myclimate, 2020), who helps local communities to plant trees in Nicaragua, at the same time that it empowers them to manage their own resources. Specificaly, the reforestation takes place near a watershed that feeds the Estereo Real, one of most important estuaries of Nicaragua.

Finally, the last step consists on paying the carbon compensation after deciding the weight that SAF and trees will have on the offset. Apart from introducing the payment information, Lufthansa provides a summary where litres of SAF and the amount of planted trees is seen. The following summary is the one that belongs to the example that has been used along all this point, the Hamburg-Barcelona flight. In this case the mid point of the offset between SAS and trees has been chosen. An offset with a ten-years-effect presents the following numbers:

Figure 5.5 Last step of Compensaid. Extracted from (Lufthansa, 2020a)

Lufthansa says to have calculated the amount of emitted carbon dioxide analysing data from over 43000 flights performing a study along with SWISS and Myclimate. An algorithm was developed. This algorithm keeps being updated with the most recent data, being the last update in September 2018. The following table recaps the savings gained by the SAS and trees offsettings:

Table 5.2 Overview of Lufthansa offsetting numbers. Data extracted from (Lufthansa, 2020b) and (Lufthansa, 2020c)

Method	Community contribution	Purchased quantity	CO_2 savings
SAS	581k €	577kl SAF	1182.9t
Trees replanting	119k €	35415 trees	5902.41t

To sum up, Lufthansa performs its carbon offset through buying sustainable fuel and planting trees. Passengers have the option of choosing how strongly one option or another is applied.

Flysas

SAS is an Scandinavian airline that allows the passenger to offset the carbon they produce in two ways: on the one hand, buying biofuel and on the other hand, joining the loyalty program of the airline, SAS EuroBonus, or buying Youth tickets, which results into carbon offsetting.

Passengers are given the chance of buying biofuel when booking a ticket or at any other time before the flight departure. SAS gives the possibility of buying the amount of biofuel corresponding to 20 minutes of flight for one passenger. Passengers can buy as much 20 minutes blocks as they want. According to (SAS, 2020b) the price are 10 € per block. The amount of biofuel bought by a traveller is not necessarily used for the flight of the passenger, but for future operations. As Lufthansa also claimed, SAS says that by using biofuel a reduction of 80% of carbon dioxide emissions can be achieved. SAS emphasizes that the problem that biofuel presents is its production prize, as well as Lufthansa does. SAS estimates that producing biofuel is between 3 and 4 times more expensive than normal fuel, this is why has partnered with Preem, a biofuel supplier, to build a facility that increases the biofuel production.

When a passenger that is part of SAS Eurobonus, buys a ticket, SAS offsets the carbon dioxide produced because of their ticket for free. SAS does the same for Youth tickets. Employers tickets are offset as well.The airline is not the one that manages the offset, but a third part: Natural Capital Natural Capital Partners. It is stated in the website of SAS (SAS, 2019a) that the offsetting is conducted through investing in renewable energy projects in Asia.

Finally, something interesting about Flysas is its emission calculator. Unlike others, that just show the amount of carbon dioxide, SAS calculator breaks down the total emissions into the different emitted species and includes a brief explanation of them. Moreover, it allows the passenger to choose the aircraft with which the flight is performed. By doing this the differences between the several models of the fleet can be seen. Using (SAS, 2020a), the emissions that a flight between Hamburg and Barcelona produces will be shown. In this case, the calculator does not allow to choose the travel class. The following image is a screenshot of the result.

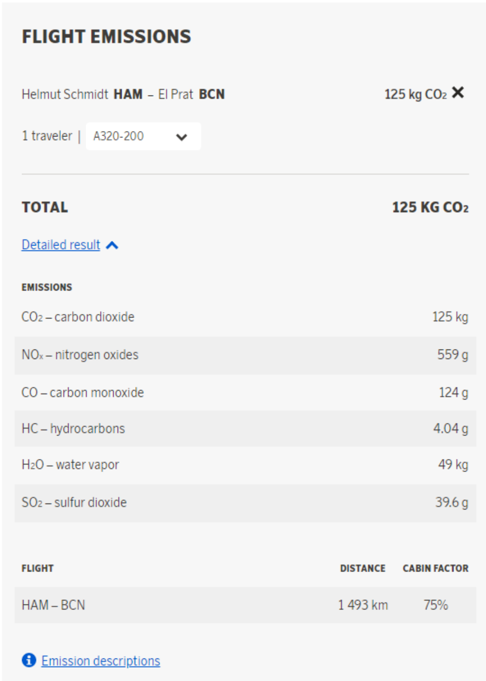


Figure 5.6 Flight emissions calculated using SAS website. Extracted from (SAS, 2020a)

It can be seen that an Airbus A320-200 was chosen because of being one of the most common aircraft. If an Airbus A320-200NEO had been chosen, the carbon dioxide emitted amount would have been of 95.7kg. This shows that the election of the aircraft is very important when it comes to emissions.

Easyjet

Easyjet works in its offsetting differently compared with the last two airlines. It does not give the passenger the possibility to offset as much as they want, but they promise to offset all the fuel they use. Something that stands out is the variety of offsetting strategies it provides. In (EasyJet, 2020) the following carbon offsetting projects are listed:

– **Afforestation and prevention of deforestation:** this project takes place in South America and Africa, since due to the poverty of the region much forests have been lost because of fires and agricultural expansion. The projects that easyJet promote are said to help local users to manage responsibly their resorces and create more job opportunities.

- **Investment in renewable energy sources:** this project takes place in India due to the excessive weight that fossil fuels have in the energy production of the country (75% according to (EasyJet, 2020)). The project that easyJet supports aims to build a solar installation in Tamil Nadu so the use of coal can be diminished.

- **Helping local communities:** this project takes place in developing countries and aims to reduce the emissions of the day to day life. Specifically, easyJet participates helping with its offseting programs in Uganda and Eritrea. It aims to provide local communities with access to clean water: when the access to clean water is not possible water has to be boiled to make it safe for the human consume. Boiling water is accomplished by burning firewood, with causes carbon emissions.

Norwegian

Norwegian gives the option to passengers to offset their flight by participating in a CO_2-reducing program. These programs are managed by the climate-focuses technology company CHOOOSE. Norwegian says to have focused on projects that take place in regions where they flight in order to compensate their carbon footprint. According to (Norwegian, n.d.), the following projects the airline together with CHOOOSE participates in are the following:

- **Installing wind generators:** this project takes place in the coast of Viietnam. By doing this, it aims to reduce carbon dioxide emissions producing clean energy while creating new jobs.

- **Building landfill gas converters:** this project takes place in Thailan. Specifically, the infraestructure is thought to be build in Bangok, where they capture methane from a landfill to avoid harmful methane release and at the same time convert it to electricity.

- **Investing in hydro energy:** this project takes place in the Houtay Makchan River in Laos. Again, it pretends to provide local communities with clean energy sources.

The thing that all these projects have in common is the certification emitted by the United Nations and Gold Standard, which ensures the passengers the contribution go directly to the said projects.

Virgin Atlantic

Virgin Atlantic is again an airline that relies on an external organisation to offset their emissions. In this case is called ClimateCare. This company leads several projects in developing countries, such as installing wind power generators, helping local communities to achieve more sustainable ways of life or replanting forests. By doing this they say to reduce the money spend on fuel, the need of charcoal, reduce air pollution and create job opportunities. Until now this seems to not present any differences compared to the other airlines. Nevertheless, the difference relapses into the emissions calculator. At (Virgin Atlantic, 2019) it can be seen. The following image represents an screenshot of the tool.

As it has been done so far, the flight between Hamburg and Barcelona will be taken as example.

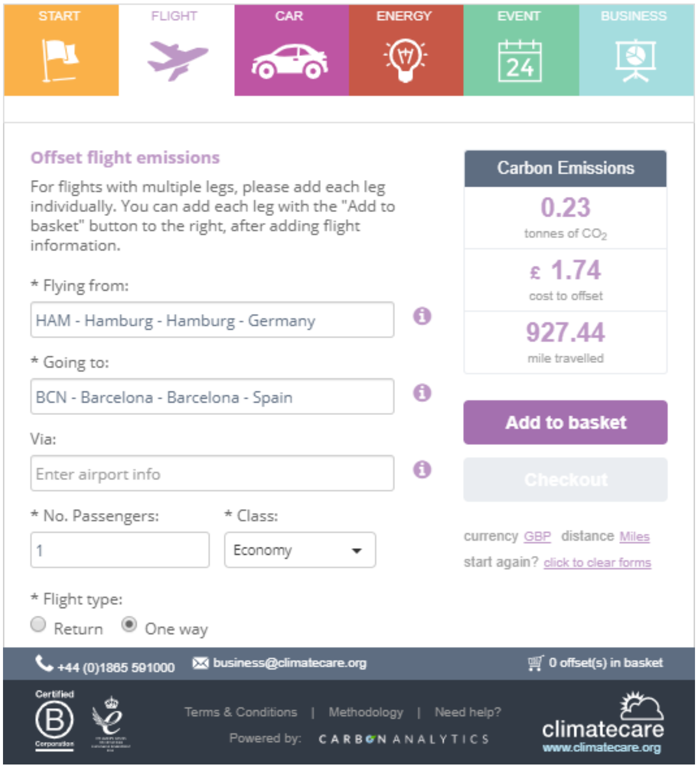


Figure 5.7 Flight emissions calculator of Virgin atlantic. Extracted from (Virgin Atlantic, 2019)

As it can be seen in Figure 5.7 the travelled miles, the amount of produced carbon dioxide and the price it will be paid. Later the option of paying an extra 10% is given.

However, what is interesting about this calculator is that allows the passenger to offset other emissions apart from the ones coming from the flight itself. In the first option, entitled "Start", one can pay for an specific quantity of carbon dioxide to be offsetted or directly pay a certain amount of money. In the third option, "Car", the distance driven per year, the engine type and the economy of the vehicle are asked to calculate the emissions to offset. In the fourth option, "Energy", the offset is calculated regarding the energy type and the consume. The "Event" tool aims to offset an event that includes travelling and accommodation; the amount of emissions depends on the duration of the event, the number of people and its comfort level. Finally, the last option, "Business", aims to a more professional target; although a quick offset can be approximated entering the amount of carbon dioxide, more specific impacts can be calculated joining an specific service called "Carbon analytics". However, although this last tool seems to be very interesting and useful, falls out from the scope of this study. The same calculator appears at the website of the company that Virgin has partnered up with, Climate Care (Climatecare, n.d.). Virgin says to give a discount code if the offset is performed via its partner. It is important to remark that other airlines, such as China Airlines, provide the offsetting service via Climate Care too (China Airlines, 2018).

Alaska Airlines

Alaska airlines gives the passenger the possibility to offset their flights through teaming up with Carbonfound.org Foundation. The process of choosing the carbon compensation is performed through the website environmental association (Carbonfund, 2020). Two different options are given. The first one consists on purchasing categories of flight distances: each category represents flights up to a certain distance, and each category costs a certain price; there are three categories in total. This option works as a quick and estimated way to offset the flight. The second one consists on using a calculator. This calculator is not like others where the origin and departure airports are introduced: instead of doing that, the total miles travelled or the amount of carbon dioxide are introduced to calculate the cost of the offset. However, what stands out in the case of Alaska airlines are the projects where the money goes. Most of the carbon offset projects have developing countries as targets: they help local communities to improve their way of life and make it more sustainable or install renewable energy sources generators. However, in this case Alaska airlines allocates the money to renewable energy projects in the United States. It is one of the few airlines that use money in their own country.

Air Canada

Air Canada has partnered with Less emissions to allow passengers offset their flights. When its emissions calculator is searched, the webpage of its partner, Less, shows up directly (Less, 2020). The first set of options of the tool is very similar to the other: the airports of origin and destiny and the number of passengers. However, what is different from the rest is the possibility to offset high altitude effects.

As it was already seen at Section 2.2.1, when certain emissions, such as oxides of nitrogen, are released at higher levels of the atmosphere the effects increase. This is why when this option is selected the price and the carbon to be offsetted almost doubles. In the following picture an offset example of a flight between Hamburg and Barcelona can be seen.

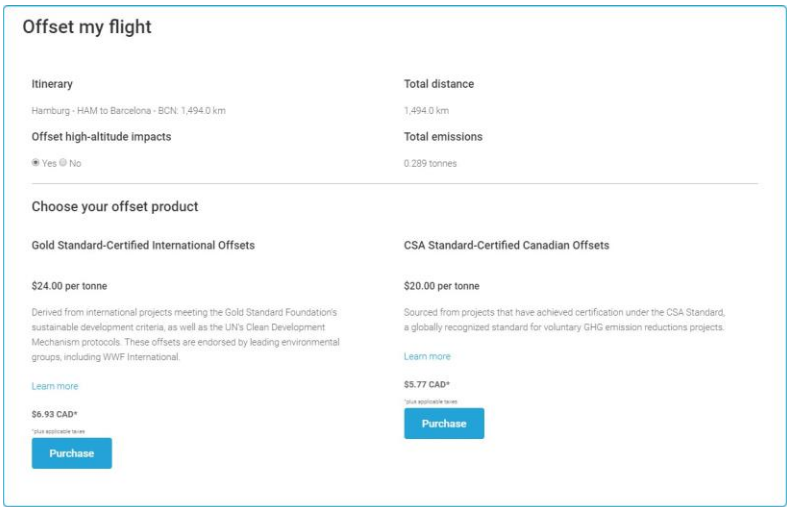


Figure 5.8 Flight emissions calculator of Air Canada. Extracted from (Less, 2020)

Something interesting about that is the possibility that is given to choose the project where one wants to participate. Similarly to the case of Alaska airlines, a project that uses the funds in the own country of the airline is found. Although in this case the option to allocate the offset to international projects, the offset can stay in Canada as well. The projects are related to the use of renewable energy sources and helping communities to live a more sustainable and independent way of life.

Brussels Airline

Brussels airline delegates its offset to CO2logic. The emissions calculator of this company, called Greentrippe (Greentripper, n.d.), presents more option than the others. The following image shows the emission calculator tool:

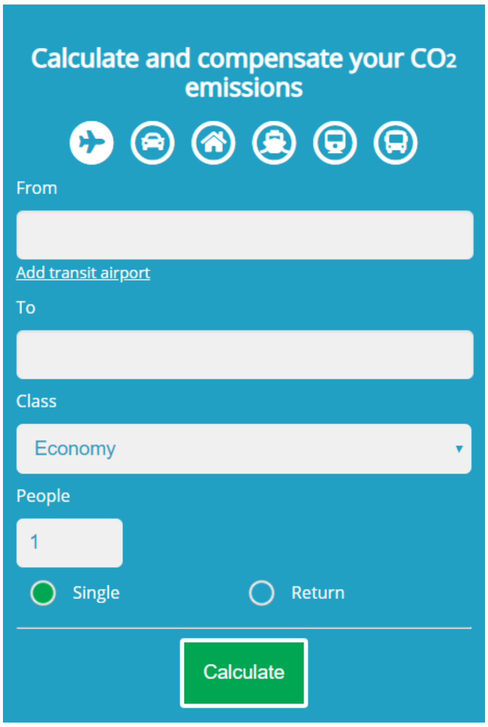


Figure 5.9 Flight emissions calculator of Brussels Airlines. Extracted from (Greentripper, n.d.)

As it can be observed, a part from the flight five more options are given. It is similar to the calculator provided by Virgin Atlantic, but it presents other options that might be more interesting when it comes to comparing aircraft to other means of transport. This calculator will be used in later sections. The plane option asks for the same parameters as the others. The second option, which is about cars, is very similar to the Virgin one: the passenger has to introduce the car consumption and then the distance covered per year. The third option is again very similar to the one that Virgin calculator presents: the kwh consumed per year at home coming from different energy sources have to be introduced.

Finally, the last three options are the ones that imply a notorious change. A shipping option is available: the passenger has to include the distance or duration of the trip and if the ferry includes or not its personal vehicle. The train and bus options are very similar: the user has to say the type of vehicle they will be using and the departure and arrival locations. However, in this section the analysis will be focused on the flight option. Once the departure and arrival airports are introduced, the following appears:

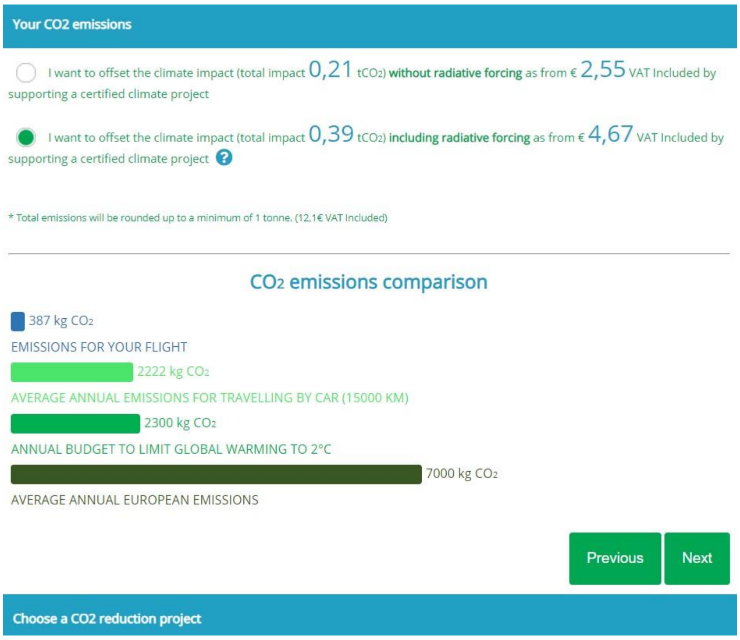


Figure 5.10 Result of the emissions calculator of Brussels Airlines. Extracted from (Greentripper, n.d.)

As it can be seen, the same Hamburg-Barcelona flight keeps being used as an example. However, which is different this time is the possibility to offset the radiative forcing as well. According to Greentripper, radiative forcing is caused by the constrails that air-crafts leave when they fly. This phenomenon was already presented in Section 2.2.1. As it was explained, they are responsible for a greenhouse effect. In general terms, radiative forcing, usually expressed through the radiative forcing index, is a weighting factor that indicates how non CO_2 compounds impact the climate. It quantifies how much do the rest of emissions increase the climate change with the same warming effect carbon dioxide has, so if calculations want to be strict, they have to sum the effects of these other sub-stances. This is why the calculator gives the possibility to offset its effect as well. If this option is leaved unmarked, the emissions to offset are approximately 50% less (211kg).

Japan Airlines

With that many airlines reviewed at that point is difficult to find offset tools that present noticeable differences. Japain Airlines, although having a very similar mechanism if compared to the previous ones, is slightly different when it comes to choosing the project where the offset money ends. This adds an extra level of transparency that can be highly valued within some passengers. The following figure is a screenshot of the step where the passenger has to decide which project to help.

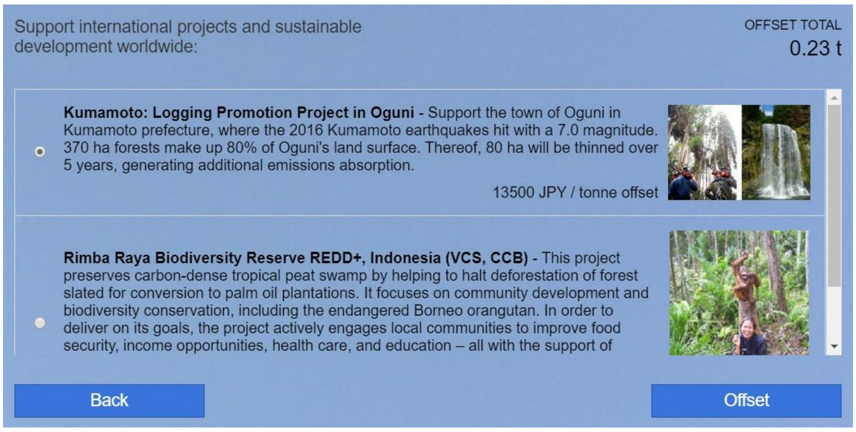


Figure 5.11 Project decision step at the Japan Airlines emission calculator. Extracted from (Japan Airlines, n.d.)

British Airways

The case of British Airways is worth mentioning due to the fact that it partially offsets the flight emissions for free. This means that if the passenger wants to offset their ticket, only has to make up for part of it. The following image represents the message that British Airways displays explaining that in its calculator. The flight between Hamburg and Barcelona has been again used as an example.

Your total CO2 emissions for this flight are **0.22** tCO_2e.
British Airways has already accounted for **0.10** tCO_2e** so you only need to offset **0.12** tCO_2e.

Cost to offset **£1.00**.
Please note that the minimum transaction size is £1.00. Any surplus from rounding will be donated to the BA Carbon Fund, a charitable fund supporting community projects in the UK and Africa.

**The emissions from your flight are regulated by the EU Emissions Trading System. We have subtracted the emissions reductions already accounted and paid for through our participation in this scheme so that you only offset the residual emissions.

Figure 5.12 Result of the carbon offset by British Airways. Extracted from (British Airways, 2019)

Finnair

Finnair is an unusual case. Although the majority of the airlines offer an offset service, Finnair does not, but not because of a lack of will, but because being forbidden to do so. At (Teivainen, 2020) the reasons are explained. At the article is said that the National Police Board of Finland determined that offering passengers the possibility to pay for carbon offsetting is a scheme that results unlawful for business. The explanation that is given for this decision is based on the fact that carbon offset is considered a compensation and a money collection act. It is stipulated that money collection is permitted as long as it does not imply any compensation.

Initially, the carbon offset projects in which Finnair participated were the purchase of biofuel and an initiate of more energy-efficient stoves in Mozambique. This was very interesting, since there are not many airlines that use the carbon offset compensations to buy biofuel. Although Finnair can not offer to their passengers any offset possibility, an emission calculator is provided in their website (Finnair, 2020).

In the following image an example of the emissions calculated in a flight between Hamburg and Beijing will be shown. No flight between Hamburg and Barcelona was offered, this is why the example had to be changed.

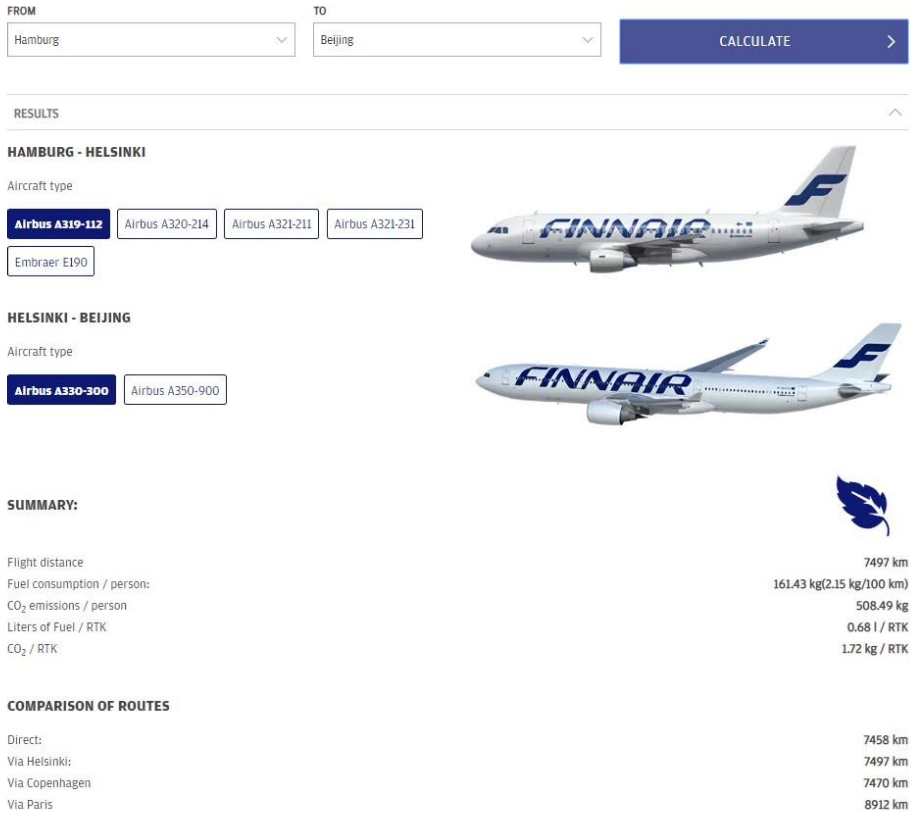


Figure 5.13 Emissions calculator of Finnair. Extracted from (Finnair, 2020)

This calculator would not have been shown if it had not presented something different. Amongst all the reviewed calculators, the one from Finnair one of the fees that allows the passenger to compare how much the emissions of its flight would change if the aircraft of choice was different. Moreover, it is interesting that although Finnair cannot offer carbon offsetting by law, still provides their passengers with a tool to put their flight into context.

So far, all the offset tools that have been reviewed were exclusive of one airline or were the result of the collaboration with an environmental association. Nevertheless, it is remarkable to remind that there are other tools offered by independent companies. The services that some of them offer will be now reviewed.

Atmosfair

Atmosfair is a clear example of an independent system of carbon offsetting and emissions calculator. Atmosfair is known for the "atmosfair Airline Index", a ranking that compares the carbon efficiency of the 200 largest airlines of the world. This ranking will be however analysed in more detail in later sections. So far the most recent index corresponds to 2018 (Atmosfair, 2018b).

In this section the example of a flight between Hamburg and Barcelona will be continued. One of the useful characteristics of the Atmosfair calculator (Atmosfair, 2019) is the possibility to decide the flight type (scheduled or charter) and the aircraft model. However, it is advised to not enter a concrete aircraft it a comparison between different airlines wants to be seen. The following images represent screenshots of the results of the calculator.

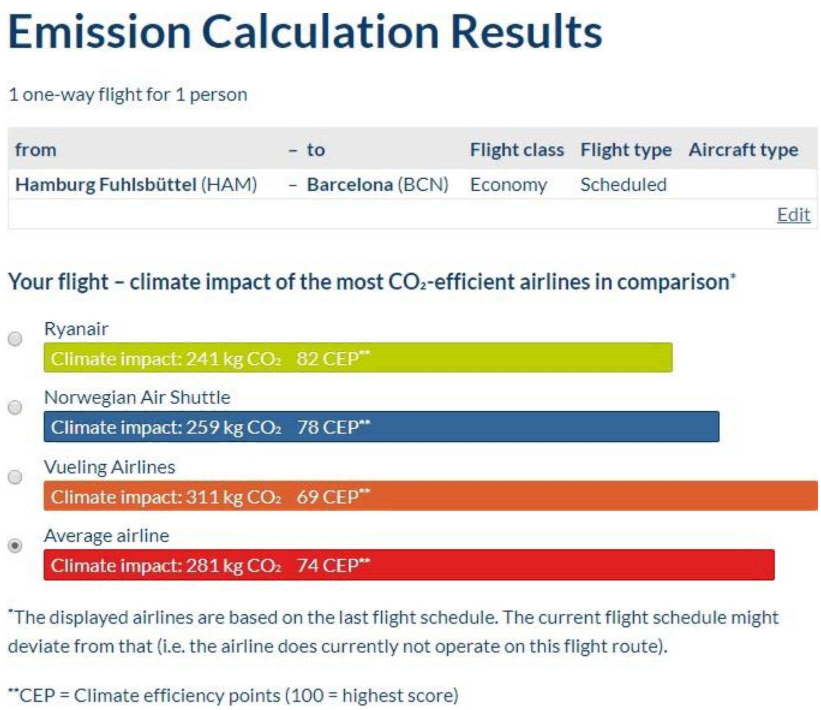


Figure 5.14 Emissions calculator of Atmosfair, first part. Extracted from (Atmosfair, 2019)

In the first part of the results the calculator shows the carbon dioxide emissions of different airlines. Depending on which one is selected, the offset money changes later.

Figure 5.15 Emissions calculator of Atmosfair, second part. Extracted from (Atmosfair, 2019)

At the second part of the results a more detailed comparison of the airlines that perform the selected flight is shown. The climate impact (amount of carbon dioxide) is the same that the one provided before, but this time the possible aircraft to be used can be seen as well. In the case of Vueling for example several aircraft models are displayed. If the passenger wants to see the difference between two models, the specific aircraft would have to be chosen from the first options of the tool. It would be useful if it appeared directly, as some small differences are found: for the Hamburg-Barcelona flight, Airbus A319 produces 306 kg of CO_2 and airbus A320 267 kg, which results in a compensation of 8 € or 7 € respectively. As the difference is small, Atmosfair seems to have chosen to show the average result of all the possible aircraft the airline provides for travelling.

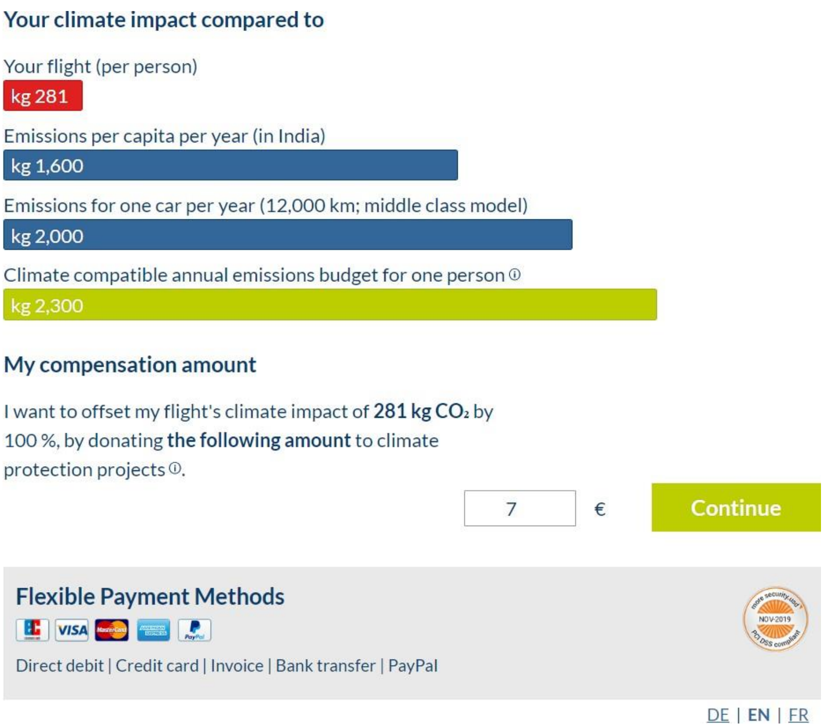


Figure 5.16 Emissions calculator of Atmosfair, third part. Extracted from (Atmosfair, 2019)

A final graphic is presented with comparative purposes. The climate impact of the selected flight is compared to other statistics. Probably the last one is one of the most interesting ones: the climate emissions budget is the amount of emission one person would be allowed to create if the objective of limiting the rise of the temperature of earth to 2^{o}C above the pre-industrial level would be wanted to be achieved.

Flygreen

Flygrn is a website with an innovative initiative. It allows the passenger to offset their carbon emissions, but in a different way compared to the others. Essentially Flygrn is a flight search tool that works in a similar way to others: an origin and a destination airports are introduced, the dates of the departure and the return (if the flight is not a one way one) and the number of tickets as well as the class type. Then Flygrn searches several booking sites and displays them. Different filters can be also added besides an specific order of show according to a parameter of choice. After that, if a flight is booked, Flygrn receives an economic compensation from the booking site through which the purchase of the ticket was performed. Until that point everything follows the normal functioning of any search engine. However, from that point is where the service that Flygrn offers differs from the rest: with that fee, Flygrn offsets the flight carbon dioxide emissions partially o completely. The offset it is said at (Flygreen, 2020b) consists on trees replanting or the installation of solar cooking facilities. Following the last examples, a Hamburg - Barcelona flight will be used for illustration purposes. The flights are searched for the 16/06/2020 and the searched was performed at the 11/05/2020; the results will obviously change with the pass of time.

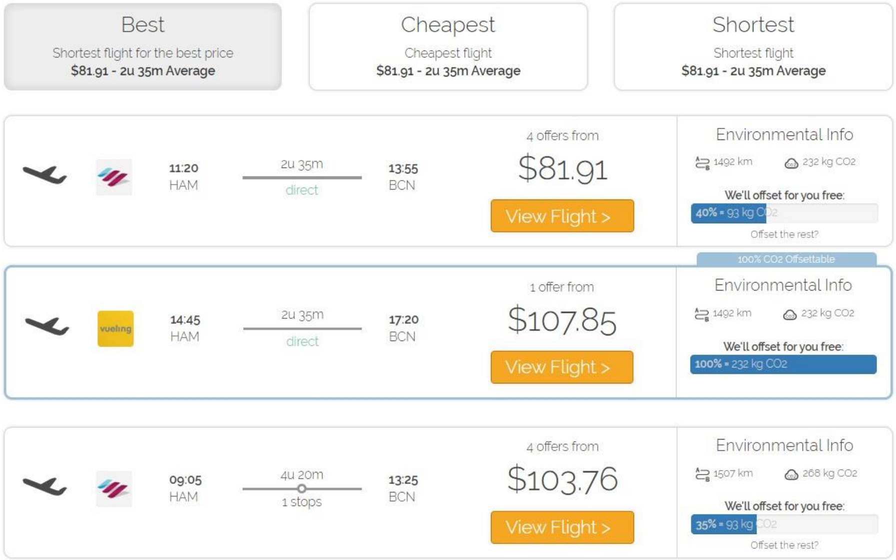


Figure 5.17 Flights searched using Flygrn. Extracted from (Flygreen, 2020b)

The Figure 5.17 is a good example because shows three types of flights: one without stops, fully compensated; other without stops as well, but partially offset, and finally one with a stop and partially offset too. The ones that are partially offsetted appear with a message that reminds the passenger to possibility to compensate the rest on their own. This possibility might be given during the ticket purchase once Flygrn redirections to the buying websites, but this will depend on the options given by the other part. If the passenger wants to offset the rest of its flight or do an extra compensation it can be done as well through the emissions calculator service that Flygrn offers at (Flygreen, 2020a). One thing interesting about this is that once the amount of carbon dioxide is computed, Flygrn shows equivalencies based on daily actions. Using techniques like this helps to make the impact of the flight easier to understand. The following image shows that. As always, the Hamburg - Barcelona flight has been used as example.

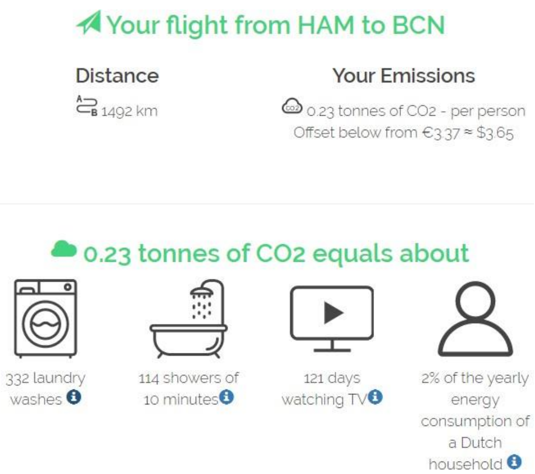


Figure 5.18 Results of the Flygrn carbon calculator. Extracted from (Flygreen, 2020a)

On the other hand, an specific amount of carbon dioxide or an specific amount of money can be offset with another tool provided at the same website. This is specially useful if the part that Flygrn did not offset wants to be covered. As it can be seen at Figure 5.17, the partially offset flights show the percentage covered. Using the percentage showed, which is the one covered free by Flygrn, and the amount of carbon dioxide that this represents, users can easily calculate how much does it lack to achieve the 100% and offset it.

Finally, something interesting about Flygrn is the possibility that offers to compare flights with trains automatically. When the journey details are entered, if the option of travelling by train exists, it is shown. Between Barcelona and Hamburg the engine search does not give any chance to travel by train, this is why to see the example the travel Hamburg - Frankfurt is set. The following image shows its result.

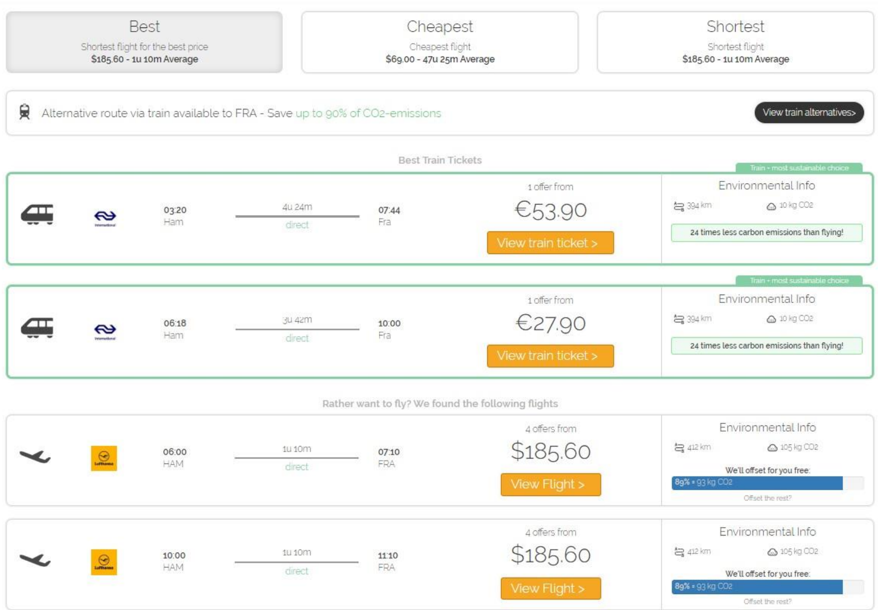


Figure 5.19 Results of the Flygrn carbon calculator when trains are possible. Extracted from (Flygreen, 2020a)

As happened in Figure 5.18, the results shown at Figure 5.19 will depend on the day where they were searched. As it can be seen, in the case of trains the offset emission is not performed (since the direct emission level of trains is almost zero if they are electric, which is the majority) and they are highly encouraged to be used.

The possibility of offsetting a business is given if Flygrin is contacted. Moreover, the possibility of offsetting a train or bus travel is also possible. It was seen at the last Figure 5.19 that the web did not offset. Flygrn proposes to compute the emissions using the web (Eco Passenger, 2020) and then, once known the amount of carbon dioxide to offset, use its own calculator (the one seen before). However, a more detailed look into tools such as (Eco Passenger, 2020) will be taken in later sections.

SCX

Although it is not a carbon offsetting tool thought for passengers, it is worth mentioning due to its nature. SCX consists on a private climate stock exchange that has been created for airlines in the Southern Hemisphere. Big airlines, such as LATAM, joined it on 2015 according to (Greenair, 2015). The services that SCX offer can be synthesized in the following points: firstly, they develop a program to help companies achieve their compromise of going carbon neutral; secondly; secondly, they offer a platform of listing and trading, where companies can get access to projects of emissions reductions while the developers of such programs get visibility for them.

5.2.2 Analysis of the Results of the Carbon Offsetting Methods

Once the different tools that airlines and environmental-focused companies offer to offset carbon emissions it is important to take a general look to extract some conclusions. One of the first things that should be analysed is the numbers these calculators provide. Since the same journey was used every time, performing this comparison is possible. It is important to remark that not all the calculators will be able no analyse from a numerical result point of view, because just the calculators that provided something different were used to compute the emissions.

The following graphic shows the carbon emissions computed by the reviewed calculators.

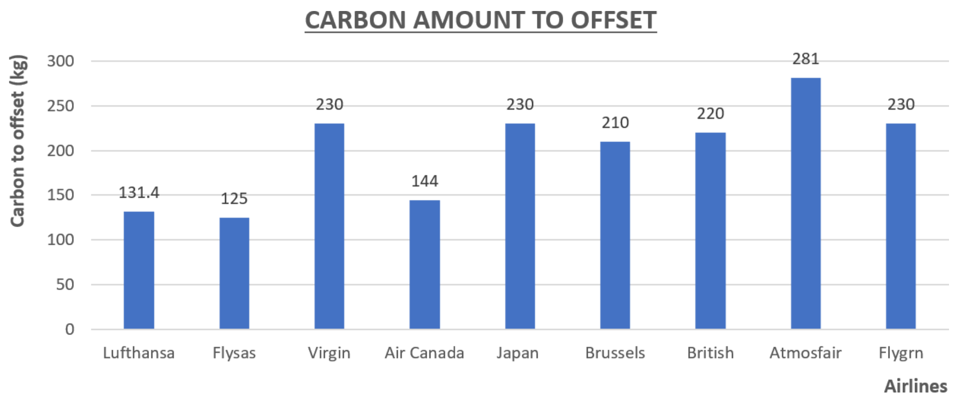


Figure 5.20 Carbon emissions calculated by the reviewed offset tools.

The average amount of calculated kg is 220, with a standard error of 17.96. However this measurement presents a strong dependency to the type of aircraft used. This is why although at a first glance it seems pretty homogeneous, no firm conclusions can be extracted. There is no standard in the industry and every airline use its own method. Moreover most of the times the aircraft model used in the flight it is not known, as well as the engine model or the seat layout. Finally, although no conjectures should be made, calculations can always be made using the most suitable numbers for marketing reasons.

Apart from the amount of carbon dioxide the calculators predict that will be consumed, the price the passengers pay per offsetted kg is also an important metric. The following graphic shows this magnitude.

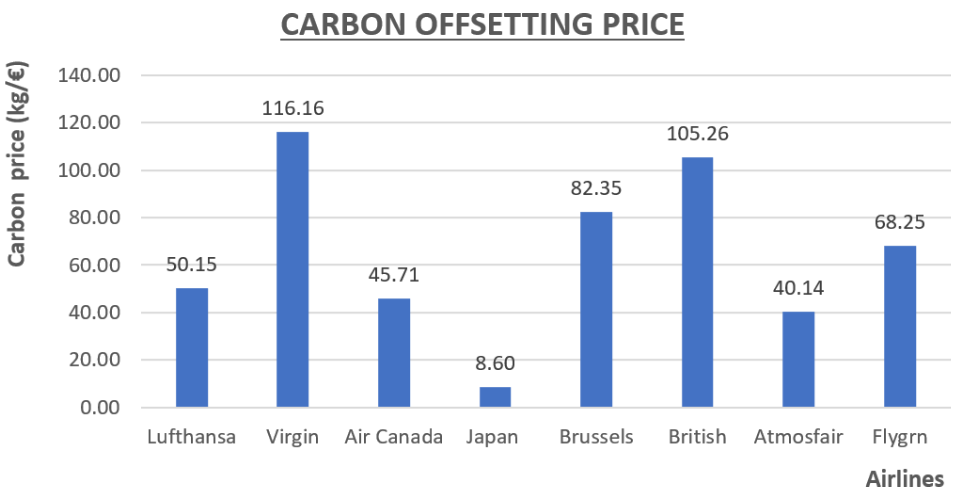


Figure 5.21 Amount of carbon that can be offsetted with 1 euro

The graphic of the Figure 5.21 represents how much kg of carbon dioxide can the passenger buy with 1 e. This time neither the average result nor the standard error are worth calculating. It can be seen how much different the numbers are. This is originated by the different purposes the money has. For example, in the case of Lufthansa the price that is shown is the one corresponding to the 20 years offsetting by planting trees; if the offsetting choice had been buying biofuel, the price would have changed. In the case of British Airways the airline already offsets part of the journey, which makes the conditions where the carbon compensation happen really differ from the rest. Furthermore, each company participates in different projects which might not need the same resources. This is why an overall conclusion can not be extracted this time neither.

Apart from the numbers these offsettings present, it is also important to have a wider perspective and evaluate the purpose of offsetting. Some of them have arisen some criticism. All in all, the following types of projects that offsets pursue can be found:

Buying Biofuel

It has been seen how some airlines use the carbon offset money to buy equivalent quantities of biofuel for future flights. This is one of the carbon compensations with most short-termed results, which also means that its cost is higher. Although being a very interesting measure is not one of the most chosen offset methods used.

Planting Trees

This is probably one of the most chosen methods by airlines and other companies to offset carbon dioxide emissions. Its effects are known to be very long-termed. By doing that, airlines use the intrinsic nature of trees, which store carbon dioxide and produce oxygen, to fight climate change. Lufthansa define its benefits as follows:

> *"Reforestation is one of the most effective methods to fight climate change according to recent studies. [...] The local community will reforest the region, which will not only store CO2, but also help conserve the wetlands that host unparalleled biodiversity."*

Nevertheless, although Lufthansa is very positive about the advantages of this method, the truth is that there are other parts that have different opinions. The problem with trees is its volatility, as it has been explained before: if a forest fire happens, a plague kills them or they are chopped down, either by humans or by natural causes, they lose its offsetting power. The worst part is that controlling this is very difficult, because as Lufthansa stated, 20 years of trees functioning are necessary to offset the required amount of carbon dioxide; controlling that nothing happens in 20 years is extremely complicated. Moreover this effect is much more difficult to quantify than the change from fossil fuels to other type of energy source, which as being a human installation is better to monitor. Finally, most of times these replanting projects happen in developing countries, whose political situation are not always the most transparent. This last argument might fall a bit into speculation, but it is a prove that easily doubts arise.

Installing Energy Generators Powered by Renewable Sources

This is as well a widely used project. When airlines decide to participate in such projects, two types are clearly differentiated: firstly, the ones that take place in developing countries; secondly, the ones that take place at the origin country of the airline, which is usually a rich American or European country. Norwegian is an isolated case, helping in countries over which the airline flies. Choosing one or another depends on the moral preferences of the passenger. Which is clear however is making renewable energy produce a certain amount of energy that was produced by fossil fuels before its easier to compute that the effect of planting trees.

Helping Communities of Developing Countries

Besides planting trees and building renewable energy generators, helping local communities is a common measure pursued with offset money. This projects take place at developing countries and have the objective of helping their citizens to improve their life standards at the same time that help them to live a more environmentally respectful way of life. Most of times they have to use fossil fuels to do certain activities, because they are easiest resources to get access to. Nevertheless, by investing in facilities that help them have a more self-sustainable way of life, the carbon dioxide emissions decrease and job opportunities are created.

The project the passenger choses to participate in is important: The majority of offsetting projects are certified by stamps of Golden Standard or the UN, this ensures their good practice. In terms of the company that performs it, to offset directly the emissions with the airline the passenger flies is a good option since a direct offsetting of the emission happens. If an independent company was willing to be used, Atmosfair is probably the best one. Others, make a general offsetting without taking into account the aircraft model or the travel class. This will be seen again when the systematics for the passenger to compare the environmental impacts of their different travelling options are seen, since Atmosfair will be one of the proposed tools.

5.3 Transition of Companies to Passengers Offsetting

As it has been seen during the past two sections an initiative such as carbon offsetting has been found in two different levels: for companies, specifically airlines, and individuals, specifically passengers. It is common that ideas carried out by big entities are eventually transported to smaller levels. After airlines seeing that they needed to pay for what they pollute, they thought that this possibility could be offered to their costumers as well. By giving them the chance to help in the environmental issue they were getting on the first hand a better image, and on the other hand, a helpful contribution in the fight towards a more sustainable industry, since that money was used for projects that helped the industry in different ways.

So far everything related to carbon offsetting seems very positive, but is not always like this. The action of carbon offsetting has been sometimes defined as a moral greenwasher, and several opinion articles have been written about it. The following article of The Guardian is a good example (Cosgrove et al., 2019). They argue that although a situation of carbon neutrality is achieved, if the pollution keeps rising, the offsetting prices would rise consequently, but so would do the temperature of the Earth. There are groups that criticise that if the purpose of ofsetting is misunderstood, passengers could increment their flights with the most pollutant options thinking they are making no impact. This is why is important to deeply understand offsetting. By offsetting carbon emissions, the passenger is not making them disappear, they are just helping for making the future a little bit more sustainable. This is the key of the idea, they are helping in the future, not the present, so offsetting can not be the unique strategy in the fight against climate change and air pollution.Flying in more efficient aircraft and following airlines suggestions, such as pack lighter, since lighter planes means less consume, are actions that really help in the present.

Going back to offsetting, if the doubts that rise after looking at these schemes are neglected, such as considering that offsetting the emissions is the airline job and not a passenger task, it can not be denied that it is a very positive initiative. However, as it has already been said, it is nothing more than a palliative solution: it tries to get something positive from something negative such as the produced emission. The question is, what if existed something that helped before the ill appeared, before the emissions? It could be more useful to allow the passenger choose the best alternative that produced less emissions, instead of paying money for compensating them once they were already released. This is where the idea of an ecolabel for the passenger aviation sector is born, an environmental indicator with which the passenger can know which aircraft, and eventually which flight, is more environmentally sustainable. This will be studied in the next section.

6 Ecolabel for the Passenger Aviation Sector

As in the title of this thesis can be seen, the main topic of this project revolves around how informing aviation passengers about the environmental impacts of their flights. This is why the analysis of informing tools will have a very important role. It is always important to remember that this thesis is supposed to follow the work that previous students did on this subject. At the beginning the thesis were mainly focused in developing the idea of the ecolabel. There was not any tool that was created with the purpose of informing the passenger about the several types of pollution their flight participated in.

Tim Haß created the first ecolabel (Haß, 2015), which stablished the basis for future work. Lynn Van Endert (Van Endert, 2017) continued the work by developing the final design of the ecolabel; it consisted on a more polished version with a more visually appealing style and some metrics variations. Finally, Sophie Sokour and Tobias Bähr improved the development of the ecolabel by automatising the process of its creation (Sokour et al., 2018); moreover, as they were able to obtain a greater number of ecolabels a comparison between some of them was performed. Reached this point it is necessary to look at the job done and analyse what can be done to continue the study of the techniques to environmentally inform the passenger.

If the ecolabel is isolatedly analysed not much flaws can be pointed. It accomplishes perfectly its purpose inside the limitations its own nature. However, although the ecolabel covers everything it could cover considering the inherent characteristics of a tool like that, it does not cover everything that should be said about the environmental impacts of a flight. At this step, several paths can be seen ahead: one possibility would be to redesign the concept of the ecolabel to include the things that it lacks. The problem with that is the overloading of information that would cause. The ecolabel is thought to be an image that, with a quick glance, gives information about the efficiency of an aircraft; an excess of information would worsen its comprehension. Other option that could be thought would be creating from scratch another tool, different than the ecolabel, that covered the information that the ecolabel does not in order to fulfill the goal of completely informing the passenger. This however might not be the most efficient solution. The ecolabel itself is not a from-scratch creation, but an adaptation from an existing idea that other sectors use. This is why this option should be discarded as well, specially due to the great numbers of informing tools that already exist.

This last reasoning leads to the third option: combine the ecolabel with other existing tools to provide the passenger with the whole evironmental information. As it has been seen in the Section 5.2, which treated the possibility to offset flights as an individual passengers, there are tools that help the passenger to clearly conceive the impact of their flight. Although the chapter was focused on analysing tools that airlines provided to allow passengers compensate the environmental impact of their flight, a great number of emissions calculator was seen, and some of them even allowed to compare between aircraft models. If this many comparing techniques were found collaterally, as the goal of the chapter was searching calculators but the offsetting itself, if an specific research is done just on informative tools a greater number are very likely to be found. This is why in this section the combination of the ecolabel with other tools will be discussed. It will be structured as follows: firstly, the ecolabel will be reviewed and analysed; once the things it lacks are found, a research on other tools will begin. Finally, the method resulting in the combination of all the given tools will be presented.

6.1 Origin of Environmental Labels

The aviation ecolabel, in a few words, is pretended to be a document that summarizes the environmental impacts of an aircraft. However, before starting to analyse what could be improved about the ecolabel a brief review of what the ecolabel is should be made. Once its purpose and origin are understood a closer look will be taken.

6.1.1 Origin of the Ecolabel

One thing that it is important to know is where does the idea from the ecolabel come from. It is clear that the aviation sector was not the first one to try to implement such a concept. This is why, in order to do a proper research about its origins, the most accurate name that defines this aviation ecolabel has to be acknowledged. If one types the word ecolabel on the internet, the following image would appear:

Figure 6.1 Image found if ecolabel is searched. Extracted from (European Commission, 2020)

The Figure 6.1 represents completely what the European Comission, its creator, shows as the ecolabel. One could think that this stamp is far from a document that intends to synthesize the environmental information of an aircraft. A look will be taken at what the European Comission at (European Commission, 2020) defines as an ecolabel:

> *"Established in 1992 and recognised across Europe and worldwide, the EU Ecolabel is a label of environmental excellence that is awarded to products and services meeting high environmental standards throughout their life-cycle: from raw material extraction, to production, distribution and disposal. The EU Ecolabel promotes the circular economy by encouraging producers to generate less waste and CO2 during the manufacturing process. The EU Ecolabel criteria also encourages companies to develop products that are durable, easy to repair andrecycle."*

This definition does not seem to match with what the aviation aircraft is thought to be. Moreover, if at the same website, the option "EU ECOLABEL FOR CONSUMERS" is clicked, the definition of what the ecolabel in which consumers are interested should be. As the ecolabel for avitaion is ultimately something that interests passengers, or consumers, the most, the definition should apply as well to the ecolabels for aircraft:

"When you're rushing round the aisles of the supermarket or picking up something from the shop, with so many green labels and claims lining the shelves, it can be hard to tell which ones to trust. The EU Ecolabel logo makes it simple to know that a product or a service is both environmentally friendly and good quality. It's easy to recognise and reliable. The logo can be found on the packaging of every EU Ecolabel product."

With this last definition it can be clearly seen that the original idea from the EU Comission, the EU Ecolabel, differs considerably from the aviation ecolabel. The EU Ecolabel is simply a stamp that confirms that a product is environmentally friendly, without any deeper analysis of the metrics of the product. Nevertheless, the aviation ecolabel does intend to provide information of these metrics, not just a confirmation or not for if the product is environmentally friendly.

6.1.2 Origin of the Energy Label

The difference between the ecolabel and energy label definitions does not mean that the aviation ecolabel is a completely from scratch creation. Calling the aviation ecolabel, ecolabel, is just a language abuse, because actually it is an energy label. Nonetheless it is easy to understand what it has been called ecolabel and not energy label: the first name is much more catchy and generates a greater impact when read. If the term energy label is searched on the internet, the European Comission website (European Commission, n.d.[a]) provides the following image:

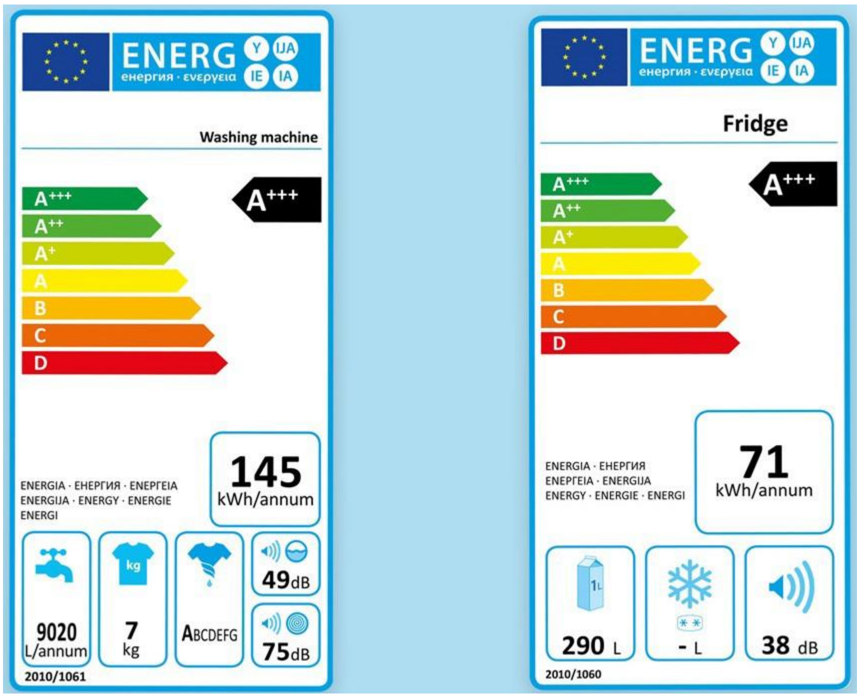


Figure 6.2 Image found if energy label is searched. Extracted from (European Commission, n.d.[a])

This time, the last image, the Figure 6.2, actually represents what the aviation ecolabel was thought to represent. In this case it shows the metrics that can help to explain how environmentally friendly a fridge and a washing machine are: the energy efficiency (in terms of consumed energy per year) besides other product specifications. As it has been done with the ecolabel, whose picture was presented besides with its definition, will be done with this energy label. At (European Commission, n.d.[a]) the European Comission defines the energy label as follows. This time the definition should match the purpose of the aviation ecolabel.

> *"The EU energy labels provide a clear and simple indication of the energy efficiency of products at the point of purchase. This makes it easier for consumers to save money on their household energy bills, while reducing greenhouse gas emissions across the EU. [...]*
>
> *First introduced for a number of household appliances in 1994 and subsequently expanded in 2004 – with a comparative scale from A (most efficient) to G (least efficient) - the concept has been a key driver for helping consumers choose products which are more energy efficient. At the same time, it also encourages manufacturers to drive innovation by using more energy efficient technologies."*

It can be seen at the prior definition that what the goals of the EU Energy labels are the same as the aviation ecolabels: inform users about the energy consumption levels of a product. Although it has been said that energy label is a more accurate denomination for the aviation ecolabel, its name it will not be change due to marketing reasons: ecolabel is a better name when it comes to impact the consumer. Once that the origins of the energy label have been set, how the aviation ecolabel began will be explained.

6.2 Review of Other Vehicles Environmental Labels

What is important to do now is review already existing ecolabels that inform the passengers about the environmental impacts of their flights will be shown. Three ecolabels in total will be reviewed: firstly, the one created by the airline Flybe; it was the first aviation ecolabel. Secondly, the one that Hass created in his bachelor thesis (Haß, 2015); it was the first ecolabel of the sequence of thesis that covered the topic of environmental information under the supervision of Prof. Dr.Ing.Scholz. Thirdly, the one that Van Endert developed; it was the final model of this sequence of thesis, started at (Van Endert, 2017) and followed in (Sokour et al., 2018).

However, before starting to explain these models, an example of energy label of a another vehicle will be analysed. Although an aircraft is different than other transport means, it is always important to see what other more consolidated models have done. The car will be the chosen vehicle. First of all, because is one of the most popular means of transport for performing considerably long journeys and, secondly, because due to its extensive use is a product very likely to have a solid background on a matter like this.

6.2.1 Cars Energy Labels

Taking the energy label as an example is much better than taking other labels, even being more common, such as the ones that can be found at fridges, for example. Although when one thinks about energy labels the first thing that pops into their mind are the ones of fridges or televisions, since they are electric powered, the information shown differs vastly. However cars are combustion vehicles too. In household appliances the major efficiency indicator is the electrical efficiency, but in motor-vehicles, carbon dioxide emissions in grams per kilometre travelled.

What happens with cars, unlike other products, is that not all the manufacturers have adopted the same design. The following images are examples of five different types of energy label:

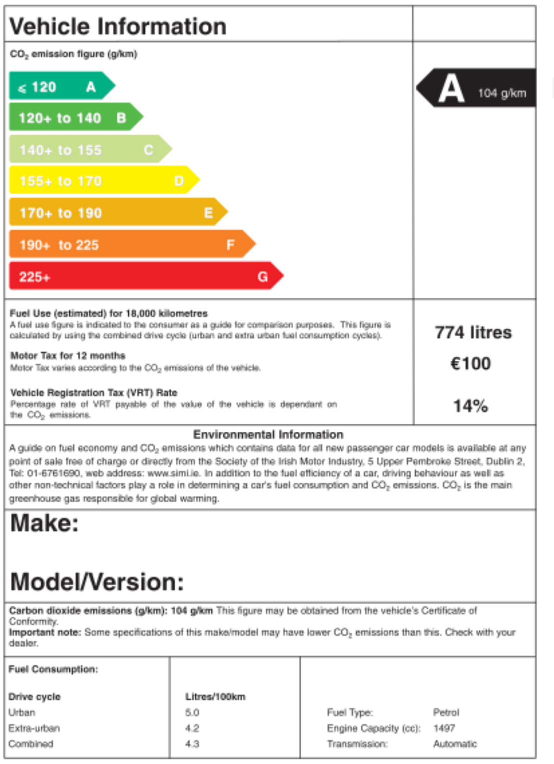


Figure 6.3 Example of an Irish car energy label. Extracted from (Wikipedia, 2019)

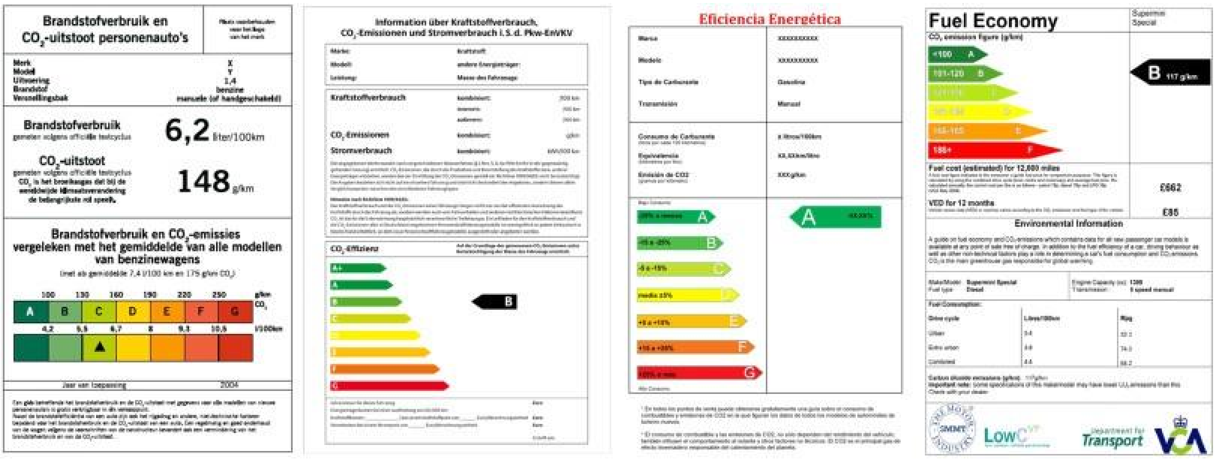


Figure 6.4 Example of energy labels from four different countries. Extracted from (Haq et al., 2016)

In the Figure 6.3 and Figure 6.4 several information can be seen, the most relevant will be now highlighted. Firstly, different specifications can be found, such as the vehicle model, the engine type, the transmission or the taxes the driver should pay. Every label presents it differently and through diverse designs. However, there are two metrics that stand out from the rest: the fuel consumption and the carbon dioxide emissions. Although the units in which the information is shown can differ (liters per 100 km or liters per 18000 km for instance) at the end the four of them present both as the main energy indicators. Which, nonetheless, varies and seems that it should not, is the magnitude used for the color scale grade. All of them, except the fourth one, use the emissions of carbon dioxide in grams per kilometer. The third one, which is an Spanish label, uses the fuel consume. Although both efficiencies are connected, there is no universal bound, which makes it different for the user to read the two versions. Nevertheless, what can be extracted is the common philosophy that stands behind both magnitudes. This lack of standardisation is caused due to the fact that vehicles do not form part of the EU energy label: not making it compulsory to participate in the scheme gives freedom to each manufacturer to use its own criteria, which impossibilities accurate comparisons. Just in household appliances it is mandatory, but this will be seen later.

These types of labels are however not the only type that vehicles have. Their tyres display as well informative tags. The rolling resistance (which ends up affecting the fuel consume of the vehicle), the wet grip and the noise emissions are shown.

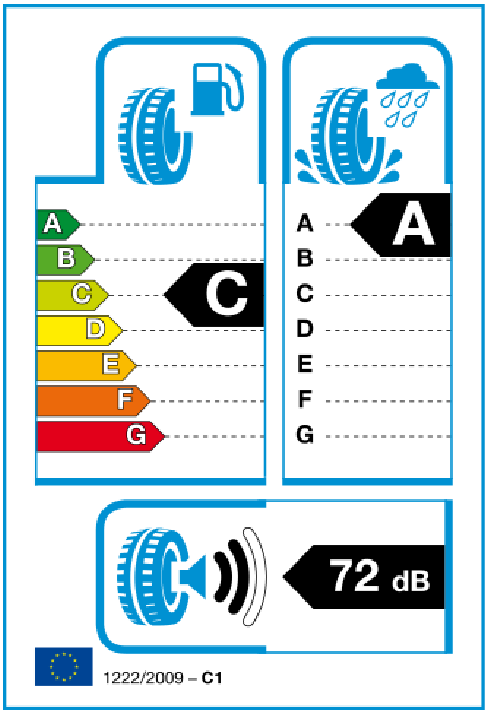


Figure 6.5 Example of tyre labels. Extracted from (Wikipedia, 2020o)

In the last image, Figure 6.5, it can be seen the metrics that were described before. Although a tyre label is not part of the aviation ecolabel, it is always good to take it into consideration for possible ideas that could upgrade the concept.

6.2.2 Cars Ecolabels

There are several types of "ecolabels" if the concept is taken as a mark that shows the environmentally well behaviour of a product. If however when speaking about the ecolabel the EU ecolabel is considered, there is just one stamp. The mark has however different meanings regarding the considered product. The European Commission website has to be consulted if someone wants to check the criteria for a certain product (European Commission, 2017). Consulting this web it can be seen how there is no section for cars. There are however other "ecolabels" that are not the European one. At (Ecolabel Index, 2020) a big list of ecolabels in the transportation sector can be found. The following classification is a recompilation of some of them:

China Environmental Labelling

It provides environmental standards for several products, among which vehicles are included.

Figure 6.6 China Environmental Labelling logo. Extracted from (Ecolabel Index, 2020)

EPA SmartWay

Designation that a vehicle gets if it gets a score higher than average in the scales of greenhouse gas and smog-forming emissions that EPA develops.

Figure 6.7 EPA SmartWay logo. Extracted from (Ecolabel Index, 2020)

TRA Certification - Green Recreation al Vehicles

Designation that suppliers of vehicles parts get using the ANSI ICC 700-2008 National Green Building Standard. Therefore, a vehicle manufacturer can end up building a more environmentally friendly vehicle if it uses greener providers.

Figure 6.8 TRA Certification logo. Extracted from (Ecolabel Index, 2020)

With these three examples of ecolabels the idea that has to be extracted is that there is not just one designation of environmental good practices; several companies exist that emit several certificates. The scope of this thesis does not include the development of an ecolabel like that because of obvious reasons: the ecolabel is a recognition of a third part for given characteristics. However, later will be analysed if an ecolabel or a similar institutional stamp could be included besides the aviation ecolabel.

6.3 Review of Aircraft Ecolabels

Now that the examples of how energy labels and ecolabels are integrated in cars, the aviation ecolabels will be reviewed. The similarities and differences will be closely compared, so as to detect where improvements could be made.

6.3.1 Flybe

Flybe was the first one to create an energy label for aircraft, or as it has been said several times during this section, an aviation ecolabel. Before continuing further this part it will be cleared out that, although the most strict denomination is energy efficiency label for aircraft, for comfort it will be referred to as ecolabel. Moreover, it was the term that originally was chosen to denominate the idea by professor Scholz. Although at the beginning it was analysed the proper name the label should have, it was just an initial discussion to understand its characteristics.

Flybe (Flybe, 2020) is a british airline that according to (Wikipedia, 2020h) began its operations in 1979 and ceased them in 2020. The economical problems the airline had, together with the extraordinary complicated situation for aviation that Covid-19 generated, made the company collapse and went into administration. According to the same web, before stopping its operations it was the biggest regional airline in Europe.

The Guardian covered the releasement of the Flybe ecolabel (Osborne, 2007). It was said to be an answer to the call for consumers to be provided with better information about the environmental impact of the products they were buying. The scheme will be now reviewed to see which information was displayed and how. Understanding the basis of the idea will be helpful when designing the final informative tool. The problem that there is currently with the cease of activity of Flybe is that its website is inoperative. Because of this, information can not be extracted directly from the official website. The information will be obtained mainly from prior thesis on the topic, such as (Haß, 2015) and (Van Endert, 2017), as well as from other third parts that have performed different external analysis.

Before starting the review, the ecolabel will be shown. The following image is an example of the ecolabel of an aircraft that belongs to the Flybe fleet.

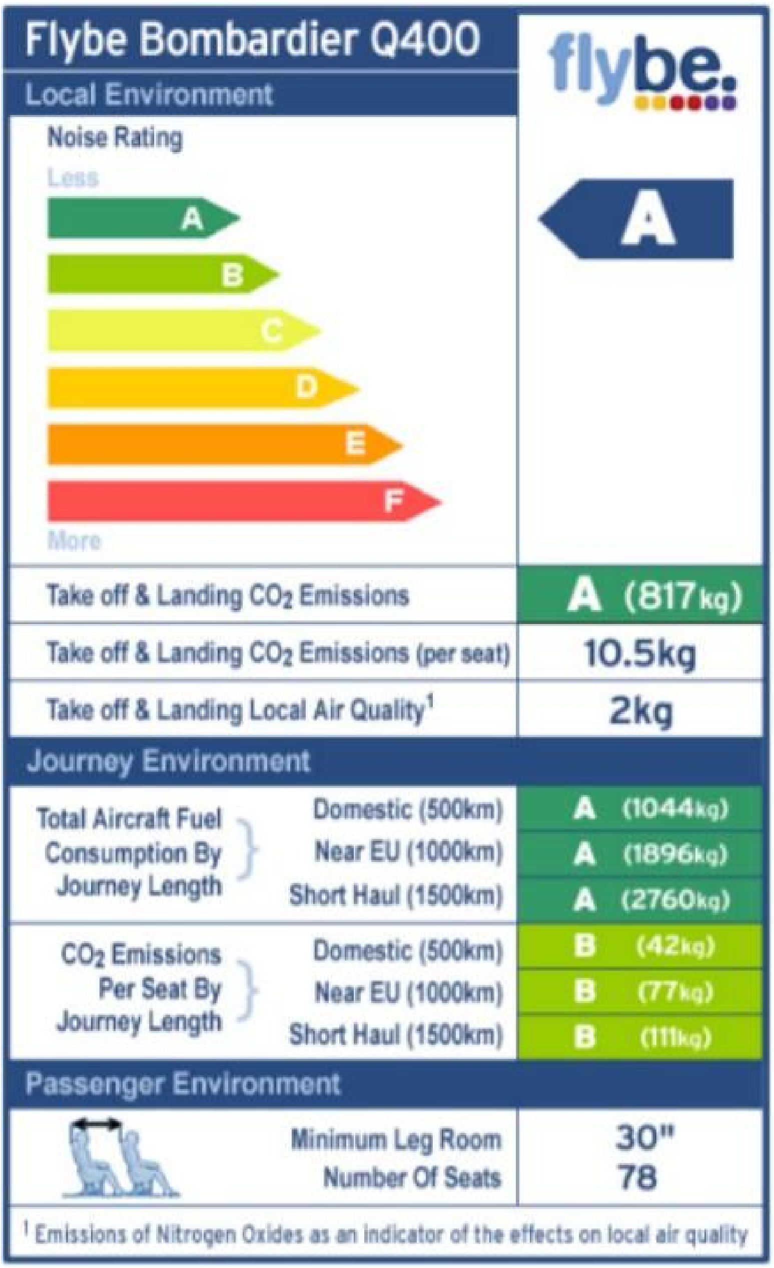


Figure 6.9 Example of one Flybe ecolabel. Extracted from (Van Endert, 2017)

As it can be seen, it is a label that follows approximately the concept of EU Energy label of Section 6.1, with the name of the product on top (the aircraft model in this case), and then all the metrics that evaluate the environmental impact of the airplane. It was a tag that appeared, according to (Osborne, 2007), on the website of the airline when the search of the flights was performed, on the side of the aircraft and in the information brochures that can be found in the seat pocket. According to the company, the scheme was audit by the consultancy firm Deloitte. The information is classified in three categories: local environment, journey environment and passenger environment. The first one includes the noise rating and carbon dioxide and nitrogen oxides emissions during take off and landing. The second one, fuel consumption by journey length and carbon dioxide emissions per seat by journey length. Finally, the last one leg room and number of seats.

In the case of the energy label for cars the explanation did not deepen into how the metrics were computed. With these three labels however, the equations to calculate them will be presented; the car energy label, although being from a vehicle, it was not directly linked with aviation. Otherwise, a correct comparison could not be performed. Since the guide Flybe released can not be consulted no more due to the cease of activity, the thesis made by prior students (Haß, 2015) and (Van Endert, 2017) will be used. The different subcatetories, which will be now reviewed:

Noise Rating

The noise rating is evaluated in a scale that goes from A to F. The method used to its evaluation is known as Quota system, which is used in English Airports such as Heathrow and Gatwick. The classification the method provides divides the sound levels into 7 categories separated by increments of 3 EPNdB (Effective Perceived Noise level in decibel). To each level a Quota Count value (QCv) is assigned.

However, before looking at the sound levels, how the noise level is obtained has to be understood. According to (ACL-UK, 2013) the formulas are the following. They use the EPNL at three main points: lateral, flyover and landing.

$$EPNdB_{take-off} = \frac{EPNL(lateral) + EPNL(flyover)}{2} \tag{6.1}$$

$$EPNdB_{landing} = EPNL(approach) - 9 \tag{6.2}$$

$$EPNdB = \frac{EPNdB_{take-off} + EPNdB_{landing}}{2} \tag{6.3}$$

The expressions that calculate the noise levels are now set, but how the EPNL is obtained for each of the three points should be cleared as well. This is explained at the Volume I of ICAO Annex 16 (EASA, 2017). Since this is just needed for a brief clarification, the summarise that was made at (Haß, 2015) and (Van Endert, 2017) will be used. The points lateral, flyover and landing can have been marked besides the points given by ICAO.

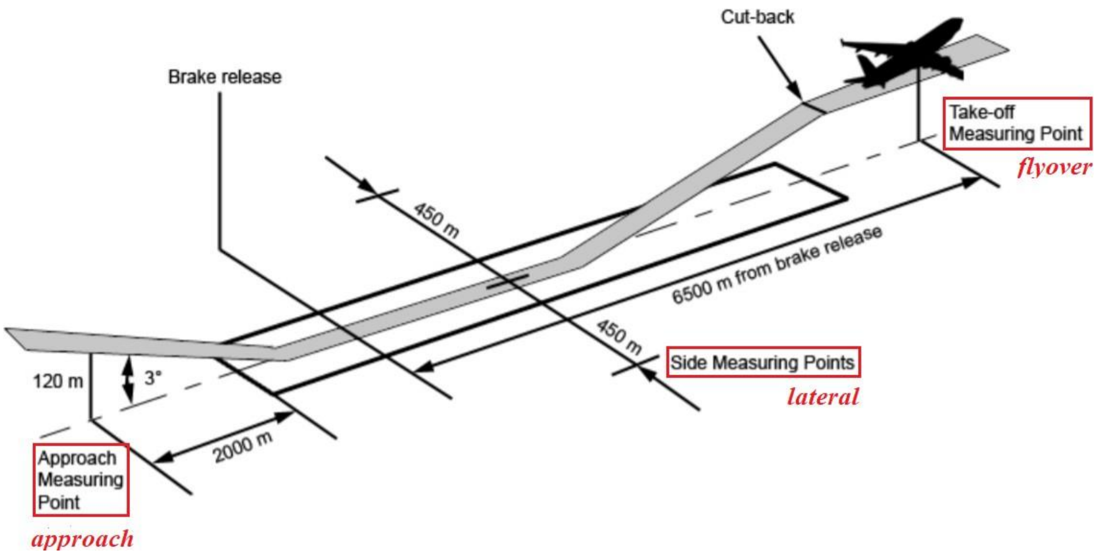


Figure 6.10 Reference points for the noise measurement. Adapted from (Haß, 2015)

The steps that ICAO says at (EASA, 2017) are the following:

1. Measure the sound pressure level (SPL) and convert it to perceived noise level (PL) using a noy table.

2. Calculate a tone correction factor (C)

3. Add the correction factor (C) to the perceived noise level (PL) to obtain the tone corrected perceived noise level (PNLT)

4. Determinate the maximum value of (PNLT), which will give the (PNLTM).

5. Calculate a duration correction factor (D).

6. Add the maximum tone corrected perceived noise level (PNLTM) to the duraction correction factor (D) to obtain the effective perceived noise level (EPNL).

These procedure has obviously to be performed by a competent authority, it is impossible to perform theoretical calculations, as they imply physical measurements. It will be seen later at Section 6.3.2 that a database is used to obtain EPNdb (EASA, 2019c). However, since it is the first time this variable appears, it is good to understand where does it come from. Once how the noise level and its computation are understood, how the categories are disposed can be presented. The following table assigns a Quota Count value, or number of points in the Quota Count System, to each noise level.

Table 6.1 Rating scale of Quota Count system. Adapted from (Wikipedia, n.d.[b])

Noise level (EPNdB)	Quota Count value
<84.0	Exempt
84.0-86.9	0.25
84.0-86.9	0.25
87.0-89.9	0.50
90.0-92.9	1.0
93.0-95.9	2.0
96.0-98.9	4.0
99.0-101.9	8.0
>101.9	16

Flybe divided the Quoata Count value spectrum into ranges, to each of which a rate was assigned. This can be seen at the following table.

Table 6.2 Noise rating scale of Flybe. Adapted from (Van Endert, 2017)

Rate	Quota Count value range
A	<0.177
B	0.177 – 0.354
C	0.354 – 0.707
D	0.707 – 1.414
E	1.414 – 2.828
F	>2.828

The advantages and disadvantages of this ranking will be later explained. It will happen the same with the rest of environmental impact rates, instead of analysing them step by step, they will be reviewed by the end to achieve a more global perspective. It is important to remind that previous thesis have already weighted its positive and negative points, and the newer ecolabel schemes are supposed to have learnt from previous errors. However, a brief reminder is always good in case a new perspective can be added.

Takeoff and Landing CO_2 Emissions

At (Sokour et al., 2018) is said that Flybe used the ICAO Engine Emissions Databank (EASA, 2019c). At the website is provided a datasheet with a vast list of engine models. Each of them shows several specifications, one of which is the amount of fuel used during the LTO cycle. This variable can be found like that:

Table 6.3 Fuel LTO cycle decription of the ICAO databank. Adapted from the datasheet of (EASA, 2019c)

Column	Heading	Full description if different from heading
CG	Fuel LTO cycle (kg)	kg of fuel used during the LTO cycle

Knowing the kg of fuel burned during LTO and the kg of CO_2 emitted per kg of fuel, which is 3.15 according to (Verifavia, n.d.) and (Van Endert, 2017), the kg of carbon dioxide emitted per engine can be easily computed multiplying both variables. Then, with the number of engines the aircraft has the total amount of carbon dioxide the air-plane emits is obtained; this represents the second variable of the ecolabel of Figure 6.9. Finally, dividing this by its number of seats, the third point of the Local Environment category can be as well easily obtained.

Takeoff and Landing Local Air Quality

This variable accounts for the emissions of nitrogen oxides. The thesis of Van Endert describes that the amount of NO_x emitted during LTO, is directly obtained from the ICAO databank (EASA, 2019c) too. This is how the variable is found if searched in the datasheet:

Table 6.4 Nitrogen oxidses during LTO cycle decription of the ICAO databank. Adapted from the datasheet of (EASA, 2019c)

Column	Heading	Full description if different from heading
BL	LTO total mass (g)	The total mass of oxides of nitrogen emitted during the LTO cycle (sum of time in mode x fuel flow x average EI at each of the four power settings)

This time the calculation of the variable shown at the ecolabel is even easier. With the carbon dioxide emissions, instead of giving that data directly, the amount of fuel was given and the carbon dioxide index for kerosene had to be used. This time however the only calculation left to do is multiply the found number of the datasheet and the number of engines of the aircraft.

Total Aircraft Fuel Consumption by Journey Length

This parameter ranks how much aircraft fuel is consumed for given standard flight distances. Since the ecolabel is made for the aircraft itself and not the flight, it can not be personalized for each journey; this is why the behaviour of the aircraft in front of three flight distances is shown as a reference. In (Van Endert, 2017) is said that in the Flybe ecolabel guide was stated that using the flight plans the fuel consumption for certain routes can be easily known.

The categories in which the journeys are divided follow the classical definitions. They are extracted from (Van Endert, 2017), which extracted it from the Flybe guide. They can be collected in the following table:

Table 6.5 Journey length categories defined for the Flybe ecolabel. Adapted from (Van Endert, 2017)

Journey type	Distance (km)	Route example
Domestic	500	Brussels - Birmingham
Near EU	1000	Stansted - St. Etienne Boutheon
Short-haul	1500	London Gatwick - Palma de Mallorca
Medium haul	3000	Birmingham - Heraklion
Long haul	5000	Schiphol - Halifax
Ultra-long haul	10000	Frankfurt - Los Angeles

The ecolabel shows the three most common journeys considering the range of the aircraft. It is clear, for example, that a very small airplane would not perform an ultra-long haul flight.

These are the categories used for classifying the flights. Finally, for each journey length six ranks are established (A-G), to each of which a range of fuel consumption is assigned. This is collected at the following table:

Table 6.6 Fuel consumption ranks by journey length. Adapted from (Van Endert, 2017)

Journey type	A	B	C
Domestic	<1097	1098 – 2852	2853 – 4607
Near EU	<1948	1949 – 4837	4838 – 7726
Short Haul	<2802	2803 – 6832	6833 – 10862
Medium Haul	<9127	9128 – 15856	15857 – 22585
Long Haul	<13973	13974 – 25598	25599 – 37223
Ultra Long Haul	<104515	104516 – 109120	109121 – 113726

Table 6.7 Continuation of table 6.6

Journey type	D	E	F
Domestic	4608 – 6363	6364 – 8118	<8119
Near EU	7727 – 10616	10617 – 13505	<13506
Short Haul	10863 – 14891	14892 – 18921	<18922
Medium Haul	22586 – 29314	29315 – 36044	<36045
Long Haul	37224 – 48847	48848 – 60472	<60473
Ultra Long Haul	113727 – 118331	118332 – 122936	<122937

CO_2 Emissions per Seat by Journey Length

The philosophy this section follows is very similar to the one of the aircraft fuel consumption. Again, the amount of carbon dioxide emissions are shown for the same journey categories than in the last point. As it happened before, just three categories are shown at the ecolabel. For this point, the procedure to compute the carbon dioxide emissions will be the similar to the one for the carbon dioxide emissions during LTO: knowing the total fuel consume from the flight plan, the carbon dioxide index will be used to obtain the total amount of emissions (through a multiplication of both variables). The final step consists on dividing the result by the number of seats the aircraft has. Finally, the table that shows the rank that is assigned to each emissions range will be shown.

Table 6.8 CO_2 emissions ranks by journey length. Adapted from (Van Endert, 2017)

Journey type	A	B	C	D	E	F
Domestic	<35	36-45	46-54	55-63	64-73	>74
Near EU	<63	64-80	81-97	98-113	114-130	>131
Short Haul	<90	91-114	115-139	140-164	165-188	>189
Medium Haul	<173	174-211	212-250	251-289	290-327	>328
Long Haul	<278	279-346	347-414	415-482	483-550	>551
Ultra Long Haul	<871	872-928	929-985	986-1041	1042-1098	>1099

Maximum Leg Room and Number of Seats

This category is pretty self explanatory. This is shown so as the passenger gets an idea of the comfort the aircraft provides. Together with how much environmentally friendly the airplane is, the user can make an educated choice where comfort and respect for the environment are taken into account.

The review of the first ecolabel that was created has been finished. The second one can be now introduced.

6.3.2 The Ecolabel by Hass

Tim Hass was the first to develop an ecolabel during the series of thesis and projects where this Bachelor thesis takes place. During his work (Haß, 2015) an extensive explanation of how it was designed was provided. During this explanation it can be seen how some initial hypothesis are discarded and some others modified. Since its goal was to describe the process it was needed to achieve the final result, it is logical to disclose all the followed steps. However, if one wants to quickly understand where do all parameters come from, the extensive dissertation it provides might not be the most efficient solution. This is why, as this section aims to work as a review, will focus exclusively on what metrics are shown, what do they mean and how are obtained. A summarise will be given so as the reader can quickly understand the ecolabel that (Haß, 2015) created. Firstly, the ecolabel design will be presented:

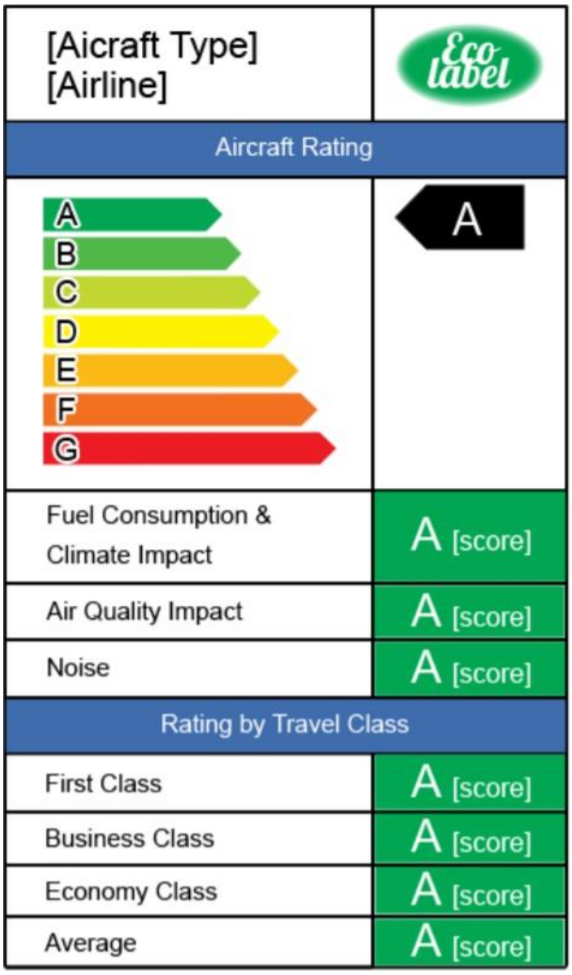


Figure 6.11 Design of the Hass ecolabel. Extracted from (Haß, 2015)

It can be seen how the design is still very similar to the ones that can be seen at Figure 6.2 and Figure 6.9. As it was done with the Flybe ecoalbel, the categories that appear at the label will be analysed point by point.

Similarly to the Flybe ecolabel, some general categories are displayed, which are divided again in smaller subcategories. As a main difference, this ecolabel presents an overall rating like in the EU energy label, something that Flybe did not include.

Fuel Consumption and Climate Impact

Climate impact is included in the same category as fuel consumption because it has seen several times that both variables are proportional. The process followed to arrive at the specific evaluation method of this magnitude is extensive. Several parameters had to be taken into account. However, if the whole discussion wants to be read, (Haß, 2015) has to be consulted. In this point just the outcome will be shown.

SAR (Specific Air Range) was the chosen magnitude to evaluate this category. SAR is a parameter developed by ICAO in the third volume of Annex 16 (ICAO, 2017b) that aims to assess not only fuel consumption or carbon dioxide emissions, but the overall aircraft fuel efficiency in general. This is why fuel consumption is not chosen as the indicative parameter for this category: it depends on the specific flight route, which makes it impossible to extrapolate it as a standard parameter. SAR is defined by (Haß, 2015) as the distance travelled over the next incremental amount of fuel burnt.

The following equation shows how SAR is defined and finally calculated:

$$SAR = -\frac{dR}{dm} \tag{6.4}$$

In order to do that, the payload-range has to be used. The payload range diagram is a graphic that aircraft manufacturers provide in documents called "Documents for Airport Planning". They contain important information related to the corresponding aircraft; they are needed to dimension airports infrastructure. The following image is an example of a payload-range diagram:

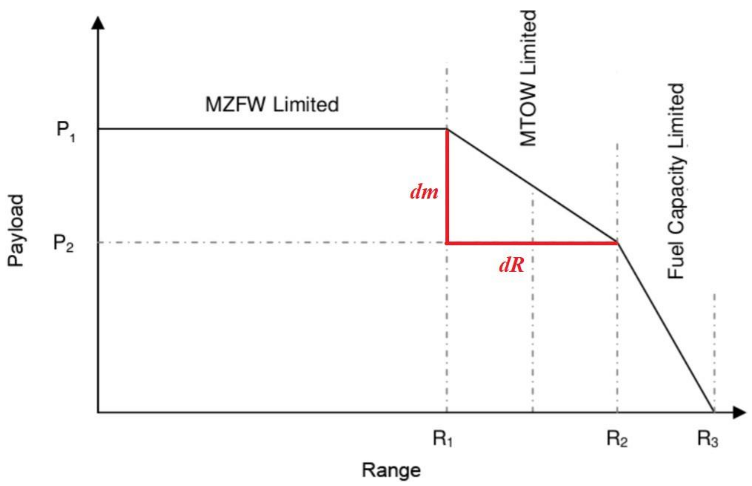


Figure 6.12 Example of a payload-range diagram. Adapted from (Haß, 2015)

As it can be seen, the variables that appear at Equation 6.4 are marked in red in Figure 6.12. To obtain dm, P_2 is subtracted from P_1 (both points at the y axis); to obtain dR, R_1, from R_2 (both points at the x axis). These four points are always shown at the payload-range diagram of the "Documents for Airport Planning".

At (Haß, 2015) the SAR for a group of aircraft was calculated. It is said during the description of the process that instead of searching every document for airport planning for every aircraft whose SAR had to be calculated a book with a recompilation of the most important parameters of some aircraft (Roux, 2007). At the following image an example can be seen:

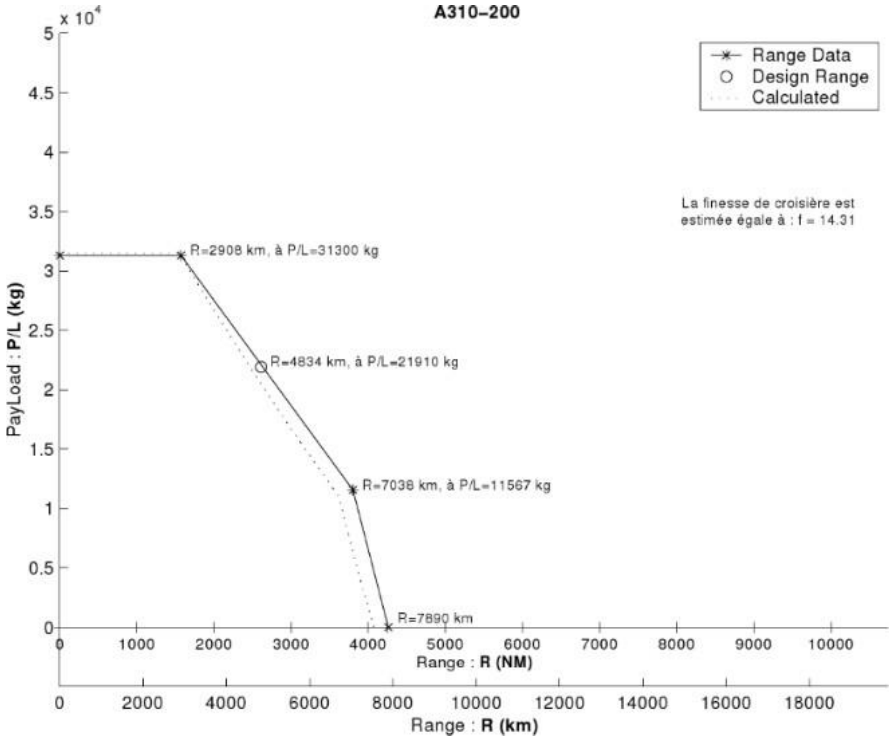


Figure 6.13 Example of the payload-range diagram of the Airbus A310-200. Extracted from (Roux, 2007)

A total of 21 SAR's, of 21 different aircraft, were calculated. These were used to obtain the OEM (original equipment manufacturer) fuel consumption. This is calculated as follows:

$$OEM\ Fuel\ Consumption = \frac{1}{SAR \cdot n_{pax,OEM}} \quad (6.5)$$

The inverse of SAR is calculated in order to read the variable as kg/km and not the other way round. Then, it is normalised with the number of the passengers the aircraft has in a standard configuration. This can be obtained from the Document for airport planning of the corresponding plane, or from (Roux, 2007).

Once this new variable is computed is represented in a graphic: in the x axis the value of the magnitude is seen, and in the y axis the number of aircraft that have that same value of OEM Fuel Consumption per Seat. This is needed to later set the ranges that will determine the ranks. At the following graphic the distribution can be seen:

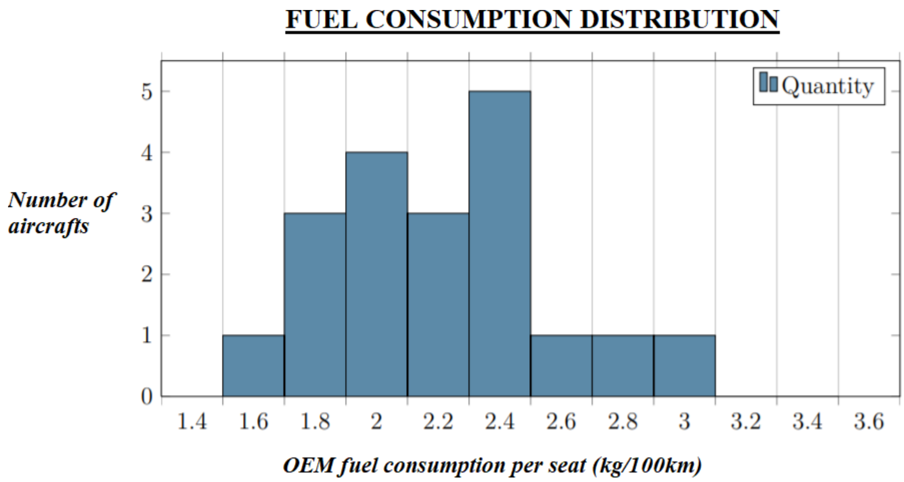


Figure 6.14 OEM Fuel consumption per seat graphic. Adapted from (Haß, 2015)

In order to obtain the seven ranks (A-G), the difference between the highest and lowest value is calculated and then divided by 7, so as the 7 ranks that conform the sample are equally spaced in terms of the variable value. The samples are thought to follow more or less a normal distribution. Once the ranges of OEM Fuel consumption per seat in which each rating is contained, the values are normalised to be between 0 and 1: 0 is assigned to the lowest value, 1 to the highest and the rest are spaced proportionally. The seven intervals of the 0-1 normalised ranges are equally spaced as well.

The final result is presented at the following table, which has to be used to assign a mark to a value of fuel consumption:

Table 6.9 Rating ranks and ranges of OEM Fuel consumption per seat. Extracted from (Haß, 2015)

Rating	Variable range (kg\100km)	0-1 normalised variable range
A	$x \leq 1.73$	$x \leq 0.143$
B	$1.73 < x \leq 1.96$	$0.143 < x \leq 0.286$
C	$1.96 < x \leq 2.19$	$0.286 < x \leq 0.429$
D	$2.19 < x \leq 2.41$	$0.429 < x \leq 0.571$
E	$2.41 < x \leq 2.64$	$0.571 < x \leq 0.714$
F	$2.64 < x \leq 2.87$	$0.714 < x \leq 0.857$
G	$2.87 < x$	$0.857 < x$

If an aircraft wants to be evaluated regarding its fuel consumption and climate impact, the SAR has to be calculated to obtain the OEM Fuel consumption and finally locate the result in the ranges given at Table 6.9.

Air Quality Impact

At (Haß, 2015), it is provided the complete explanation of how the metric that evaluates the air quality impact is obtained. This discussion is extensive and includes a discussion of which of the components that pollute the atmosphere are relevant in the global picture. This discussion will not be included here, just the final outcome. Nitrogen oxides are determined to be the most relevant factor. Moreover, among all the generated particulate matter, the part created as a secondary effect of releasing nitrogen oxides is proved to be more relevant that particular matter created because of other compounds.

This is why the amount of nitrogen oxides emitted during the LTO cycle will be used to rank the air quality impact. This data is obtained from the ICAO emissions data bank (EASA, 2019c). It can be searched as was already shown at Table 6.4.

However, it has to be taken into account that bigger and more powerful engines emit more NO_x (as well as other compounds). This is why in order to be able to compare several engines the values of the nitrogen oxides have to be normalised. The variable used for this normalisation is the maximum rated thrust (F_∞) (the maximum thrust of the engine in static at sea level). It can be searched at the ICAO databank at follows:

Table 6.10 Maximum rated thrust decription of the ICAO databank. Adapted from the datasheet of (EASA, 2019c)

Column	Heading	Full description if different from heading
G	Rated Output (kN)	Engine maximum rated thrust, in kilonewtons

Once the nitrogen of oxides emissions were normalised using the maximum rated thrust the values were presented in a graphic similar to the one of Figure 6.14. The x axis shows the normalised emission value and the y axis the number of engines that present these values. It can be seen at the following picture:

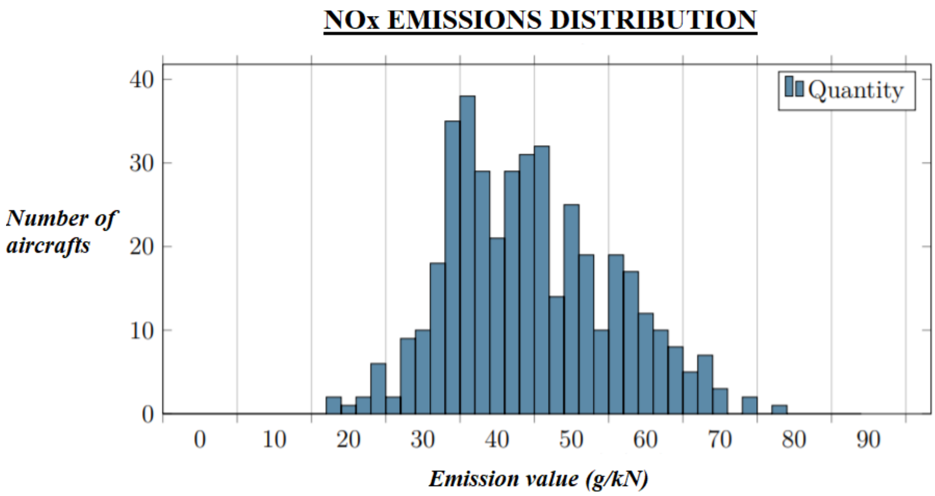


Figure 6.15 Normalised nitrogen oxides emission graphic. Adapted from (Haß, 2015)

The process to divide the sample into ranks was the same of the last point. The following ranks are obtained:

Table 6.11 Rating ranks and ranges of NO_x emissions. Extracted from (Haß, 2015)

Rating	Variable range (g \kN)	0-1 normalised variable range
A	x ≤ 30.57	x ≤ 0.143
B	30.57 < x ≤39.14	0.143 < x ≤0.286
C	39.14 < x ≤47.71	0.286< x≤0.429
D	47.71 < x ≤56.29	0.429 < x ≤0.571
E	56.29 < x ≤64.86	0.571 < x ≤0.714
F	64.86 < x ≤73.43	0.714 < x≤0.857
G	73.43 < x	0.857 < x

The last table represents the final outcome of the evaluation. If the impact on the air quality of an aircraft wants to be ranked, the first step is to know its engine model. Then, its emissions of nitrogen oxides during the LTO cycle have to be normalised and placed in the prior ranges.

Noise

Noise is the next metric displayed at the ecolabel and the last of aircraft rating. The process used to determine the ranks was again very similar to the last two: the metric is computed for a group of aircraft and the divisions where aircraft have to be placed are made. The first step, as it has been done, will be explaining the metric of choice.

The metric that will be used is noise level. Specifically, the EPNdB will be the one of choice. Its meaning was already seen in the Noise subpart of Section 6.3.1. The three points that take part in the noise measure were also seen at Figure 6.10. Moreover, the steps that ICAO said that needed to be followed to convert this measures into the effective perceived noise level were also seen. However, although the basic items needed for the calculations are the same in both ecolabels, the way they are treated it is not equal. With Equations 6.1, 6.2 and 6.3, the way Flybe processed the measures can be seen. This time, the effective perceived noise level was decided to be calculated in a different way. The following equation represents that:

$$Average\ Noise\ Level = \frac{EPNdB_{take-off} + EPNdB_{approach} + EPNdB_{lateral}}{3} \tag{6.6}$$

It can be seen how this equation differs from the Equation 6.3 that Flybe used. However, this plain value can not be used to compare aircraft between each other: bigger aircraft produce more noise than smaller ones. According to (Haß, 2015) although noise depends on mass, it is not proportional, but logarithmic. The value that it is used to make this relation appear is the noise limit. The final magnitude that will be computed for the several aircraft is:

$$Noise\ Index\ Value = \frac{Average\ Noise\ Level}{Noise\ Limit} \tag{6.7}$$

The Noise Limit is obtained using the same equation as Equation 6.6, but using the Noise limit for each of the three points instead of the EPNdB:

$$Noise\ Limit = \frac{Noise\ Limit_{take-off} + Noise\ Limit_{approach} + Noise\ Limit_{lateral}}{3} \tag{6.8}$$

In order to obtain the data of EPNdB (Noise Level) and Noise Limit for Take-off, Approach and lateral, as well as the noise limit, (Haß, 2015) used the Type Certificate Data Sheets for Noise (TCDSN) (EASA, 2020c). As it happened with the other metrics, once the calculation method is chosen, a distribution graphic is plot:

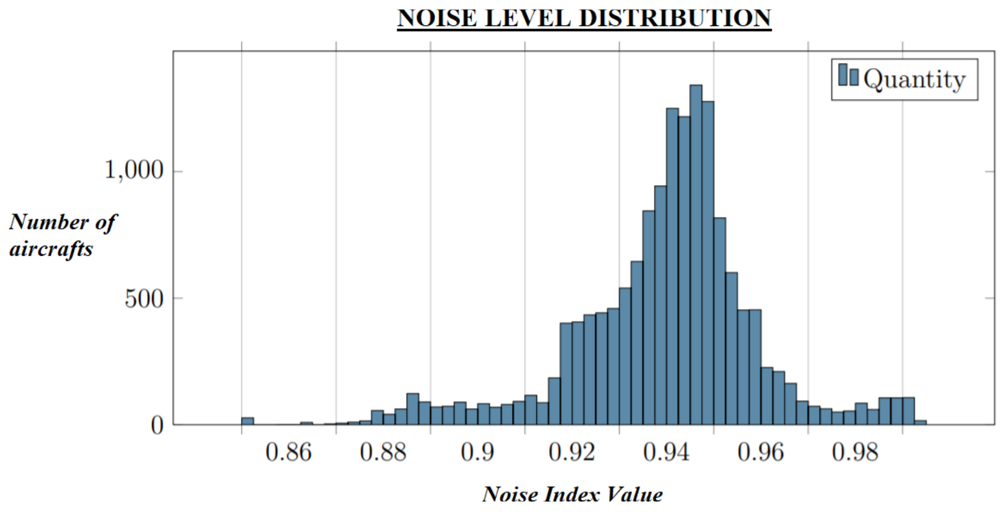


Figure 6.16 Normalised noise level distribution. Adapted from (Haß, 2015)

The last step, as before, consists on creating the ranges that will determine the ratings. The table that allows to assign the mark is the following:

Table 6.12 Rating ranks and ranges of noise level Extracted from (Haß, 2015)

Rating	Variable range	0-1 normalised variable range
A	x ≤ 0.919	x ≤ 0.143
B	0.919 < x ≤ 0.927	0.143 < x ≤0.286
C	0.927 < x ≤ 0.936	0.286< x≤0.429
D	0.936 < x ≤ 0.944	0.429 < x ≤0.571
E	0.944 < x ≤ 0.953	0.571 < x ≤0.714
F	0.953 < x ≤0.961	0.714 < x≤0.857
G	0.961 < x	0.857 < x

Rating by Travel Class

This is the last point shown at the ecolabel. Although it is not explicitly said what is being "rated by travel class" if (Haß, 2015) is read it can be seen that the fuel consumption is the rated metric. The problem with the category "Fuel consumption and climate impact" is that when the number of passengers is included in the calculations, it does not allow to differentiate between travel classes, since it shows an average consumption per seat.

A weighting factor had to be introduced, as it is not the same flying in the economical class, where the space is limited, than in business, where the concentration of passengers per space is way lower. This weighting factor is said to take a value of 1 if the fuel consumption for the given class is equal to the average fuel consumption, higher in classes such as buiseness, and lower such as in economy. It has been seen at Table 6.9 that the higher the value of the metric, the lower the rank. This suits the effects the weighting factor has. The following equations show where the weighting factor (K_{class}) comes from:

$$K_{class} = \frac{S_{class} \cdot n_{class}}{S_{total}} \div \frac{n_{class}}{n_{total}} \tag{6.9}$$

The parameter S represents the seat surface, and the n the number of passengers. The subscript "class" represents the given class whose weighting factor wants to be computed, and the subscript "total" appears at a variable where a sum of all classes is made. Finally, the travel class fuel consumption is obtained as follows:

$$Travel\ Class\ Fuel\ Consumption = \frac{1}{SAR \cdot n_{pax,airline}} K_{class} \tag{6.10}$$

Once the last formula is used for every class of the aircraft, the obtained values are placed at the ranges of Table 6.9 and a rank is assigned. Although the difference is subtle, one could think that the "Fuel consumption and climate impact" and the "Average fuel consumption by travel class" are the same, but they are not. At Equation 6.5 the number of passengers has the subscript OEM, but at Equation 6.10 the subscript is airline. This is because in the original configuration the manufacturer gives, the maximum number of passengers is stated, but not the final configuration, as it is a task that belongs to the airline. This is why these two parameters might not be the same, since the number of passengers the manufacturer says and the final number the airline wants might differ.

Aircraf Rating

The aircraft rating will be the last variable to be described, although it is the first that appears when the Figure 6.11 is seen, because the aircraft rating include all the previous metrics.

At (Haß, 2015) was decided to use a weighted average to compute the overall rating. The weights that were given were the following:

- Fuel consumption and climate impact: 60%.
- Air quality impact: 20%.
- Noise: 20%.

As the three last variables were normalised between 0 and 1, the final result will be still between 0 and 1. The final step is to place the result in the range of ranks. Those can be seen at any table of the prior metrics, such as Table 6.12 using the column "0-1 normalised variable".

As it was priory said when the review of the Flybe ecolabel was over, the advantages and disadvantages this scheme presents will be exposed later once the last ecolabel is analysed.

6.3.3 The Ecolabel of Van Endert

This ecolabel is the last one developed during this series of thesis and projects. It was created at (Van Endert, 2017) and continued at (Sokour et al., 2018) where an automatising of its production was achieved.

As it is a continuation from (Haß, 2015), some of the calculations or methods use might be the same. In case this happened, they will not be repeated again: just the added or modified parts will be reviewed.

The following image is an example of one ecolabel designed by Van Endert at (Van Endert, 2017):

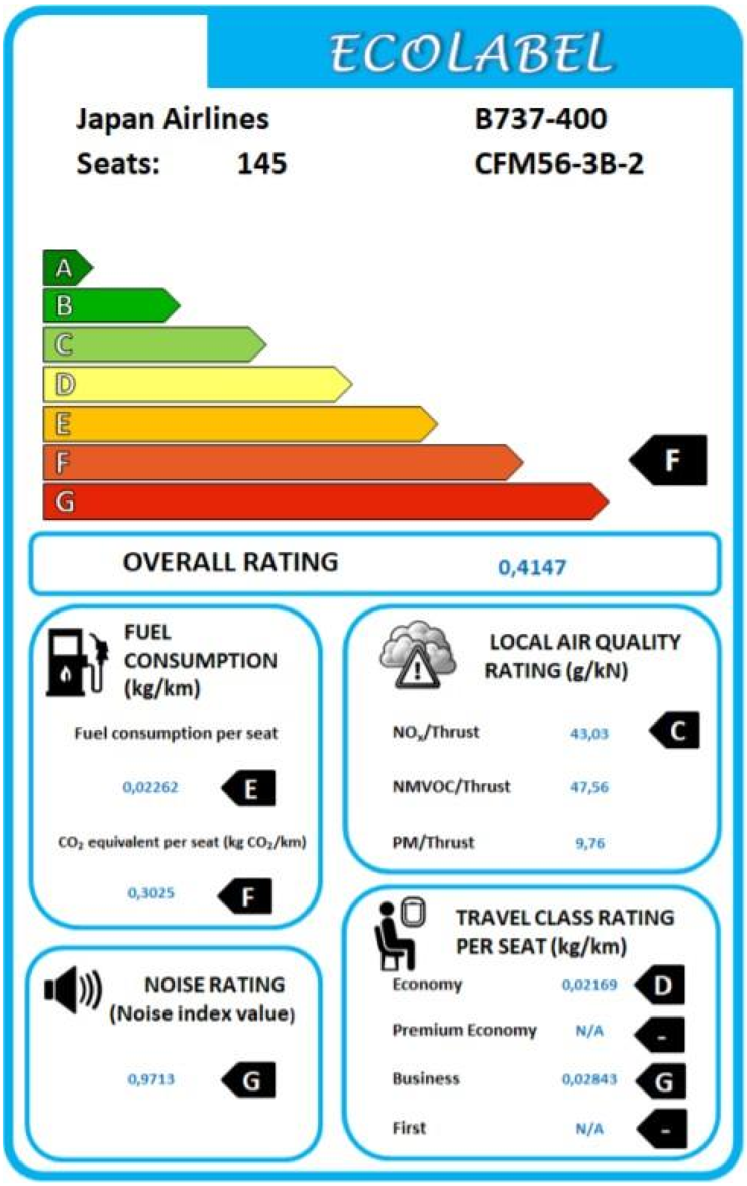


Figure 6.17 Example of one ecolabel calculated by Van Endert. Extracted from (Van Endert, 2017)

As it was done with the ecolabel of Hass, the information that appear at Figure 6.17 will be reviewed point by point.

Ratings Generation

One of the main differences that (Van Endert, 2017) and (Sokour et al., 2018) present in respect to (Haß, 2015) is the way of creating the ranks also varies. At (Haß, 2015) 0 was assigned to the lower value, and 1 to the highest, the rest in between were spaced proportionally. This time, each rank has the same samples per range, so the normalisation process is different. At (Haß, 2015) if any of the tables where the ranges of the ranks were observed, it could be seen that the 0 to 1 normalised ranges are always the same. This is not the case for (Van Endert, 2017). This is because at the first one, the interval 0 to 1 is equally spaced, but at the second one the following formula is used:

$$Normalisation\ 0\ to\ 1 = \frac{value_i - value_{min}}{value_{max} - value_{min}} \quad (6.11)$$

In other words, at (Haß, 2015) the sample was divided so as the seven segments of the distribution had the same variable value increment, and at (Van Endert, 2017), the sample was divided so as the seven segments of the distribution had the same number of elements.

The last Equation 6.11 is the one used for normalising all the metrics, this is why it has been introduced in its general forms, with the variables named "value", instead of making it specific for the fuel consumption per seat. The process for creating the ranges will be now in more detail explained: the total number of aircraft of the sample is divided by seven, the total number of ratings. This time, the lowest interval is is conformed by the "X" lowest values of the sample. Each segment will have "X" values. Adding "X" more values to the previous interval and delimiting each time new frontiers, the seven ranks are created. Once the intervals are generated, the Equation 6.11 is used to convert the interval limits in values between 0 and 1. In the following table an example can be seen of how this distribution is:

Table 6.13 Rating ranks and ranges of the fuel consumption per seat (kg/km). Adapted from (Van Endert, 2017)

Rating	Variable range (kg\km)	0-1 normalised variable range
A	$0.01493 < x \leq 0.01772$	$0 < x \leq 0.0781$
B	$0.01772 < x \leq 0.01983$	$0.0781 < x \leq 0.1370$
C	$0.01983 < x \leq 0.02131$	$0.1370 < x \leq 0.1783$
D	$0.02131 < x \leq 0.02246$	$0.1783 < x \leq 0.2106$
E	$0.02246 < x \leq 0.023923$	$0.2106 < x \leq 0.2514$
F	$0.02392 < x \leq 0.02602$	$0.2514 < x \leq 0.3099$
G	$0.02602 < x \leq 0.05070$	$0.3099 < x \leq 1$

Unlike at the last Section 6.3.2, where all the graphics and tables were included, at this section this will not happen. The last one was an exception for understanding purposes. With the last section it was already understood the methodology of making a graphic distribution, dividing it into ranges, and showing it in tables. Although the specific values change at (Van Endert, 2017) it would not add any value to repeat it again, since it has to be remembered that this section is just a review of existing ecolabels.

Fuel Consumption per Seat

The calculation of this parameter is very similar to the one done at (Haß, 2015), with a slightly difference: the number of passengers used to normalise the inverse of the SAR is not the one from the Original Equipment Manufacturer, but the one from the layout provided by the airline. This in fact has more sense, since the ecolabel is a card provided by the airline, not the manufacturer, as it is a method to inform the passenger. In fact, the "Fuel consumption" is the same variable as the "Average rating by travel class" of Hass.

CO_2 **Equivalent per Seat**

This is one of the first major changes that was introduced at (Van Endert, 2017) compared to (Haß, 2015), since it did not appeared at the ecolabel before.

Unlike some explanations of (Haß, 2015), where the description of the steps to arrive at the outcome of the metric evaluation included some theories that were lately discarded, this is not the case. Although being the explanation extensive and detailed, it is direct and very well organised. Repeating it again would not add any value to this work, this is why in this case the formulas needed to arrive at the final metric will not be included. If the specific steps wanted to be understood, Section 4.4.2 "Determination of Metric for CO_2-Equivalent" of (Van Endert, 2017) (pages 56-64) would need to be reviewed. Moreover, taking a look at the tool provided by (Sokour et al., 2018) would help to understand better the calculations by visualizing exactly which variables are being used and when.

However, which it is important to understand is the meaning of the variable. This carbon dioxide metric is not like the one of Flybe of Section 6.3.1, where the total amount of emitted CO_2 was presented. At (Eurostat, 2017) a good definition of this metric is provided:

> *"A carbon dioxide equivalent or CO2 equivalent, abbreviated as CO2-eq is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential. [...] The carbon dioxide equivalent for a gas is derived by multiplying the tonnes of the gas by the associated GWP."*

GWP is a derivation of the radiative forcing, which was already seen in some offsetting tools. GWP accounts for the effects of the gases over a period of time; raditive forcing is referred to a particular time moment, which makes difficult a proper comparison. In the case of the ecolabel that is being currently reviewed the gases that are considered are carbon dioxide, nitrogen oxides and contrails (which are actually H_2O vapour). The difference between the last definition is that instead of using GWP it is used the SGTP (Sustainable Global Temperature Potential). This variable according to (European Commission, n.d.[b]) *"evaluates the change in global mean surface temperature at a chosen point in time*. In the case of this ecolabel, the time perspective is 100 years: in (Van Endert, 2017) the metric contains the global temperature change after 100 years of maintained emissions.

It is important to remark that not only this variable is used, but this sets the base of all the calculations. A variable called CF can also be found, which shows the ratio between the SGTP of a considered gas and CO_2. In this variable is also included the height forcing factor of that gas (s), which makes appear the effect of the height where the gases are emitted by slightly increasing or reducing the SGTP. In the case of nitrogen oxides and contrails, since they are the consequence of other primary emitted gases, the summatory of the CF of various species has to be performed. The next step consists on multiplying the CF by the quantity of emitted gas, which is obtained with the product of the mass of used fuel and the emission index of the given gas. Finally a normalisation of the variable is performed; this is done with the number of passengers and the SAR. It is important to remark that for the contrails effect instead of using the SAR (which is actually another form of fuel consumption) the stage lentgh of the flight is chosen.

The needed data is obtained from (EASA, 2019c) and other papers, projects and thesis that are cited in (Van Endert, 2017) when needed. The ranking method is the same that was already explained at the last point of this section.

Noise Rating

Except the final normalisation of the rank ranges, the methods used to evaluate the noise rating are the same of (Haß, 2015) which were already explained at Section 6.3.2. This is why no further comments will be made regarding this topic. It has to be remembered that during this thesis two different databases existed for turbojets and turboprops; this made necessary to have two rating scales. However, in (Sokour et al., 2018) it was managed to merge both metrics into a same ranking scale.

NO_x **\Thrust**

The calculations used to obtain this metric are exactly the same of Section 6.3.2. This is why no more explanations will be provided. The only thing that changes, as it has been said before, is the way of dividing the ranges ranks, but this is something that will happen for every metric.

NMVOC\Thrust

This point covers the non-methane volatile organic compounds. This did not appear at the ecolabel of (Haß, 2015). Some of the species that fall under this tag will be used. Actually, the complete name of this category is NMVOC-equivalents or ozone formation potential. According to (European Environment Agency, 2010) NMOVCs species contribute to the formation of ground level ozone, also called tropospheric ozone, an important air pollutant.

The calculation of the total amount of ozone equivalents (the sum of species that participate in the production of ozone) is obtained by summing each of this species multiplied by its emission factor. These factors can be seen at (Van Endert, 2017) (were obtained from (ReCiPe, 2012))). The amount of emissions during the LTO cycle of each species, as it was done at (Van Endert, 2017) were obteined from (EASA, 2019c).

$$NMVOC_{LTO} = 1\,(NO_x)_{LTO} + 0.081\,(SO_2)_{LTO} + 0.046\,(CO)_{LTO} + 0.476\,(HC)_{LTO} \tag{6.12}$$

The final step consists on normalising the result by dividing it by the rated output, the maximum engine thrust. This is the same procedure that had done at (Haß, 2015).

PM\Thrust

This section focuses on rating the emission of particular matter. As well as the last point, this is something new that this ecolabel adds. In the ecolabel of (Haß, 2015) it appeared indirectly at the NO_x emissions, since it was said that the most important part of particulate matter emissions came from the ones of nitrogen oxides.

Two metrics for the particulate matter are proposed at (Van Endert, 2017), the first one is the actually used, which is the particulate matter without further specifications. The second one is the particulate matter equivalents. This concept is similar to the CO_2 equivalent, a calculation that include species that generate a similar effect compared to the main one. This last metric includes the effect of NO_x and SO_2 to the normal PM using the factors given at (ReCiPe, 2012). However, it is not the used metric.

Regarding the metric that actually appears at the ecolabel, it presents an extensive calculation that details step by step the followed procedure. Similarly to what happened with the calculation of the CO_2 equivalent, repeating the whole explanation again would not serve any purpose, since there is no need to reorder it or clarifying in any way. If all the steps followed want to be consulted, Section 4.2.2 of (Van Endert, 2017) between pages 46 and 50 need to be read. What is important to know, nevertheless, is that the total of particular matter is divided in volatile and non-volatile. The volatile type is considered to be exclusively from organic origin and when it comes to calculating the non-volatile kind a distinction has to be made between turbofans and internally mixed turbofans. Again the data is obtained from (EASA, 2019c) and the final outcome normalised with the maximum thrust of the engine.

Travel Class Rating per Seat

Apart from the rank ranges organisation, the procedures followed in this section are exactly the same that were done at (Haß, 2015) to compute the same metric.

The only difference is that at this ecolabel the category "Premium economy is included". However, although being given the opportunity of calculating a rank for this flying class, it does not necessarily imply that the airline has it: it exclusively depends on what the company offers.

Overall Rating

This is the final shown metric of the label and probably one of the most important ones, as it allows the reader to get the overall qualification of the aircraft. Starting with the fact that this ecolabel shows more evaluating points than the ecolabel of (Haß, 2015), it is normal that the evaluating method includes some changes.

The reasoning followed to choose how much does weight in the overall mark is taken from (Johanning, 2016). According to (Van Endert, 2017), at (Johanning, 2016) is said that the weighting factor of fuel consumption in the environmental impact is 60%. However, fuel consumption does not act as an individual category, but as a part of another two indicators: resource depletion and climate change. The weight that they represent can be seen at the following graphic:

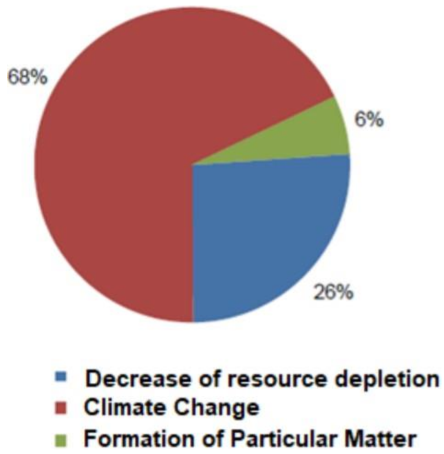


Figure 6.18 Distribution of the influence of each parameter on the overall environment impact. Extracted from (Van Endert, 2017), where it was adapted from (Johanning, 2016)

As the ratio of climate change over resource depletion equals to 2.6, it was decided at (Van Endert, 2017) that the relation would be approximated to 2. This is why, in the 60% that fuel consumption represent it was decided that climate change (CO_2 equivalent emissions) accounted for the double as resource depletion (fuel consumption). This results in a 40% and 20% respectively. The other 40% is divided in air quality and noise in equal parts.

At the explanation of (Van Endert, 2017) it is said that NO_x has the most relevant impact in air quality, this is why at the end the only of the three metrics of the local air quality that has a grade is the ratio of nitrogen oxides emission and the maximum engine thrust. Moreover, if the excel tool of (Sokour et al., 2018) is consulted it can be seen clearly how at the calculation of the overall rating just the value of normalised nitrogen oxides emission is considered.

To sum up, the percentages that are used to calculate the weighted average of the overall rating in jets are the following. In order to calculate the final mark, the normalised values (the ones that appear next to the rates of each category) will be summed with its corresponding weighting factor.

- Fuel consumption per seat: 20%.
- CO_2 equivalent per seat: 40%.
- Noise rating: 20%.
- Local air quality rating (NO_x \ Thrust): 20%.

The travel class rating per seat is not considered, as it derives from the fuel consumption per seat.

Finally, it has to be said that at (Van Endert, 2017) is marked that for turboprops the local air quality metric can not be used, since (EASA, 2019c) is only available for jet engines and does not exist a similar database for turboprops. This is why for turboprops the 20% of air quality is erased and the average is calculated over 80% instead over 100%.

6.4 Flaws of Aircraft Ecolabels

Now that all the ecolabels have been reviewed, their flaws will be studied. The most important one to be evaluated is the last one, since it is the most up to date version. However, the first two ones will be briefly looked at in order to get potentially profitable ideas.

6.4.1 Flybe Ecolabel flaws

Noise Rating

The problem with noise rating in the flybe ecolabel is the lack of normalisation, so no comparison can be made between aircraft. Bigger aircraft produce more noise, which makes it unfair to rank them badly. By its marks assigning method Flybe evaluates absolute values, not efficiency, which does not allow to rate the performance of the system.

The reason why Flybe did this actually made this has sense, since it is a regional airline. This means that its aircraft will tend to be less loud, which will ultimately give them better marks. If the most common Flybe routes are searched, this can be quickly proved. For instance, at (Wikipedia, 2020h), it can be seen how all the flights labeled as "base" are the ones that happen inside the United Kingdom, the rest are labeled as "seasonal" and are flights with destinations outside the country. With these type of flights it is normal to use smaller and quieter planes.

Moreover, although the Quota Count system already offers a punctuation system, Flybe translated its points into its own ranks, which can be seen at Table 6.2. This arbitrary translation from points to alphabetical ranks can lead to think that Flybe has made it to fit its necessities and give its aircraft the highest qualifications.

Finally, the visual scheme that shows the noise rating rank occupies half the ecolabel. The way it is designed makes it very easy to confuse the noise rating with the general rating, which is not true. This is clearly seen at Figure 6.9

Takeoff and Landing CO_2 Emissions

This metric presents a similar problem to the noise rating: it evaluates the aircraft with an absolute value instead of with a relative one, which makes impossible the comparison between models. Bigger aircraft produce more carbon dioxide because of obvious reasons. This represents an advantage for smaller aircraft, and considering that Flybe mostly flies short ranges (for which smaller airplanes are enough) it can lead to think that Flybe designed that in order to favour itself.

Moreover, looking again at the ranking system it could be thought that the way it has been arranged is arbitrary. Since no clearly reasoning is for how it was done, it could be misinterpreted as a move to favour itself.

Takeoff and Landing CO_2 Emissions (per Seat)

The good thing about his metric is that includes a normalisation that allows to the comparison with other aircraft: the number of passengers. Bigger aircraft produce more carbon dioxide, but at the same time have more passengers. By normalising the metric with the aircraft capacity the efficiency of the journey is better reflected. However, in this category just the numerical value is presented, no ranking system is shown. This difficulties the comparison, since it is hard to know if the difference of two numbers is remarkable or not without a context.

Moreover, since this metric derives from the last one, it drags the problems of the previous: the fact that it uses an amount of fuel predicted to be burned calculated with no clear methods does not provide the sufficient transparency.

Takeoff and Landing Local Air Quality

This category presents the same problems of the CO_2 emissions. The amount of emitted NO_x is presented as an absolute value, which makes it unfair for bigger aircrafs and does not allow the comparison between models.

Moreover, in this case there is not any ranking system given, which makes it more difficult to put numbers in context.

Finally, talking about how this variable is displayed, it could be argued that showing what actually the metric consists on (NO_x), at the bottom and in small print does not ease the task of understanding at a first glance what this is about.

Total Aircraft Fuel Consumption By Journey Length

For the calculation of this measurement, Flybe uses the amount of fuel defined in the flight plan for the journey. This is an internal data of the airline, difficult to get access to and with not very much transparency. Although it is a measurement that encloses not only the engine but the aircraft general performance, since it is internally calculated by the company it could not be used if a general ecolabel system wanted to be applied: the method should be able to be performed by a third part using public data.

This measurement shows again a lack of normalisation. As it is an absolute value it does not allow to compare with model with another, while clearly favouring small aircraft. Moreover, the way of deciding why certain values belong to certain ranks remains unclear.

Furthermore, the idea of selecting certain routes to represent the general behaviour of the aircraft can lead to some inconsistencies. The distance is not the only relevant parameter when it comes to calculating the fuel used. Several others, such as weather conditions or the actual journey weight of the aircraft are very important as well: a severe head wind besides a very busy aircraft can drastically increment the fuel consumption. This is why speaking about representative journeys without specifying the conditions in which the measurements were taken might not be the most strict solution. Since when studying the flaws always the worst case scenario has to be considered, it could be thought that Flybe chose certain routes to favour itself.

CO_2 Emissions per Seat by Journey Length

Although this metric includes a normalisation parameter, which is the number of passengers, it is a directly derivation from the last one. This means that drags all the previously explained problems: the lack of transparency when it comes to the used data, the uncertainty of why ranks are as they are and the inconsistency of the choice of representative journeys.

Minimum Leg Room and Number of Seats

The problem with this metric is that although it shows measures that are not difficult to be conceived by a passenger, it does not provide any sort of comparison. A normal person does not know how much space does an airplane usually have, so even they could measure it previously to get an idea, they would have no reference.

Design

The most remarkable thing about the design of the ecolabel is the lack of an average global mark. The problem with that is that firstly, not all the parameters that appear are ranked, and secondly, the ones that are present different mark measures: the noise rating has a much bigger grade than the other ones. This can lead to misinterpretations, as one could think that noise rating equals the generic one.

6.4.2 Hass and Van Endert Ecolabels Flaws

As it has been seen both ecolabels of (Haß, 2015) and (Van Endert, 2017) are very similar. The second one is a continuation of the first one, which makes the second an extended version of the first one. This is why both will be reviewed at the same time. For comfort purposes, when talking about the ecolabel, although it was explicitly said, the explanation would be referred to the newest one (Van Endert, 2017). Since both of them are similar, and the second one is supposed to be an upgraded version of the first, it makes more sense to focus on the most recent label.

If thought, there is almost no sense on criticising the way the content itself of the ecolabels was created. The points that the ecolabel of (Van Endert, 2017) shows at Figure 6.17 were reviewed three times not only but its creators but by professor Scholz. (Haß, 2015), (Van Endert, 2017) and (Sokour et al., 2018) share the majority of points. Ant those which are not equal because were introduced in the second version, were maintained at the third one. This indicates the level of refinement the methods presents.

To get an idea, "fuel consumption per seat", "noise rating", the subcategories of "local air quality rating" and "travel class rating per person" were kept the same in the three versions. Just "CO_2 equivalent per seat" was a completely new added metric in the second version. However it is true that some changes were applied in most of them, but they did not change completely the evaluation. One example is the use of the number of passengers of the airline layout to normalised instead of the number of passengers given by the original configuration of the manufacturer. This was a changed introduced at (Van Endert, 2017) in respect to (Haß, 2015). The other main change is how the 0-1-normalised ranges are created, which was already explained at the beginning of Section 6.3.3.

Nevertheless, some points can be briefly discussed. The analysis will be mainly centered in how the content of the ecolabel is presented, since the calculation procedures, as it has been said, have been reviewed many times, which proves its accuracy. The points to be discussed are the following:

Its Optional Character

One of the most important things that is needed to be defined for the ecolabel is its character. If the method is voluntary or it has to be obligatorily displayed by airlines is an important decision. In both (Haß, 2015) and (Van Endert, 2017) it is said that the ecolabel has to be voluntary. However, this might be thought to be a mistake.

If the ecolabel is not make compulsory to be shown by airlines is very likely that ends up not being used. It obviously all depends on how strict the evaluations are: if airlines find it easy to get good marks, although being voluntary, they might use the system in order to reinforce the advantages compared to the competitors. However, the airlines that see their possible ranks as too low would not participate in the scheme. This would cause to see just labels with the "A" qualification, which would not allow no comparison. It could be thought than then the passenger would clearly identify the ones that do not show an ecolabel as airlines with pollutant aircraft, but it can be said very safely that these companies would find marketing strategies to overcome that.

Moreover, considering all the pressure that is being put over the aviation sector it might be good to accelerate the race for achieving a more sustainable industry. If all airlines are forced to show their aircraft qualifications, the ones with bad marks will rapidly start an updating process. Furthermore, aircraft manufacturers will start to have the environmental specifications of their products as more priority matters.

The problem is that (Haß, 2015) and (Van Endert, 2017) focus on the ISO normative that talks in general about all the types of environmental labelling instead of focusing on the most similar one. At (Cerem Comunicación, 2019) the three types of ISO normative that regulate ecolabelling are explained. They are found in the framework of ISO 14024. The characteristics of each type that will be now presented to discuss the nature of the ecolabel will be extracted from that website.

- **ISO Type I:** (Haß, 2015) says that the ecolabel has to be voluntary because it should be associated to a Type I form of ecolabelling. An example of these types of eco-labels is the EU Ecolabel described at Section 6.1.1. They are stamps that external entities give to products ensuring their low environmental impacts. Obviously, they are voluntary, because as signs of good practice they are just given to the products that meet certain criteria. The products that do not meet these criteria can not show them, and the ones that do, have the possibility of displaying it or not, but it would be unlogical not to.

  However, the aviation ecolabel is nothing like that. As it has been already said the aviation ecolabel is not a sign that proves the environmental good practice of the product. This is why it can be concluded that arguing that the aviation ecolabel has to be optional because the Type I's are, is not valid.

- **ISO Type II:** as it can be read at (Cerem Comunicación, 2019) these type of eco-labels are self-declared by companies. Companies are supposed to be transparent about the used data to guarantee its credibility. This type of ecolabel is obvious that it is not the best solution. It could be argued that Flybe created an ecolabel that could fit in this category, although it was not approved by the ISO standards. However, as it was already seen at the previous analysis of Section 6.4.1 the outcome was not very trustworthy. Both (Haß, 2015) and (Van Endert, 2017) agreed on this, so it will not be further discussed.

- **ISO Type III:** (Van Endert, 2017) said as well that the ecolabel should be voluntary because of its resemblance with a Type III form of ecolabelling. An example of these types of ecolabels is the EU Energy label described at Section 6.1.2. According to (Cerem Comunicación, 2019) these type of labellings can be either voluntary or mandatory, depending on the case. Both are based on the the life cycle analysis of the product. The ones that are mandatory happen to be the ones that are focused on a single phase of the cycle of life of the product. As it can be seen, this matches the definition of the aviation ecolabel. Moreover, (Cerem Comunicación, 2019) gives as an example the EU energy label, which happens to be the model in which the aviation ecolabel is based.

This mandatory character is expressed at (European Union, 2020). At the regulations of energy labels the group of products that are required to have this labelling can be found. All household appliances are listed, such as air conditioners, refrigerators or washing machines. It excludes however second-hand products and means of transport. This means that it could be argued that since cars do not need to have an energy label, aircraft should not as well. However, if the success of the race for energy efficiency of cars and washing machines is compared the outcome is clear. It is true that car manufacturers are making an effort to create less consuming vehicles, but buyers do not have the same comparing standard that they have with household appliances.

Looking at the success the energy label has had in household appliances, it could be determined that the aviation ecolabel should be mandatory. Aviation is not the most less-pollutant industry. This is why any effort to walk towards a greener future would be positive not just for the environment but for the public opinion

Overall Rating

It could be argued that the overall rating is a parameter difficult to analyse. Being a 0 to 1 grade, where 0 the best grade is, might not seem very clear for some users. A better method should be found to improve its understanding.

Names of the Variables

It can be seen how some inconsistencies about the displayed variables can be found.

On the first hand, the name of the aircraft model and the engine model are not introduced by tags such as "Aircraft" or "Engine". However, easier to understand names such as the ones of the airline and the number of passengers are introduced by "Airline" and "Seats". The first two variables should have an introductory tag as the other two ones do.

On the other hand, some variable titles have the word "rating" in them, but not all (such as the fuel consumption). It makes more sense to not have it than to have it, since it is obvious that all of them are ratings. The space this word occupied can be used to add other more explanatory terms.

Finally, the fuel consumption category could be a little bit criticised. It was clearly stated at (Haß, 2015) and (Van Endert, 2017) that the SAR parameter that is used in its both items it is in fact not a metric of fuel consumption, but a metric of the whole efficiency of the aircraft. It can be clearly understood by looking at where does SAR come from: although having kg in its unit definition, these kg come from a decrease of payload, but not of fuel. This is why this variable should be renamed. It has to be remarked that the titles have the words "per seat" on it, but not "per km", which is inaccurate because avoiding one of the two clarifications would be a mistake. This has to be changed.

Units of the Variables

The units of the displayed variables present some inconsistencies too. Continuing with what was explained before, some variables have in their titles per seat but not in its units, where they just say per km. It would be better to have both dividing magnitudes in the units definition instead of the title. On the other hand, all the metrics have their unit definition except the Noise rating, which seems to try to express that it is an adimensional value but with an unclear way; this should be improved as well.

Number of Shown Parameters

One of the problems that could be remarked about the ecolabel is the considerably big amount of displayed information. The aim of the tool is to provide the passenger with a method that allows them to quickly understand how environmentally efficient their aircraft is. An excessive amount of information could difficult this process. This is why some parameters could be eliminated.

On the one hand, the category of air quality rating might be thought to present too much items. Since the metric of nitrogen oxides is the only one used for the overall rating, it could have sense to eliminate the other two. Although they represent interesting information, if the ecolabel had to dispense with something, it would be the metric of NMVOC and particulate matter.

On the other hand, the category of travel class rating present blank metrics in some cases. If an aircraft does not have a certain class, it would be more logical to not show it instead of show it with a N/A sign. However, this case is different from the other one. It is understandable that since the tool that generates the ecolabel is an academic work made with excel it is easier to generalise it for any existing class. Nonetheless, if it ended up being made more professionally the non appearing classes should be removed.

Finally, although not so common, the metric of nitrogen oxides can represent a problem in turboprops. As it has been explained, this variable does not apply for turboprops, since ICAO does not provide a emissions databank for this type of engines. If no data could be finally found, the metric should be removed for turboprops, since it would just add information with no value to the label.

As a last comment, It should be remarked that "adding" new variables can be useful too. Splitting fuel consumption and carbon dioxide emissions in two different items could be interesting to give both of them the importance they have. The general variable that allocates both of them might not be very clear to understand.

Displayed Grades

The problem with the grades that every metric has and the overall rating is that it is very easy to assume that all the metrics participate in the overall rank, which is not the case. Travel class rating is not part of the overall rating. It should be marked somehow that just the first four variables are used for calculating the final grade.

Number of Decimals

The metrics display an excessive number of decimals, which makes it more difficult to understand: more exact numbers are usually more difficult to conceive.

Lack of Variables Definitions

Unlike the EU Energy label, which presents easy to understand variables, the aviation ecolabel has more complex ones. This is why the ecolabel should be accompanied by an extra information piece. Depending on the format of the ecolabel (physical, as an image on the internet, as a part of a mobile application etc.) it should present different formats. However, its objective should be briefly summarise the content of the ecolabel and its methods.

Two Types of Numerical Values

The problem that could be seen with the numbers that appear in the ecolabel is that there are two clearly differentiated types: the one conformed by the overall rating, which is a 0-1 normalised value, and the rest, which are the metric of the presented magnitudes, each with different units. The problem is that although in the metrics the units of the variables can be easily seen, the fact that the overall rating is a 0 to 1 normalised value is not that obvious. This should be pointed somehow, not just in an extra descriptive information, but in the main ecolabel itself.

Explanation of the Travel Class Rating

One of the problems this point presents comes from its name: with travel class rating it can not be understood which type of travel class rating does the metric talk about. It should be named so as it was clearly conceived that it is a Fuel consumption variation.

The other problematic that this point represent differs from the rest in the explanation that is given in the thesis (Haß, 2015) and (Van Endert, 2017), but not the ecolabel. It will not be changed in any sense. At Section 6.3.2 it was seen how the travel class rating was obtained by multiplying the CO_2 emissions amount by a factor specific for each travel class. The carbon dioxide emitted amount is just an average value, but more expensive classes imply more emissions per person, since the space that a single passenger occupies could be used for fitting more. This is precisely the more natural explanation: talking about the occupied or not occupied "space", not factors that seem to appear from scratch. The outcome however is correct, but the procedure to arrive to it, it might not be the most understandable one. A better explanation should be found that instead of giving a factor with an specific name, provides a more natural explanation.

Another discussion that is also interesting is not the analysis of the last ecolabel flaws, but the analysis of the deficiencies of the ecolabel as an informative tool. The objective of this thesis is to study a method that allows to inform the passenger about the environmental impacts of the flight, not just creating an ecolabel. This will be made in a different section in order to prevent its relevance from being diluted. However, first, the previously commented flaws of the ecolabel will be used to create a new model.

6.5 New Aircraft Ecolabel Proposal

Two images are shown. The first one corresponds to an extra site that could help the passenger to understand the content of the label, the seond one, to the Ecolabel itself.

RATING METHOD

Each metric is calculated for an specific aircraft.
Its value is translated into a range that goes from 0 to 1. 0 is the higher grade, 1 the lowest.
The 0 to 1 range is divided in 7 segments.
Its divisions are unique for every metric:
They depend on the sampe used to design the metric.
Each of the 7 segments has a grade: from A to G.
The value of the metric is placed in these segments.
A grade is assigned depending on the segment.

OVERALL RATING

The travel class rating DOES NOT participate in the overall rating.
A weighted average is calculated for the 4 metrics marked with * and its 7 range limits:

$$For\ turbojets = 0.2 \cdot Fuel + 0.4 \cdot CO2 + 0{,}2 \cdot Noise + 0{,}2 \cdot \text{Air quality}$$

$$For\ turboprops = \frac{0.2 \cdot Fuel + 0.4 \cdot CO2 + 0{,}2 \cdot Noise}{0.8}$$

A value between 0 to 1 is obtained, being 1 the lowest grade.
The A to G grade: by placing it in the 7 ranges; its limits come frome the weighted average
It is finally translated into a 0 to 10 range, where 10 is the highest grade.

FUEL PERFORMANCE*

It IS NOT directly the fuel consumption, but its overall efficiency.
It uses the SAR: a ratio of how longer distances an aircraft can fly and how much payload has to reduce to do so. Normalised with the number of passengers.

CO2 EQUIVALENT EMISSIONS*

Amount of emitted CO2 plus the amount of other emitted gases that produce the same EQUIVALENT warming effects that CO2 has. It uses the SAR.

LOCAL NOISE LEVEL*

Average noise level (normalised) produced during 3 phases of landing and take-off.
Normalised because the 3 noise levels are divided beforehand by its normative limit.

LOCAL AIR POLLUTION*

Amount of NOx produced by the engine during landing and take-off.
Normalised with the maximum thrust of the engine.

TRAVEL CLASS FUEL PERFORMANCE

Actual amount of fuel that a passenger "consumes" depending on its travel class.
Determined by how much space is used for actually people transport, or left unoccupied.
It is the same variable as Fuel performance but specified for each travel class.

Figure 6.19 Proposal of an addition to the ecolabel

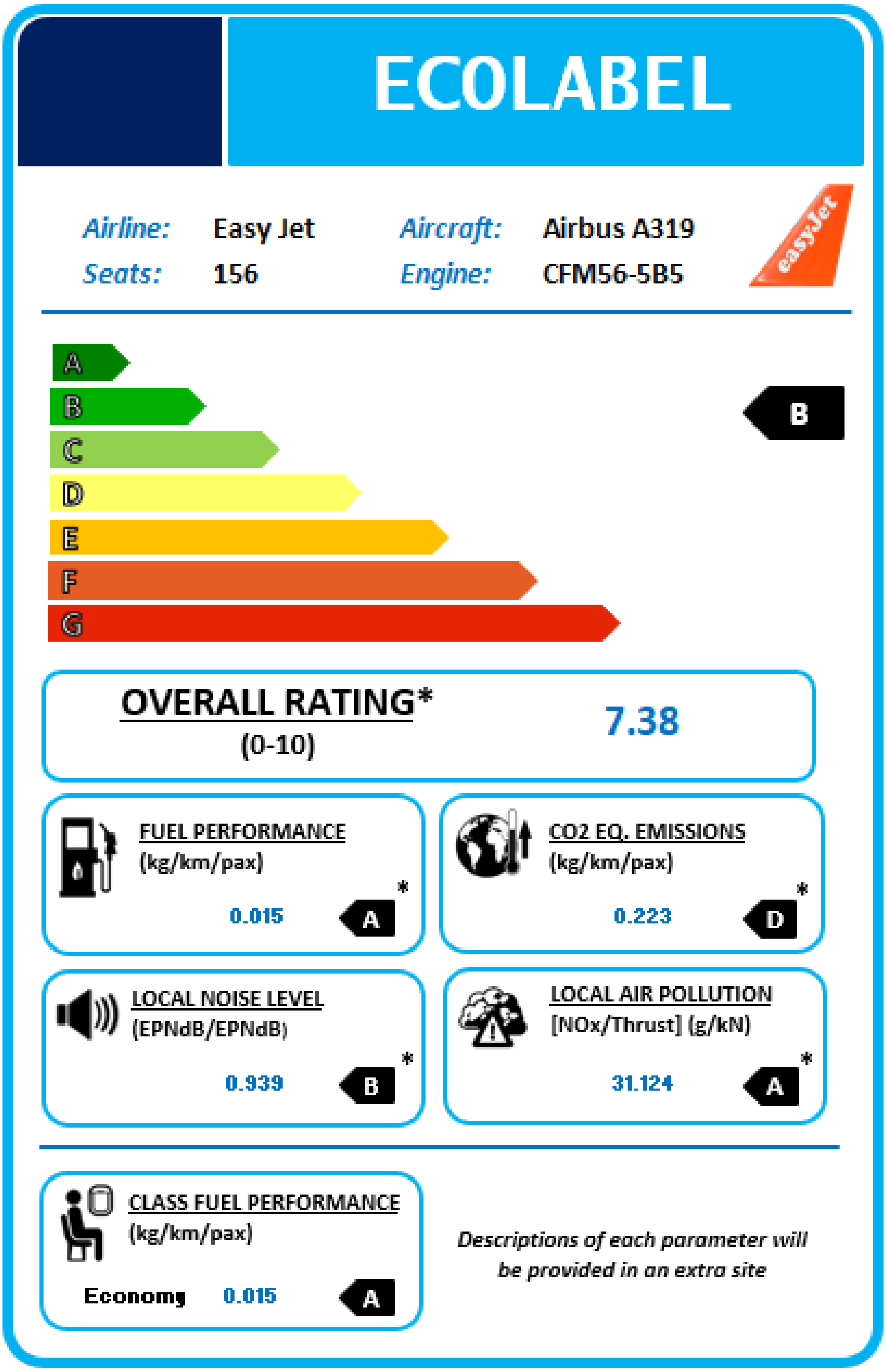


Figure 6.20 Proposal of new design of ecolabel. Designed modifying (Sokour et al., 2018)

The old version of the Ecolabel will be now also presentead for easing the comparison. It has to be remarked that both Ecolabels belong to the same aircraft and engine model to allow the reader to allow the reader to analyse the changes better.

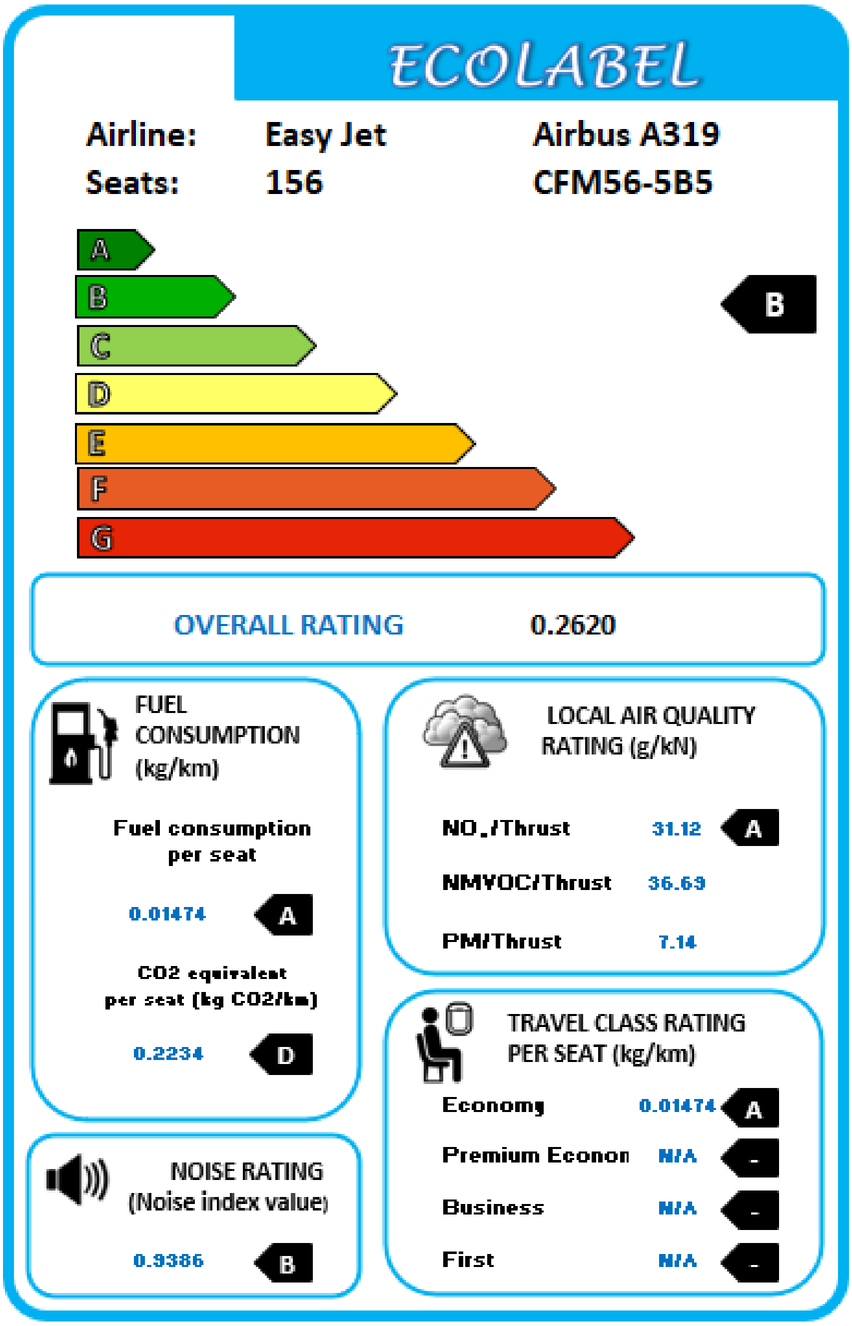


Figure 6.21 Example of the old ecolabel designed by Van Endert. Extracted from (Van Endert, 2017)

Now that the new designs of ecolabel has been seen the changes that were done will be explained. The points will be the same as the ones of Section 6.4.2 to prove that the introduced modifications were done not just because, but following the initial criteria with which the deficiencies were analysed.

6.5.1 Reasons for the Design Change

The following section will try to explain the criteria followed change the ecolabel design. As it has already been said, the organisation will follow the points used to discuss the flaws of the ecolabel of (Van Endert, 2017).

Its Optional Character

As it was said in the previous section, one of the weak points of the Ecolabel was its optional character. It was seen that a mandatory ecolabel certified by an external organism would be the best solution, which corresponds to the ISO Type III. This is why a space on the upper left corner has been saved for the stamp of the certifying organisation. It has the shape of a dark-blue rectangle, following the design of the EU Energy label.

Overall Rating

It was explained at Section 6.4.2 that a grade system going from 0 to 1 might seem difficult to understand. This is why it has been changed to a 0 to 10 scale, which is more common and therefore easier to interpret. The method to do so has been very simple: the shown grade is the result of subtracting the old grade (the one in the 0-1 scale) from 1 and then multiplying it by 10. It can be made since in both scales 0.5 (or 5) would still be the middle point. The letter grade however has not been touched.

Names of the Variables

As it can be seen in Figure 6.20, the name of the variables have been changed. Firstly, the tags "Aircraft" and "Engine" have been added at the introductory section of the ecolabel to ease the understanding of the read words. Moreover, consumption is now Fuel Performance. Since at (Haß, 2015) and (Van Endert, 2017) it was clearly explained that the SAR, the variable used to calculate this metric, is not a evaluation of the fuel consumption but the efficiency of the overall aircraft, "Fuel consumption" was not accurate. It has been changed to "Fuel performance", which includes "fuel", a word that allows to understand that the metric is related with how much kerosen the aircraft burns, but also has "performance", which makes the reader understand that the variable is more related with efficiency. Nonetheless, a brief explanation for the passenger is provided at the extra site of Figure 6.19.

On the other hand, the word "rating" has been erased from all the title to avoid redundancy. This can be seen in the case of the noise metric or the metric related with the local air levels. This last one had previously the word "quality" on it, and this word has been changed to "emissions". The metric does not evaluate how clean the air is just by itself, but the amount of polluting species the aircraft emits. Quality would imply testing how good the air is, which would need a measure of all the species present at the air, not only the ones coming from from a single aircraft. Following this logic and the one of the previous paragraph, "Travel class rating" has been changed to "Class fuel performance", deleting the word rating and emphasising the need to let the passenger now that the fuel performance is the calculated metric. If this did not appeared, it could have been impossible to know which one of the metrics was the one specified for each travel class.

Units of the Variables

As it can be seen the word "per seat" has been deleted not only in the fuel metric, but in the carbon dioxide one. The problem is that these metrics are not only per seat, but per km as well. Saying just per seat would be inaccurate. Both dividing magnitudes have been added at the unit definitions. On the other hand, it was commented that the fact that the noise metric was adimensional was difficult to understand; this is why this has been expressed as a division of the noise level unit.

Although not being a unit, to make it clear that the overall rating is a metric whose values go from 0 to 10, this has been expressed in the same format of the units.

Number of Shown Parameters

As it was commented in the previous section, one of the problems of the ecolabel of (Van Endert, 2017) was its excessive number of parameters. This is why some variables have been deleted. This is the case of the the metric of NMVOC and PM: since they not participated in the overall rating they have eliminated. Furthermore, for the travel class ratings just the existing classes are shown now. In the aircraft of the example of Figure 6.20 since the aircraft just has economy class, just this class is displayed, instead of showing for example the first class with a N/A tag.

Finally, as it has been said at Section 6.4.2, the old general variable Fuel consumption has been split into two. Instead of having a big one that allocates the one relative to fuel and the one relative to caron dioxide, a single one has been assigned to every one of them to make them more relevant.

It has to be said however, that if the aircraft was a turboprop the local air pollution metric would not be shown, since this metrics is at the moment only possible to be computed for turbojets. However, since the example corresponds to a turbojet everything is correct.

Displayed Grades

A commented problem was that in the old ecolabel it was impossible to know which parameters participated in the overall rating. To solve this, an asterisc has been added next to the title of the overall rating and to the letter grades of the parameters that are used to calculate it. An explanation at the extra support page can be found where this is clarified. Furthermore, two blue lines have been drawn at the ecolabel to even differentiate more the displayed informations: the first one separates the introductory data from the rest, and the second one the travel class metric from the other ecolabel metrics; in this way the user can see more clear that just the first four metrics participate in the overall rating.

Number of Decimals

The number of decimals has been reduced to three for the metrics and to two for the overall grade. More decimals would difficult its understanding. People are used to reading two decimals when it comes to grades and maximum three in the case of scientific magnitudes; using more does not necessarily mean a better understanding, usually has the opposite effect.

Lack of Variables Definitions

This was a problem that could not be solved by adding no extra information to the actual ecolabel. This is why an extra page has been added to help the passenger understand the content of the label. One of the points that could be highlighted is the explanation of the rating method, which is impossible to understand if the followed method is not clarified. As it can be seen, it follows the design line of the label: it is contained in a shape of the same dimeinsions, uses the same tipography and has the same divisory lines. A not on the under left corner on the main site of the ecolabel has been added to indicate the existance of the support page.

Two Types of Numerical Values

This is a problem that has been briefly commented previously. The problem was that it was difficult to differentiate which parameters had units (such as the metrics) and which ones did not (such as the overall rating). This have been solved by adding the 0 to 10 range under the title of Overall rating, by rerwritting the defining variables of the metrics and by adding an explanation on the support ecolabel page; in this extra page the origin of the overall rating is understood and therefore why it does not have units.

Explanation of the Travel Class Rating

Although this was not a problem of the ecolabel itself, since the explanation of (Van Endert, 2017) did not interfered with the label design, it could imply a concept problem. A better explanation was said that was needed to be given to ease the task to understand this concept. In the extra page of the Ecolabel a description that summarises this new explanation has been provided, but not the whole one. The complete version will be seen now.

In order to ease the explanation, it would be considered that there are just two classes: economy (e), and first (1). This should be extrapolated to as much travel classes as the aircraft had.

$$n_{pax} = n_e + n_1 \tag{6.13}$$

The first step consists on taking the Aircraft Fuel Consumption (AFC) metric (the inverse of the SAR normalised by the total number of passengers of the airline layout) and dividing it by the total area that passengers occupy. This is obtained by multiplying the surface of one seat class by the total number of seats of the class; this has to be done for every class and finally sum the results. By doing this the fuel consumption per passenger and unit of surface is obtained.

$$AFC = \frac{1}{SAR \cdot n_{pax}} \tag{6.14}$$

$$AFC\ per\ pax\ and\ surface\ unit = \frac{1}{SAR \cdot (n_e + n_1)} \cdot \frac{1}{S_e \cdot n_e + S_1 \cdot n_1} \tag{6.15}$$

If the AFC per surface unit is multiplied by the total surface that a class represents and the total number of passengers of the plane, the fuel that the given class consumes is obtained obtained. The example will be done for the economy class.

$$AFC\ economy = \frac{1}{SAR \cdot (n_e + n_1)} \cdot \frac{1}{S_e \cdot n_e + S_1 \cdot n_1} \cdot (n_e \cdot S_e) \cdot (n_e + n_1) \tag{6.16}$$

The final step consists on dividing the last variable by the number of seats of the given class. By doing this, the actual amount of fuel that a passenger of a class "consumes" is obtained. It is said "consumes" since as it was already seen, SAR does not express actual fuel consumption, but overall fuel usage performance. However, for understanding purposes it is easier to talk about consuming.

$$AFC\ economy\ pax = \frac{1}{SAR \cdot (n_e + n_1)} \cdot \frac{1}{S_e \cdot n_e + S_1 \cdot n_1} \cdot (n_e \cdot S_e) \cdot (n_e + n_1) \cdot \frac{1}{n_e} \tag{6.17}$$

If the last equation is simplified the following expression is obtained:

$$AFC\ economy\ pax = \frac{S_e}{S_e \cdot n_e + S_1 \cdot n_1} \tag{6.18}$$

If Equation 6.10 is completely developed by using 6.9 it can be seen how it arrives to the same expression as Equation 6.18 (if it is calculated for economy class of course).

General Design

As it can be appreciated, the design in general terms has been also changed: the typography of the word "Ecolabel" is now more similar to the one of the EU Energy label, the corners of the rectangles that allocate the metrics are more rounded, the metric titles have been underlined and the contours of the colour rating scale have been erased. All of this has been done with the objective of making a more visual appealing ecolabel.

Having already finished this point, a very general and deep insight of the Ecolabel for the aviation passenger sector has been achieved. Although the Ecolabel model itself has been improved, there are still some flaws to do regarding the systematic the passenger has to follow to compare their travelling options. If they want to know the best way to travel from some city to another, in the current systematic, their only option is to consult the best flying option by choosing the best aircraft. This, however, presents some deficiencies that show up if they want to compare other transports or if they want to analyse flights and not aircraft. This is what is said that the systematic the passenger has to follow to be best informed about their travelling option is incomplete: it is formed by just one tool, the Ecolabel, but it is obvious that more are needed. This is why the next chapter will be focused on developing a new environmental informative tool, a systematic with which the passenger can better informed about their travelling options.

7 Systematics of Environmental Information for Aviation Passengers

In the previous section the ecolabel was fully analysed: all the existing models were reviewed and their flaws studied. It was discussed the deficiencies the ecolabels presented and how they could be improved. However, in the goal of informing the passenger about the environmental impacts of their flight, the ecolabel should not be the only available option. There are other mechanisms that together with ecolabel would be more useful. However, these methods have not been proposed yet. In order to decide which methods could be chosen, first the deficiencies of the systematics that passengers currently have for understanding the environmental impacts of travelling will be presented; then, a new systematic will be proposed.

7.1 Flaws of the Existing Systematic

Currently, the systematic that a passenger has to follow to decide which is the most environmental option for them to travel is consult the Ecolabel, but this might not be enough. The deficiencies that the ecolabel could present in the informative process will be now presented. It is important to remember that no actual deficiencies of the ecolabel itself will be said. It is considered to be a closed and polished concept. However, as the whole environmental impacts informative tool that is intended to be created, which might not only include the ecolabel, some flaws can be appreciated. This will set the base for the following section, where the addition of other tools will be proposed to complete the aviation ecolabel: the concept of ecolabel is finished, but not the complete informative tool. The points that could be improved are the following:

7.1.1 Specific Routes Comparison

One of the things that have to be remembered of this thesis is its objective. As it has been several times repeated, it aims to study methods to inform the passenger about the environmental impacts of their flight. Which is very important here is the last word of the last sentence: the goal is to educate about how its flight harms the environment, not its aircraft. The ecolabel focuses exclusively on the vehicle, and not on the journey, and this leaves blanks that can lead to misinformation. At (Haß, 2015) and (Van Endert, 2017) it has been repeated several times that the information can not be specific for the journey because there are several factors that can not be controlled and measured, such as the weather conditions. However, although these details it is true that can not be take into account, others can. For example, obviously two flights performed between the same airports and at the same time might are bound to have variations due to turbulences, air traffic, pilot maneuvers or air controllers decisions, for example. Nevertheless, there are other factors that make bigger differences between two flights between the exact same airports, such as big deviations from the most optimal route or stops at intermediate airports. The question is the following: Which flight will consume and pollute less, the shortest one, but performed with a very bad graded aircraft, or the longest one, but performed with a very good graded aicraft? Both situations will be analysed.

Stopover at the Middle of the Journey

Stops at intermediate airports can be discarded from the very beginning. Taking off is one of the phases of a flight that consumes the most fuel, it is obvious, since the aircraft needs a very big impulse of energy to start flying. Obviously a journey that implies two take-offs and two landings will consume much more fuel and pollute more (not only because of emissions, but because of noise levels) with just these two phases. Furthermore, a flight with an intermediate stop will always imply a longer travel distanced, as it is very rare that the mid airport falls exactly in the route followed to arrive at the final one. This longer flown distance implies more consume and more pollution. Overall, counting both flights, it causes to end up carrying more fuel, because of performing two landings instead of one: in a landing, normative explicitly states that an extra amount of fuel has to be carried for loitering (which means flying in circles over the destination airport for a given time, in case any delayed in landing happened) and for being able to fly to a near airport (in case it was impossible to land in the desired one). This extra amount of fuel it has to be carried for each of the flights, which makes the airplane flying in heavier conditions if both flights are looked at.

Nevertheless, it has to be remarked that the previously presented situation is the easiest but the most improbable one. Normally, when a journey that includes a stopover is purchased, both flights are not done with the same aircraft. The organisation of the flight is designed to make a connection of two preexisting flights, which implies big resources savings for all involved parts.

On the one hand, this situation would still have no sense to be analysed, as it would continue to imply a bigger travelled distance. On the other hand, it would add a big complexity: the added effects of both aircraft should be compared to the effects to just one. This could be made, for instance, by an weighted averaged that used as the weighting factor the ratio of the flown distance of each aircraft over the total one. This weighted average could not use other parameters, such as the time of flight, since they are more dependent to the flying conditions. The weighted average would be calculated for all the metrics of the ecolabel and then a final grade will be obtained. Nevertheless, this option would be still not accurate enough, since it would not consider the effect of having to perform two take-offs and two landings. Moreover, the reason for bringing up this matter passes through the consideration of an aircraft with the maximum grade compared with an aircraft placed very low in the ranking. The existence of two aircraft could not enlarge more the grade, since the beginning it is supposed to be the highest one possible.

To sum up the last paragraphs, although all the previous reasoning, doubting if a flight with an stopover could outperform a direct one leads to a clear answer: a direct flight would be always better.

However, it shows something of how the ecolabel should be displayed. It might happen that flight-search engine website shows the ticket options to fly from one airport to another and one of the options was a direct flight and the other one had a stopover. If the direct flight was done with an aircraft ranked with a "C" and the one with the stopover with two aircraft ranked with an "A" the user could think that the first option is better. However, as it has been seen, this is not true. This is why it should be warned that ecolabels just allow a proper comparison between aircraft that follow the same route. If two flights with stopovers at the same middle airport wanted to be compared the contrasting could be positively made this time through the weighted average explained before. Although it would still not account for the effects of two LTO cycles, as both options would have the same flaw, a relative analysis would be accurate. This, however, could only be used as a comparison between the two specific flights, not as an overall rating of the flight, since it would not consider the LTO cycle.

Big Deviations

This situation, unlike the previous one, it has a more logical reason of being. There are cases where two flights, although being direct, follow different routes for some specific reasons. This deviations, although being remarkable, are not that big to discard from the beginning a comparison between a bad aircraft that follows a good route and a good aircraft that flies a bad route. This situation will be now discussed alongside the reasons why these deviations could exist. With this analysis the first lack of the ecolabel as informative tool would be found, which consequently will imply the necessity of finding a solution. The solution will be shown at the next section, where an upgraded version of the environmental informative tool (which does not only include the ecolabel) will be explained.

The fact that big deviations happened in a direct flight might be thought to not have any sense. Why an airline would deviate from the most optimal and direct route? Obviously the would not do it if they were not forced to do so.

Some countries are very restrictive about allowing airlines from other countries to cross their airspaces. Examples of that are China and Russia. Russia, for instance, just allows one airline per country to cross their airspace. When European airlines have to travel to Asian countries they have to decide what is worthier: going to these destinations by flying bordering Russia or directly not flying to these places. If one of these airlines with the permit of flying over Russia denied decided to fly to Russia anyways the travelled distance would be much bigger than the one flown by an airline with the permission of crossing Russia and that wanted to fly between the same origin and destination airports. The following pictures represent this situation. The first one, Figure 7.1 represents the flight that WOW (an Icelandic airline) would like to do when connecting Reykjavic and Dehli. The second one, Figure 7.2 represents what the airline actually should do if it wanted to fly from Iceland to India.

Figure 7.1 Example of a direct Reykjavic - Dehli flight. Extracted from (Wendover Productions, 2018)

Figure 7.2 Example of a non-direct Reykjavic - Dehli flight. Extracted from (Wendover Productions, 2018)

As it can be seen at the two last pictures, the two routes are very different. According to (Wendover Productions, 2018) the deviation would cost around 45 minutes. Although not being very high, it will imply an extra fuel usage that would be translated into more pollution.

As it was previously commented, Russia is not the only one to present this problematic. China also bans certain airlines from crossing their airspace. This can be seen at the following picture:

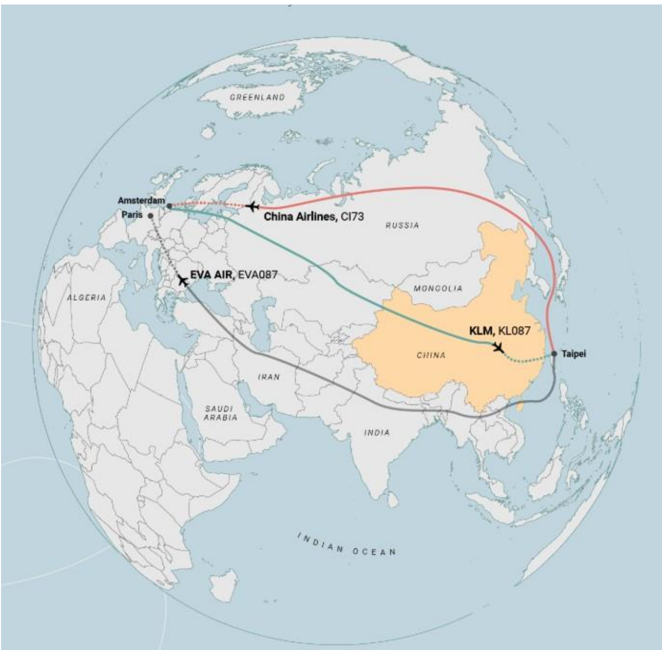


Figure 7.3 Example of Paris/Amsterdam - Taipei flights. Extracted from (Hernandez, 2018)

At the last picture it can be seen how China Airlines and EVA Air have to perform big deviations to avoid crossing the airspace of China. KLM however can fly directly. The three displayed flights are very similar, since they connect two near cities such as Paris and Amsterdam with Taipei. According to (Hernandez, 2018) the deviations imply an extra flight time between 2 and 5 hours if compared with KLM flight. This obviously causes a much bigger resources use and eventually, a higher environmental impact. It is clear that the ecolabel can not address this situation and offer the passenger a comparison between, for example, an Amsterdam-Taipei flight of an airline that flies directly and another one that can not. This is why this issue must be solved by a more complete informing tool. Since it has been made clear that these deviations do not exist because of technical reasons but because of political ones, the flight routes should be taken into account. It must be remarked, that despite knowing that if two flights following the same route will present big consumption differences because of the flying conditions, two flights that follow different routes will present even bigger differences, it is still needed a rough approximation to be able to properly help passengers to make educated choices.

7.1.2 Lack of Comparison between Airplanes and Other Means of Transport

Obviously, one of the other problem the ecolabel presents is that is focused exclusively on aircraft. On the one hand, this is positive, because it provides the passengers a very deep insight of the environmental metrics of the plane. On the other hand, this does not allow the user to analyse if other means of transport would suit better their necessities. Although being the informative tool centered in aviation, it still needs to allow a brief comparison between aircraft and other vehicles, and as it was explained in the previous point, between the specific journeys performed by these vehicles, although being the comparison a first approach.

7.2 New Systematics Proposal

Once this point has been reached a tool that can improve the deficiencies previously stated should be presented. It would make no sense analysing what the currently informative method lacks but not trying to propose a solution. It should be taken into account, that in general, there are three main indicators: fuel consumption and CO_2 emissions, noise pollution, and NO_x emissions. Fuel consumption and CO_2 are proportional, and therefore, one could be eliminated if a higher level of briefness was needed. It has to be born in mind that the informative in tool will have as its main subject airplanes over other means of transport: it will serve as a mechanism to compare aviation options between each other in terms of airlines and aircraft models and eventually, to allow the passenger compare it with other means of transport, such as cars, trains, ships or buses. Since this is a thesis centered in air transport it is obvious that this type will be the one of more relevance. If the same level of depth was wanted to be achieved a collaboration with other departments would be the best solution, since for each vehicle specific knowledge is required. Now that the objective of this section is presented, the tools will be shown, besides and explanation of how they work.

It has to be taken into account that the ecolabel will be present always in some way in these tools. It is important to realise that there are many ways in which this information can be presented to passenger. On the one hand, it can be given to the passenger through a guided process in which they are forced to review all the metrics necessary to be able to eventually make an educated choice. Nonetheless, one has to be aware of that not all passengers might be willing to go through a considerably long process. Although this was not the case, some passengers could be experts in the matter and do not need to go through an overall revision of several metrics: they might have the sufficient knowledge to just need an specific metric to make a good decisions; they could also not be interested in performing such a deep analysis and just want to compare a certain parameter. Whatever it is the case, another system that suit this necessities has to be designed. Considering this, both tools will be now introduced: the first will be the guided one, the CO_2 Flowchart, and the second one, the non guided one, the Eco Table.

Strictly speaking, they could be named systematics, since they consist on an organised way to group a series of smaller tools. Thanks to this methodical manner in which they are told to be used by the user, they can make an educated choice considering all the necessary parameters; this will not be possible if they were dispersed through the internet.

7.2.1 CO_2 Flowchart

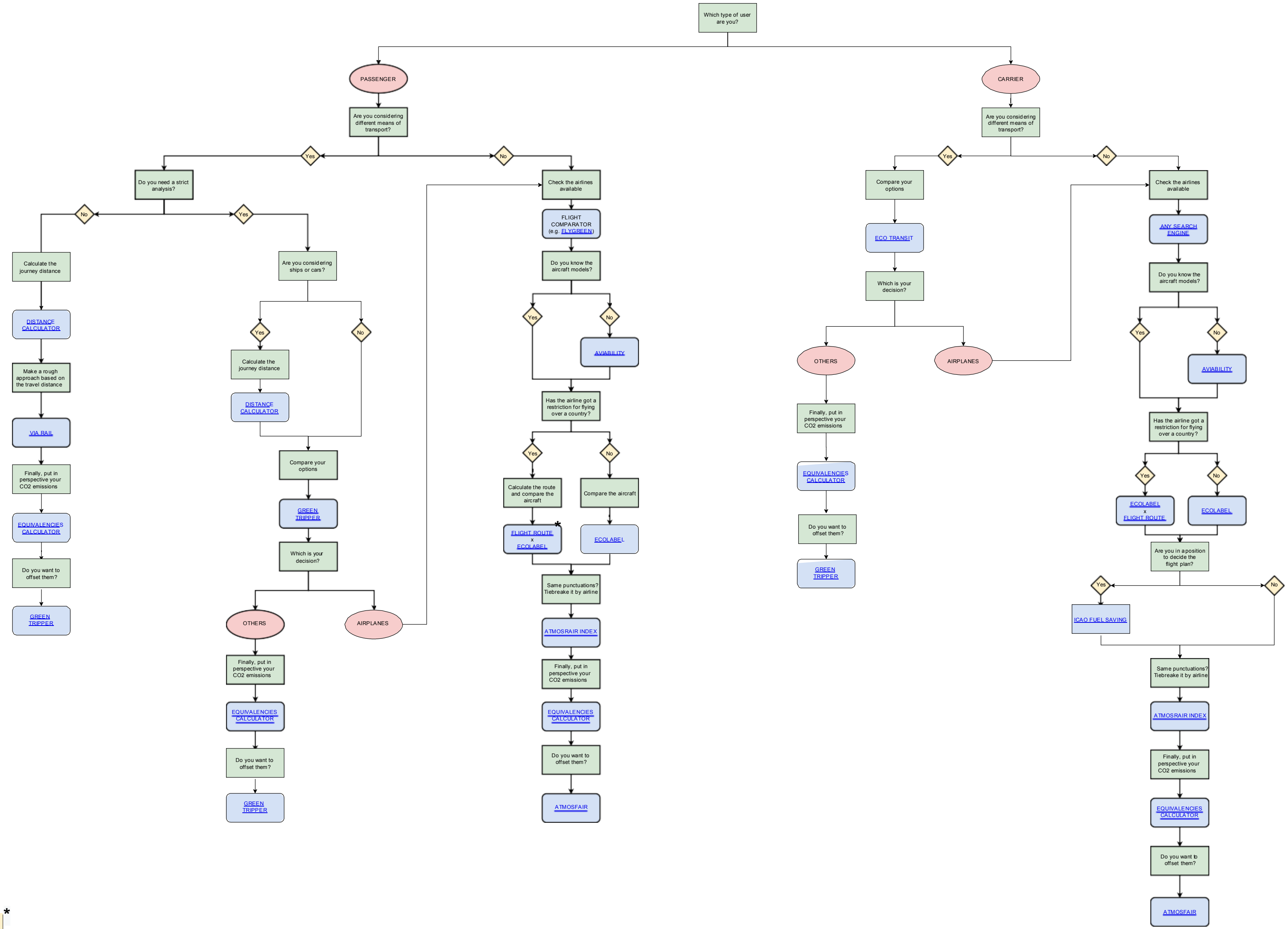
This tool, as its name clearly explains, consists on a flowchart that the passenger needs to follow in order to make an educated decision about travelling by plane or by other transport form. This decision will be focused, as well as the name of the tool says, on the amount of CO_2 the different travel options emit. The impact of carbon dioxide alone accounts for a 40% of the total pollution effects of LCA of transports, as it was seen at (Johanning, 2016). If the 20% weight of fuel consumption is added, which has a strong bound with carbon dioxide emissions, one can see the importance this parameter has. This is why having a tool exclusively designed for carbon dioxide emissions is a good decision.

Before looking at the Flowchart it has to be briefly commented how it was designed. It was created using (AppDiagrams, n.d.), an online tool that allows to easily build diagrams and flowcharts. If the CO_2 Flowchart was a real tool, it would have linked to each box the tool that they refer to. However, when embedding the pdf file of the flowchart with the whole pdf document of the thesis the links disappear. This is why, before the Flowchart itself, a list with all the tools that appear in the diagram and the links to their respective websites will be presented. For easing the task to search the tools in the list, the names will be shown in alphabetical order:

- **Atmosfair:** click here to access to the website.
- **Atmosfair Index:** click here to access to the website.
- **Aviability:** click here to access to the website.
- **Distance Calculator:** click here to access to the website.
- **Ecolabel:** click here to access to the website.
- **Eco Transit:** click here to access to the website.
- **Equivalencies Calculator:** click here to access to the website.
- **Flight Route Calculator:** click here to access to the website.
- **Green Tripper:** click here to access to the website.
- **ICAO Fuel Saving:** click here to access to the website.
- **Via Rail:** click here to access to the website.

The CO_2 Flowchart is the following:

CO2 FLOWHCART



* Multiply the CO2 eq. emissions shown in the ECOLABEL by the flight distance calculated with FLIGHT ROUTE once the restricted country is defined

As it was previously described the tool proposes a flowchart: a series of boxes that the user has to go over, there are different paths; choosing one or another depends on the answers of the passengers. Eventually the user will have chosen a certain mean of transport by reviewing its possibilities by using the concrete tools that suit their specific necessities. The proposed tools in each box are websites that compute carbon dioxide in several ways or calculate previous necessary metrics for obtaining the carbon emissions; the names that appear at the boxes are linked with their websites, in order to ease the utilisation of the flowchart. The review of the several paths that can be followed will not be reviewed, because they are enough self explanatory: in order to understand the different possibilities it is enough to read the flowchart and try to answer different things. However, it is necessary to present the websites and the reasons for their choice.

Regarding its design, it is important to remark the color code: the green boxes contain questions or guides, the blue ones website tools, the red ones disjunctive decisions, and finally, the yellow ones yes or no answers.

The tools will be reviewed beginning with the first one located at the leftmost and uppermost of the flowchart, until the rightmost and bottom-most. Some websites have already been reviewed at previous sections; when this happens, it will be referenced where the explanation can be found.

Distance Calculator

Distance calculator (Distance Calculator, n.d.) is a very easy to use tool that offers the possibility to calculate the distance that separate two locations. It provides not only the shortest route in an straight line but the distance by road. The following image provides an example of the distance between Barcelona and Hamburg.

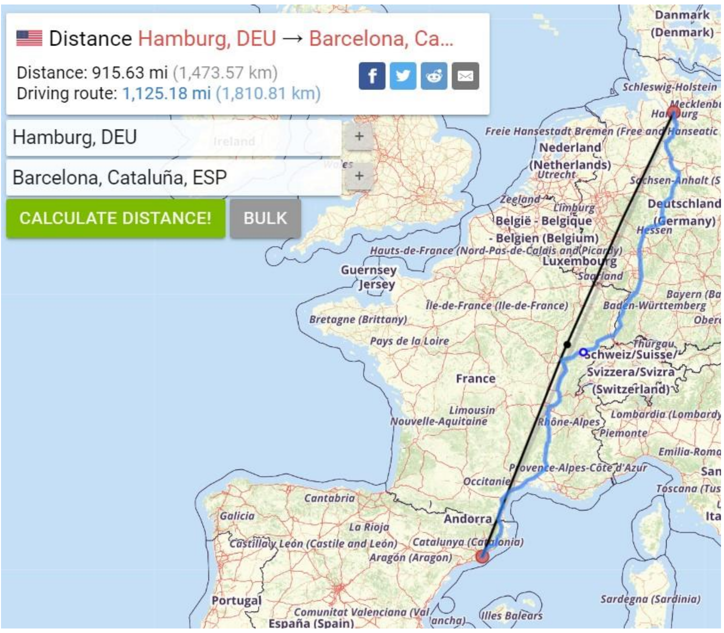


Figure 7.4 Example of the most direct and by road distance between Barcelona and Hamburg. Extracted from (Distance Calculator, n.d.)

It can be seen at the last image, Figure 7.4, how the two calculated distances are also drawn in the map using a straight black line and a segmented blue one.

Via Rail

Via Rail Canada is a railway company that operates in canada. In its website (Via Rail Canada, n.d.) offers seven example of journeys between Canadian cities; in these examples the travel time and amount of CO_2 emissions is offered, as well as the distance between the city of origin and destiny. The following image shows one of the seven examples:

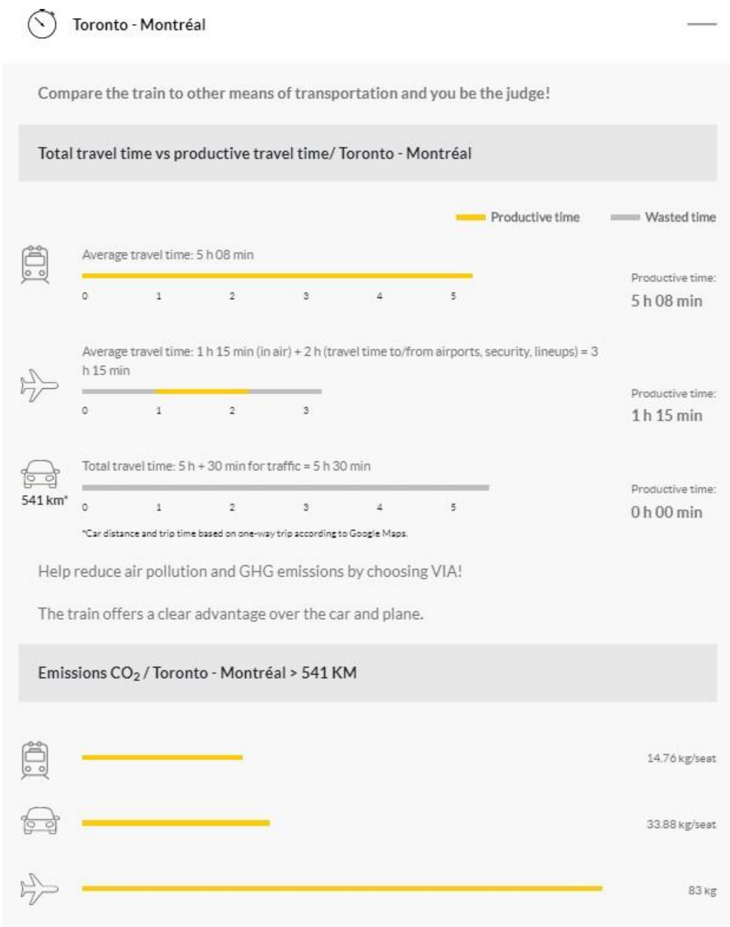


Figure 7.5 Example of Toronto - Montreal travel options. Extracted from (Via Rail Canada, n.d.)

It can be seen at the previous picture that the travel time (broken down into waiting and productive time), the amount of emitted carbon dioxide and the travelled distance can be seen. If the user wanted to quickly get an idea of his travelling options for going from Barcelona to Madrid, they could find a journey out of the seven that had an similar travel distance and get a first approach of the emissions that travelling causes, as well as how long does it take. However, as it has been repeated several times and can be seen at the flowchart, this is just an approximation to get a rapid idea with a first glance, for more accurate numbers other options have to be chosen. The distance is calculated using (Distance Calculator, n.d.).

Equivalencies Calculator

This tool, although not being strictly for the calculation of parameters that allow the passenger to compare their travelling options, it is a good idea to contextualise their emissions: the website shows daily activities that would produce the same carbon dioxide that the passenger introduced, which is the one calculated by previous tools of the flowchart depending on the journey, the airline and the aircraft. The existence of such tools is possible due to the high environmental awareness that has been risen in the recent times. It is located at the end of the path because it is needed that the passenger chose its travel option.

The functioning of the tool is very simple: the user has to enter the amount of emissions produced in the journey. The tool gives the possibility to use more than carbon dioxide, but since this flowchart is focused on CO_2, this will be the one the passenger will have to introduce. At the following image the initial menu can be seen.

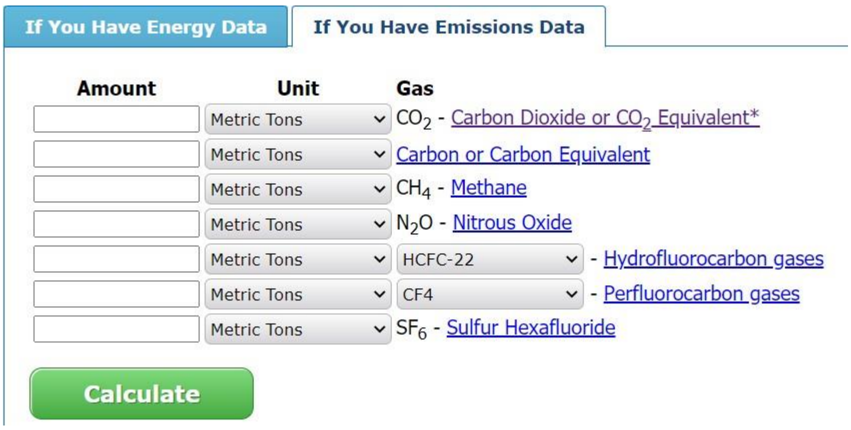


Figure 7.6 Initial menu of the carbon equivalencies calculator. Extracted from (EPA, 2020)

If, for instance, 1 metric tone of carbon dioxide is introduced (this corresponds to the first option), the following results are obtained:

Figure 7.7 Result of the equivalencies calculator. Extracted from (EPA, 2020)

This will be very useful because on the one hand, although being firm the decision of the passenger, it will help them to get an idea of their impact; and, on the other hand, it might help them to even change their decision by comparing the equivalencies with other travelling options.

Green Tripper

This website was already reviewed in Section 5.2.1, at the point of Brussels Airlines, since it is the method that the airline offers their passengers to offset their emissions. It is a good tool because allows to compare the most used means of transports for middle or long range journeys: planes, trains, buses, ships and cars. For first three ones, the emissions are calculated by entering the origin and destiny of the journey. For ships the introduced data is the distance or duration of the travel. Finally, for cars, as it can be seen at the following picture, the data the website asks for is the travelled km per year. In order to compute the actual emissions for one trip, the travelled km of the trip can be introduced instead.

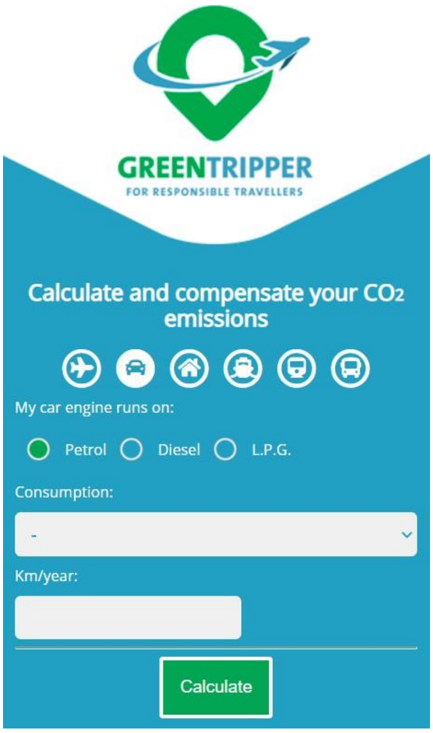


Figure 7.8 Example of the car option of GreenTripper. Extracted from (Greentripper, n.d.)

Because of the necessity of knowing the distance that separates two cities, the Distance Calculator is asked to be used in the previous step.

However, before continuing with the description of other tools it has to be remarked that for this purpose another website is also useful. Eco Passenger (Eco Passenger, 2020) is a tool that directly provides comparative graphs of the emissions produced when travelling. The problem is that this tool just functions for Europe. Nonetheless, it will be presented later in the Eco Table, since giving several options for a same purpose is more clear in a table than in a flowchart.

Flight Comparator

In order to be able to compare the different airlines and their aircraft, the first step is to know which possibilities the passenger has for its flight. This is an very common step, and most of travels would do it without even the necessity to ask them to do it, but as this flowchart reflects every step of the comparative process it has to be present. This is why the flowchart says "Flight Comparator" in general, because due to their wide variety, would have no sense proposing a specific one. Moreover, the comparison does not have to be necessarily performed via an search engine; the websites of each airline also offer the possibility to look for flights; the difference with this method is, however, that the user has to visit several ones and later compare the results.

However, if one had to be proposed, following the philosophy of raising environmental awareness, the motor (Flygreen, 2020b) can be a good option. As it was already reviewed in Section 5.2.1 this website is focused on finding the most environmentally-friendly flights while offsetting part of their emissions. However, it is not a close matter, because given the big amount of existing websites that allow to compare and find flight tickets, closing it to a single option would have no sense.

Aviability

When comparing flight tickets, some search engines will show the aircraft model that will be used, others however, will not. For this reason the flowchart has to provide passengers with a tool that lets them know which aircraft model is used in a certain flight. Aviability (Aviability, 2020) is a website that among other functions, shows the status of a flight if its number is introduced. It is interesting for this tool because among the several parameters that are shown, the aircraft model is one of them.

For example, if in (Google, n.d.) a Flight from Hamburg to Paris is searched for the 1st of July one of the proposed options is an Air France flight. In the case of this website, the aircraft model is also given. However, this will be ignored and just the flight number will be taken: AF1603. If this code is introduced in (Aviability, 2020) the following is obtained:

Figure 7.9 Result of the search by flight number in Aviability. Extracted from (Aviability, 2020)

It has to be taken in mind that this tool is not the only one that fits this purpose. As it has been seen, some search engines already have the information of the aircraft model. Nonetheless, as it could have been not the case an alternative had to be offered.

Ecolabel

It is obvious to say that this tool will not be reviewed because this whole project revolves around it. Nonetheless, it is important to make a comment about the internet page to which the word ECOLABEL in the flowchart is linked. Since currently there is no public archive where multiple ecolabels can be found, the flowchart guides the user to the website of downloading of the project (Sokour et al., 2018). Their tool is so far the one that can provide with the largest number of ecolabels.

However, as it was seen at Section 7.1.1 when big deviations occurred in the flight route, the Ecolabel was not able to compare two aircraft accurately. This is why a method that solved this had to be used. As a consequence, a tool to serve this purpose will be introduced.

Flight Route Calculator

The Flight Route Calculator (Aviapages, n.d.), or Flight Route as it appears in the flowchart, is an online tools that allow the user to compute the flight distance between two locations with the possibility of impose avoiding to fly over a certain country.

It was seen at Section 7.1.1 that some flights that presented this problem were the ones going from Norway to China. According to (Wendover Productions, 2018), SAS is the only Scandinavian airline with the rights of flying across Siberia, although Norwegian Air is also asking for it. If an Oslo-Beijing flight of SAS was wanted to be compared with another one with same origin and destiny of Norwegian, the Ecolabel would not be enough to do so, since the flown distance difference could not be neglected. Here is where this tool has its purpose. To continue with this example, this flight will be searched on its website; it will be, on the one hand, specified to avoid Russia, and on the other hand, to follow the most optimal trajectory.

The online tool asks to introduce an aircraft model, date of flight and a certain number of passengers. This is used to compute the time of flight, but this parameter will not serve any purpose this time. Just for being able to continue, an Airbus A320-200 and 1 passenger for the 31st of July has been the selected data. These first two pictures will correspond to the option where is defined to avoid Russia, which would correspond to the one operated by Norwegian Air:

Figure 7.10 Distance result of the flight Oslo-Beijing avoiding Russia. Extracted from (Aviapages, n.d.)

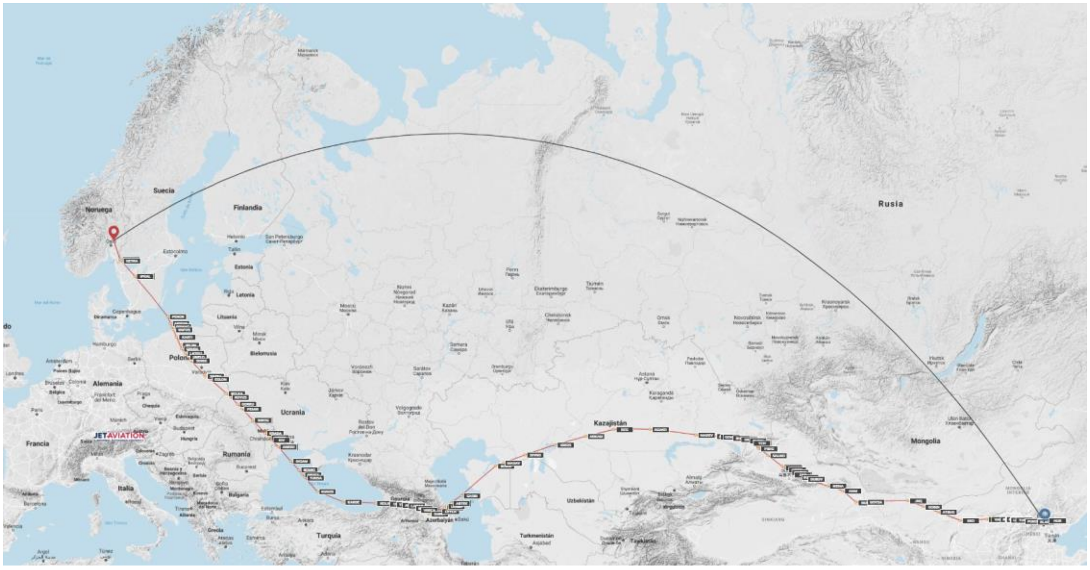


Figure 7.11 Trajectory result of the flight Oslo-Beijing avoiding Russia. Extracted from (Aviapages, n.d.)

As it can be seen at the last two images, two distances are presented: the one that corresponds to the airway, and the one that corresponds to the great circle. The latter is not relevant in this case, since planes do not fly following the exact surface of the sphere that represents the planet (which is the most optimal one). However it helps to get an idea of how different both are. Now, the same calculation will be repeated but for the flight that would correspond to SAS, which will not need to avoid Russia:

Figure 7.12 Distance result of the flight Oslo-Beijing without avoiding Russia. Extracted from (Aviapages, n.d.)

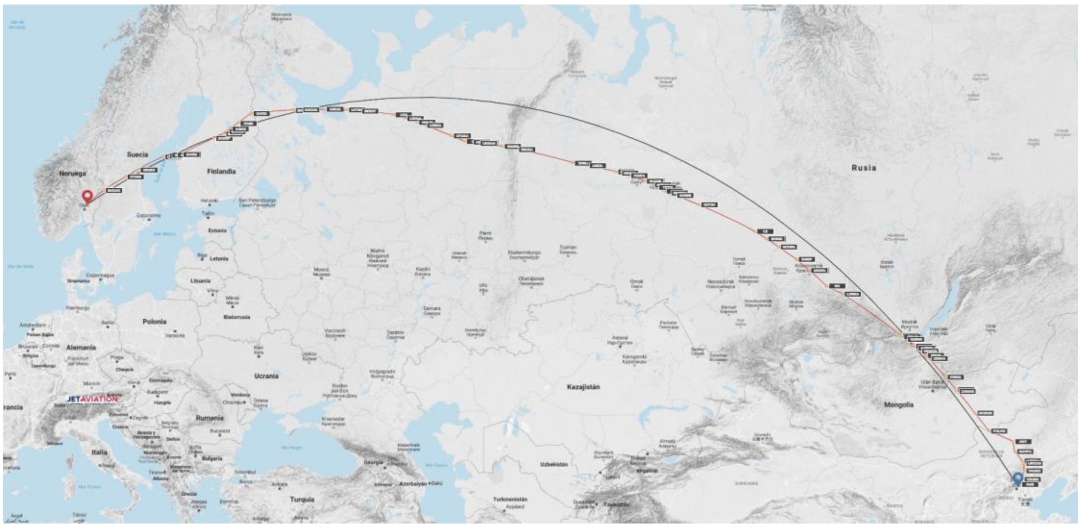


Figure 7.13 Trajectory result of the flight Oslo-Beijing without avoiding Russia. Extracted from (Aviapages, n.d.)

In the last two figures the airway distance, the actual flown by the airplane, and the one that connects with the shortest path the two points of the sphere is again shown. However, it can be seen very clealy that this time both of them are much more similar than in Figure 7.10 and Figure 7.11. This gives an idea of how much represents avoiding Russia: the difference of both airways distances is greater than 2000km, which equals to a higher fuel consumption.

Now that the tool has been understood it should be known what the user has to do: if they find that its airline has a travel restriction, which is very easy to know, since budget airlines are very likely to have them, they have to use this tool. The parameter "CO_2 equivalent emissions" is normalised with distance. In order to compare aircraft of both airlines, this metric should be multiplied by the respective distances given by (Aviapages, n.d.) and then compared. This procedure just allows to compare the carbon dioxide production. Afterwards it will be proposed for general purposes too. Although this is an approximation, since the CO_2 emissions together with the fuel consumption, the two variables that can participate here, account for a 60% of the environmental impacts, the approximation would be accurate enough.

It is important to understand the difference between this tool and (Distance Calculator, n.d.), described before: for the distance calculator a generic distance between two points is enough, since it just serves to choose a similar journey of Via Rail (Via Rail Canada, n.d.) or to introduce it as a by-road travelled distance in GreenTripper (Greentripper, n.d.). However, this time a generic metric is not enough: it is needed one given exclusively for flying journeys. This does not mean that this distance is 100% accurate and the result is so exact that can be used for other strict calculations, as eventually it will depend on the flight plan and the sky conditions of the day, but it is a sufficiently good approach to compare two aircraft.

Atmosfair

Atmosfair is the proposed tool for offsetting flight carbon emissions. This tool has been already extensively analysed. If its functioning wants to be seen again, Section 5.2 has to be consulted; in Figure 5.14 the beginning of the explanation can be read.

Atmosfair Index

The Atmosfair Index (Atmosfair, 2018b) is a ranking of airlines that evaluates them regarding their level of carbon emissions. As it can be seen in the flowhcart is proposed as a tie breaking method: given the case that two ecolabels from two different flights showed the same punctuation (which might happen if the aircraft and engine model were the same) the passengers would not know which option to choose. This is why the Atmosfair index is used: if two different airlines had the same aicraft, a good option could be to choose the most overall environmentally friendly airline, as the one with the greenest fleet should be rewarded. Nonetheless, this is just a brief introduction to this index. The topic of how environmentally friendly is an airline fleet is a very interesting topic, since it can not be forgotten that aicrafts are not isolated elements, they form part of a big fleet. This is why, the explanation of what this index consists on will be found on a later section focused on analysing how airline fleets should be treated. If the reader wants to consult this information, it can be found on Section 7.2.3.

Eco Transit

The analysis of this tool will be used now to explain the right branch of the flowchart. It could be the case that apart from individual passengers, people who want to transport goods, but not themselves, are interested in knowing the impacts of their journey. This is why this second branch is added. The range of people that could see it as useful is very varied: individuals that want to transport a single good or companies that need to contract services to perform the shipping of certain items. Whichever the case is the options provided would suit them. Eco Transit (EcoTransit, n.d.) is a website that calculates the energy consumption and the emissions produced by transporting a certain amount of cargo from one city to another. The user has the possibility of choosing the amount of cargo that is transported, the origin and destiny and the means of transport to be reviewed. The results shown represent the average travel of each vehicle.

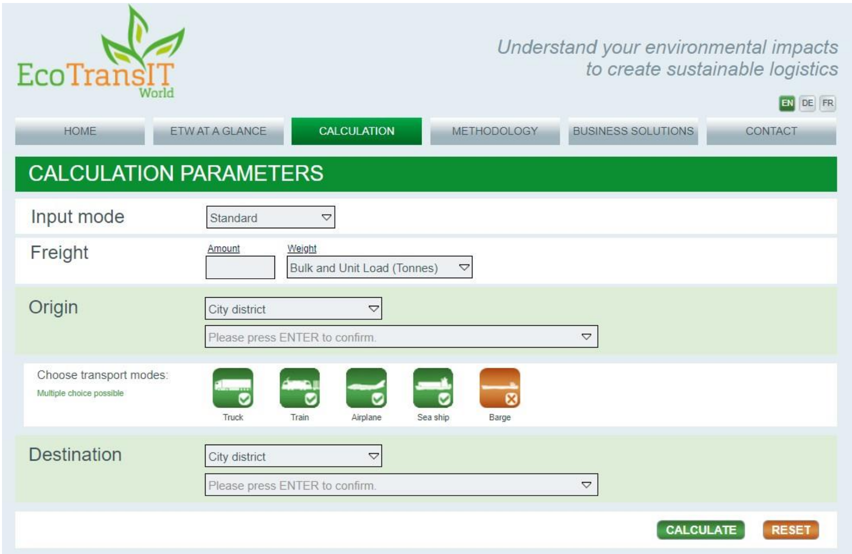
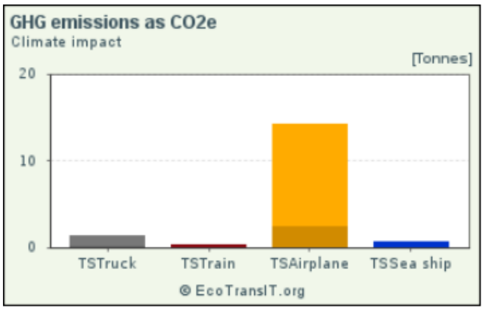


Figure 7.14 Initial menu of the Eco Transit tool. Extracted from (EcoTransit, n.d.)

For exemplification purposes, the results of a travel from Barcelona to Hamburg will be presented. The website displays several metrics, but since the flowchart is focused on carbon dioxide emissions, just the results of this specific variable will be shown now.



GHG emissions as CO2e (WTW)
Climate impact
[Tonnes]

	TSTruck	TSTrain	TSAirplane	TSSea ship
Truck	1.2947	0	0.0211	0.0098
Train	0	0.1999	0	0
Airplane	0	0	14.1374	0
Sea ship	0	0	0	0.5533
Sum:	**1.2947**	**0.1999**	**14.1586**	**0.5631**

© EcoTransIT.org

Figure 7.15 Result of carbon dioxide emissions of EcoTransit. Extracted from (EcoTransit, n.d.)

The outcome of the last figure is pretty well self-explanatory; no further comments will be needed. As it was said before, it has to be kept in mind that the results do not belong to an specific vehicle. This is why it has to be remembered that the results are just for a fist comparison, but cannot be used for strict calculations.

ICAO Fuel Saving

The last tool to be presented is the one that differentiates the most from the rest. The other tools did not allow to actually take specific decisions of the travel itself: they allowed the user to run certain calculations but just for comparison means. The obtained results had a generic character that could not be used for taking strict decisions, since they used mostly average data. This time, however, more exact results can be obtained, due to the specificity of the tool. The Icao Fuel Saving app (ICAO, 2016b) allows to take decisions regarding the flight plan itself in order to optimise it and eventually save fuel, which means emitting less as well. The userguide can be found at (ICAO, 2012).

A brief look at the tool menus will be taken now. The first step consists on defining the name of the operation that will be analysed, this can be seen at the following image;

Figure 7.16 First step of the ICAO Fuel Saving tool. Extracted from (ICAO, 2016b)

As it can be seen at the previous image the functioning of the tool is based on defining two operations, one old one and another new one: the goal is trying to make the new one more efficient than the old one. Once the analysis that will be performed is named the user can start to specify it. The type of operation can be chosen between taxiing, climbing, leveling or descending. The parameters to be chosen vary from one action to another, but they are the initial and final altitude, the flown distance and the time it takes. Once they are defined the results of fuel consumption are obtained. The example of the userguide will be taken:

Firstly, a graph that describes the old procedure is plot, along with the starting and ending points of each segment. This can be seen at the following image:

Step 3 - Estimated Fuel Changes Report

Scenario Name: Test

Distance (nm)	Altitude (ft)
0	35000
65.23	11000
85.23	11000
109.24	3000
119.24	3000

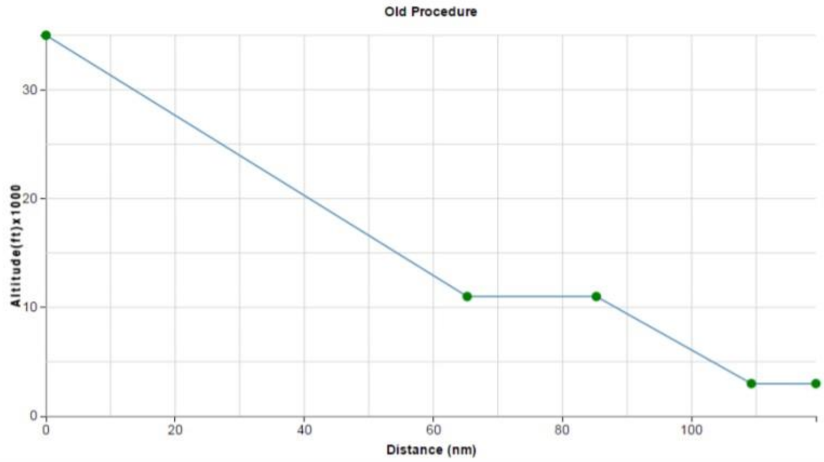


Figure 7.17 Data of the old procedure. Extracted from (ICAO, 2012)

An analogous graph is plotted for the new procedure.

Distance (nm)	Altitude (ft)
0	35000
30	35000
119.24	3000

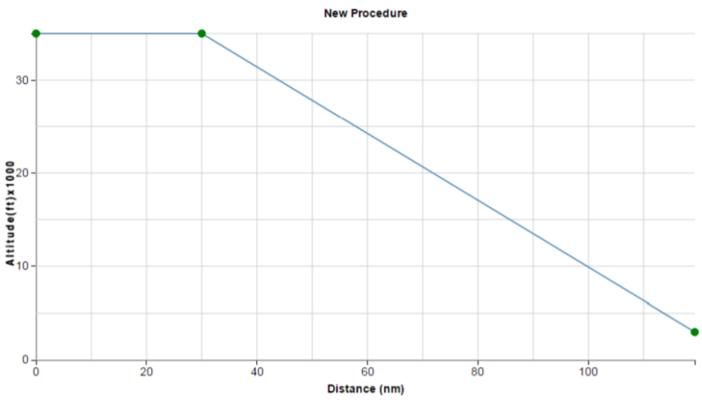


Figure 7.18 Data of the new procedure. Extracted from (ICAO, 2012)

Finally, a table that collects the data consumption for both procedures can be seen. This allows to understand how much more efficient the new procedure is compared to the old one.

The user can see in a graphical form the distance and altitude associated with the old and new procedures for each scenario defined by the user. The distance is indicated in the X axis and the altitude in the Y axis.

Estimated Fuel Changes Report

Scenario Name	Old Fuel Consumption (KG)	New Fuel Consumption (KG)	Savings (KG)	Savings (%)
Test	600	200	-400	-67.10

Estimated Detailed Fuel Changes Report

Old Climb Fuel (KG)	New Climb Fuel (KG)	Climb Savings (KG)
0	0	0

Old Descent Fuel (KG)	New Descent Fuel (KG)	Descent Savings (KG)
200	200	0

Old Level Fuel (KG)	New Level Fuel (KG)	Level Savings (KG)
400	0	-400

Old Taxi Fuel (KG)	New Taxi Fuel (KG)	Taxi Savings (KG)
0	0	0

Back Export to Excel

Copyright 2011-2016 ICAO.

Figure 7.19 Table that collects the fuel savings. Extracted from (ICAO, 2012)

By looking at the results of the table the user can determine how much better the new decision for the flight plan has been. Now that the tool has been reviewed it can be better understood why it appears at the branch of "Carriers" and not "Passengers" on the flowchart. It is a tool that is just useful for people who have a certain control on the flight definition, and passengers do not have this decision power on their hands. However, it might be the case that companies that perform shipping of goods have certain control over how the flight is planned, since they participate in the technical aspects of the travel.

7.2.2 Eco Table

Now that the explanation of the last tool, the CO_2 Flowchart has been ended, the other informative method can be now reviewed. It was stated before that the carbon dioxide emissions and fuel consumption was one of the most important metrics in the process of analysing the environmentally-friendliness of a transport mean. This is why a tool exclusively for that was created. However, it is important to not forget that they are not the only ones; another tool with a more global character is needed: here is where the Eco Table appears.

Before looking at the tool itself and starting with its review, a similar comment to the one that can be found before the CO_2 Flowchart will be again made. If the Eco Table was real, it would have to each of the name that appear in several cells the link to the corresponding tool linked. However, when embedding the Eco Table pdf file to the general file of the thesis, these links are lost. This is why a list will be presented beforehand with the names of the tools and its respective links. For easing the search of a tool, the list will be alphabetically ordered:

- **Atmosfair:** click here to access to the website.
- **Atmosfair Index:** click here to access to the website.
- **Aviability:** click here to access to the website.
- **Distance Calculator:** click here to access to the website.
- **Ecolabel:** click here to access to the website.
- **Eco Passenger:** click here to access to the website.
- **Eco Transit:** click here to access to the website.
- **European Emission Standards (EES):** click here to access to the website.
- **Equivalencies Calculator:** click here to access to the website.
- **Flight Route Calculator:** click here to access to the website.
- **Flysas:** click here to access to the website.
- **Green Tripper:** click here to access to the website.
- **ICAO Carbon Emissions Calculator:** click here to access to the website.
- **ICAO Fuel Saving:** click here to access to the website.

The Eco Table is the following:

ECO TABLE

	SUBJECT	ACTION	Fuel consumption	Noise levels	CO_2 emissions	NO_x emissions	Overall efficiency	Route
EXACT	Aircraft/s	Calculate	Ecolabel	Ecolabel	Ecolabel	Ecolabel	Ecolabel	
		Compare	Ecolabel	Ecolabel	Ecolabel	Ecolabel	Ecolabel	
	Vehicles	Compare	Ecolabel **vs** Specs**		Ecolabel **vs** Specs**	Flysas*/FRC **vs** EES**	Ecolabel **vs** Energy Label***	
	Airlines	Compare			Atmosfair Index			
	Specific flight/s	Calculate	Ecolabel **x** FRC		Ecolabel **x** FRC	Flysas*		
		Compare	Ecolabel **x** FRC		Ecolabel **x** FRC	Flysas*		
		Contextualize			Equivalencies Calc			
		Decide						ICAO Fuel Saving
		Offset			Atmosfair			
ESTIMATED	Average flight/s	Calculate	ICAO Calc		ICAO Calc	Eco Passenger		
		Compare	ICAO Calc		ICAO Calc	Eco Passenger		
		Contextualize	Equivalencies Calc		Equivalencies Calc			
		Offset			Atmosfair			
	Average journeys	Compare	Eco Passenger		GreenTripper	Eco Passenger		
		Contextualize	Equivalencies Calc		Equivalencies Calc			
		Offset			GreenTripper			
	SUBJECT	ACTION	OBJECT					

LEGEND

(blue)	Manual comparison	*	Just if aircraft model coincides
(green)	Just available in Europe	**	Check manufacturer specifications
(peach)	No specific restriction	***	Might not be available

As it has been briefly explained before, the Eco Table is thought for performing quick analysis, targeting directly the metric that is willing to be studied, instead of following a guided path with a single forward direction. Although being the way of using it much different from the CO_2 Flowchart, both tools share most of the websites that have been reviewed since then. This is why now that the functioning of the table will be explained: just the different proposed tools will be described. Moreover, as it can be seen under the Table, there is a small legend that contains clarifications for the symbols and colors that appear all over the tool. Although it is pretty self explanatory, they will be explained together with some tools where they can be found.

Nonetheless, before starting to review the tools that appear in each cell, the overall philosophy of the Eco Table should be commented. As it can be seen, the rows are divided in two main categories, "Exact" and "Estimated". This refers to the type of calculations that are performed. The columns are divided into "Subject", "Action" and "Object", which is referred to which item participates in the analysis, in which way and with what metric. Having understood this, it is easy to see why there rows can be "Exact" or "Estimated". At this point several environmental tools have been reviewed, and it has been made clear which ones refer to particular aircraft, such as the Ecolabel, and which ones calculate an approximated result, such as (Greentripper, n.d.), which when computing the pollution for a flight uses an average of the existing aircraft that perform that flight. The estimated options can be very useful if just a quick analysis is needed. Having that made clear, the review of the tools can start.

It is also important to remark that in both "Exact" and "Estimated" categories the first two Subjects are analogous: the first one is just focused on aviation (aircraft and flights) and the second one is generic for all transport means (vehicles and journeys): it can be seen how they are paired. However, the third Subject in the Exact category has not its ampliation to a non-focused one: searching for tools that allow specific analysis of other transport such as cars would imply a level of accuracy that falls out from the scope of this thesis, which has to be remembered that its central topic is aviation. Being said that, the review can begin. The order in which the options will be presented will be from the uppermost leftmost corner to the bottom-most rightmost corner.

Specs (Specifications)

This tool, as it is stated with ** in the legend refers to the specifications provided by the manufacturer of the vehicle. Fuel consumption and CO_2 emissions are the two metrics that concern the most the population, so they are always given by the manufacturers.

In this case, when the specifications of a vehicle are compared with the Ecolabel of an aircraft (which in fact reflects its specifications) the comparison has to be performed manually: there is no tool that displays both at the same time, the user has to search both separately and then compare them themselves. This is why the cell is painted in blue, as it is well reflected in the legend.

However, the user has to be aware if the emissions of both vehicles are given in the same context. If not, the comparison might not be able to take place.

European Emission Standards (EES)

The European Emission Standards, according to (Wikipedia, 2020f), has the following objective:

> *European emission standards define the acceptable limits for exhaust emissions of new vehicles sold in the European Union and EEA (European Economic Area) member states. The emission standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards.*

This classification presents six levels (from Euro 1 to Euro 6 with some subcategories named using letters starting with "a"). Each category provides emission limits whose vehicles have to comply. The data that will be used will be the column of nitrogen oxides emissions.

In most of vehicles specifications tables, such as the ones of cars or buses, the level of European Emission Standards that it satisfies is given. The following table collects the emissions limits for light commercial vehicles under 1305kg, where the data is given in g/km:

Tier	Date (Type Approval)	Date (First Registration)	CO	THC	NMHC	NO_x	$HC+NO_x$	PM	PN [#/km]
Diesel									
Euro 1	October 1993	October 1994	6.9	-	-	-	1.7	0.25	-
Euro 2	January 1998	October 1999	1.5	-	-	-	1.2	0.17	-
Euro 3	January 2001	January 2002	0.95	-	-	0.78	0.86	0.10	-
Euro 4	January 2006	January 2007	0.74	-	-	0.39	0.46	0.06	-
Euro 5a	September 2010	January 2012	0.740	-	-	0.280	0.350	0.005	-
Euro 5b	September 2011	January 2013	0.740	-	-	0.280	0.350	0.0045	6×10^{11}
Euro 6b	September 2015	September 2016	0.740	-	-	0.125	0.215	0.0045	6×10^{11}
Euro 6c	-	September 2019	0.740	-	-	0.125	0.215	0.0045	6×10^{11}
Euro 6d-Temp	September 2018	September 2020	0.740	-	-	0.125	0.215	0.0045	6×10^{11}
Euro 6d	January 2021	January 2022	0.740	-	-	0.125	0.215	0.0045	6×10^{11}
Petrol (Gasoline)									
Euro 1	October 1993	October 1994	6.9	-	-	-	1.7	-	-
Euro 2	January 1998	October 1999	5.0	-	-	-	0.7	-	-
Euro 3	January 2001	January 2002	5.22	0.29	-	0.21	-	-	-
Euro 4	January 2006	January 2007	2.27	0.16	-	0.11	-	-	-
Euro 5a	September 2010	January 2012	2.270	0.160	0.108	0.082	-	0.005*	-
Euro 5b	September 2011	January 2013	2.270	0.160	0.108	0.082	-	0.0045*	-
Euro 6b	September 2015	September 2016	2.270	0.160	0.108	0.082	-	0.0045*	6×10^{11}
Euro 6c	-	September 2019	2.270	0.160	0.108	0.082	-	0.0045*	6×10^{11}
Euro 6d-Temp	September 2018	September 2020	2.270	0.160	0.108	0.082	-	0.0045*	6×10^{11}
Euro 6d	January 2021	January 2021	2.270	0.160	0.108	0.082	-	0.0045*	6×10^{11}

* Applies only to vehicles with direct injection engines

Figure 7.20 Table that collects the European Emission Standards for light commercial vehicles under 1305kg,in g/km. Extracted from (Wikipedia, 2020f)

The problem with this table is that its data is expressed in g/km, which means that it expresses the amount of nitrogen oxides the vehicle emits while travelling. It could be thought that the section of nitrogen oxides of the Ecolabel could be used to compare the nitrogen oxide emissions of aircraft and other vehicles. However, the problem is that the Ecolabel expresses the NO_x emissions in g/kN, since they are referred to the amount of emissions during the LTO cycle, not the emissions normalised by the travelled distance. This makes impossible to use the Ecolabel, since no analogous metric for the LTO cycle can be found in other vehicles. This is why the calculator of Flysas has to be used, which will be explained in the next point.

Flysas

The Flysas calculator was already reviewed at Section 5.2.1. The good thing about it is that it gives the NO_x emissions, which is something very rare in Airline emissions calculators. The other advantage of it is that it allows to choose between different aircraft models. This can be seen again at Figure 5.6. If the right aircraft is chosen and the amount of emissions divided by the distance calculated by (Aviapages, n.d.), a number comparable to the one provided by (Wikipedia, 2020f) can be obtained.

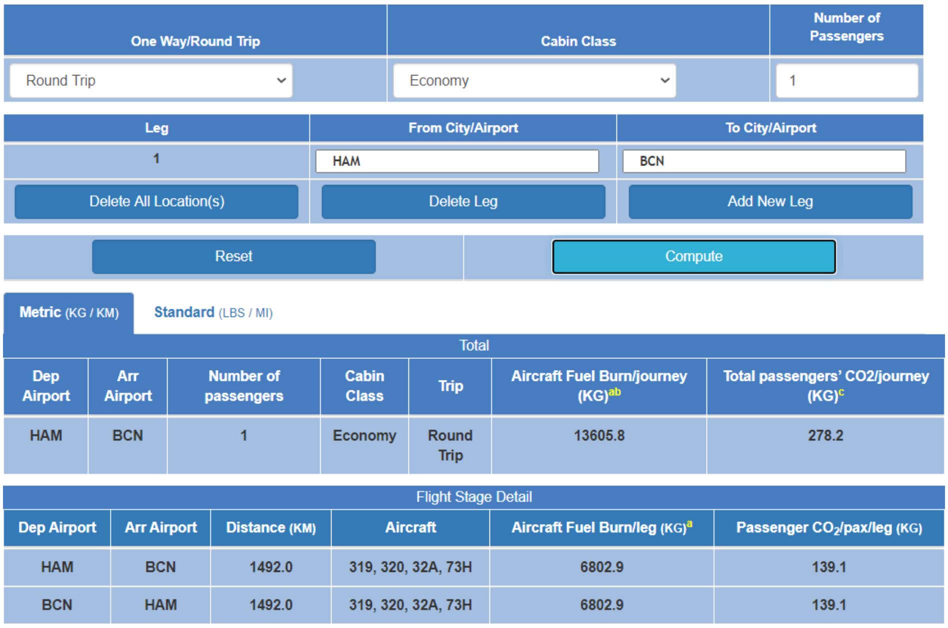
However, there are three problems that can be found about this procedure. On the first hand, the NO_x emissions depend on the engine model, and the Flysas calculator does not allow to choose between different ones; although knowing this will serve for comparisons and not for strict calculations, it has to be kept in mind that inaccuracies will be found, however, since the metric probably comes from an average of the used engines or from the most common ones, the result might not be extremely far from reality. On the other hand, this comparison appears in the row of "Vehicles", not "Journeys", which means that although the flight should not have any role in it, for using (Aviapages, n.d.) a given flight will have to be selected; in order to have the most accurate results as possible, the user should select a flight with a distance similar to the journey for which they have in mind using the other vehicle of the comparison. Finally, as the legend states with ***, there might be the possibility that the user does not find the aircraft model they are looking for, since (SAS, 2020a) is very likely to just have in its database the aircraft that the own airline uses.

Energy Label

This tool appears in the table but being aware that in the present is very difficult to use it. As it is stated in the legend with ***, this tool might not be available. It was already seen several times that the Energy Label in the European Union is mandatory for household appliances, but not vehicles. Although some examples can be found for different countries, manufacturers are not obligated to show them. This means that there is no single standard under which all Energy Labels for vehicles are calculated, and adding the fact that the Aviation Ecolabel is designed as well under different standards, right now the comparison is not possible. However it is reflected in the table as a way of making think the user that it can be possible in the future if a global standard for vehicle Energy efficiency labels is created.

ICAO Carbon Emissions Calculator

The ICAO Carbon Emissions Calculator (ICAO, 2016a), as it name says, is a calculator provided by ICAO that allow the passenger to compute the carbon emissions and fuel consumption generated by flying from one airport to another. Although this is not as specific as using the Ecolabel, it gives a rapid response while using a reliable source of information. As it has been done several times during this work, a flight example between Hamburg and Barcelona will be shown.



Total						
Dep Airport	Arr Airport	Number of passengers	Cabin Class	Trip	Aircraft Fuel Burn/journey (KG)[ab]	Total passengers' CO2/journey (KG)[c]
HAM	BCN	1	Economy	Round Trip	13605.8	278.2

Flight Stage Detail					
Dep Airport	Arr Airport	Distance (KM)	Aircraft	Aircraft Fuel Burn/leg (KG)[a]	Passenger CO_2/pax/leg (KG)
HAM	BCN	1492.0	319, 320, 32A, 73H	6802.9	139.1
BCN	HAM	1492.0	319, 320, 32A, 73H	6802.9	139.1

Figure 7.21 Table that collects the results of the emissions generated in a Barcelona-Hamburg flight. Extracted from (ICAO, 2016a)

One of the interesting aspects of this online tool is that the results it displays are an average of the most common used aircraft for the route, which unlike other tools, which do not show for which models the results are. This implies a higher level of trustworthiness.

Eco Passenger

Eco Passenger (Eco Passenger, 2020) will be the last tool of the Eco Table to be reviewed. This website offers a very interesting and complete emissions calculator. Its only problem, as the green colour of the legend says, that its calculations are only available for inside-Europe journeys. However, because of its high potential it has been decided to be used anyway. In case a comparison of travels outside Europe wanted to be reviewed, journeys with similar distances could be taken as a reference.

GreenTripper (Greentripper, n.d.) is also a good option when it comes to compare average journeys of different transport means. As an advantage it has the possibility of calculation ships emissions, but as a drawback, that specific vehicles models can not be defined. This is why Eco Passenger has been chosen for Fuel Consumption and Nitrogen oxides Emissions.

Again, a flight example between Barcelona and Hamburg will be used to see how the tool is operated.

In the first menu the website just asks for the the locations of departure and arrival, as well as their corresponding dates. After this the emission results are displayed. These results belong to pre-established vehicle models. However, these can be changed as it is shown in the following image:

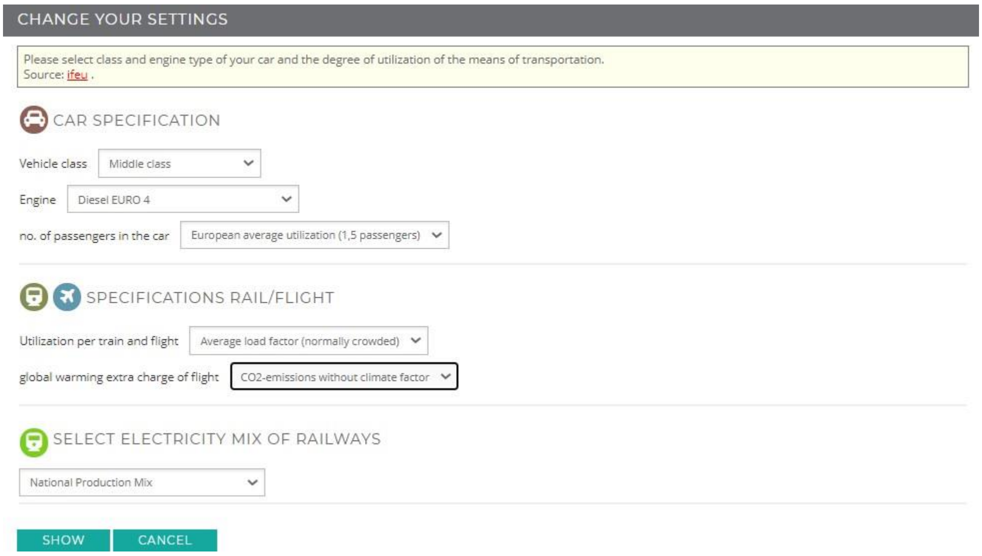


Figure 7.22 Menu of vehicles options. Extracted from (Eco Passenger, 2020)

When the user decides if the pre-entered options suit their journey or any change has to be applied, the results can be finally analysed. The two following images show how the emissions data is shown, both in form of graphs and a table:

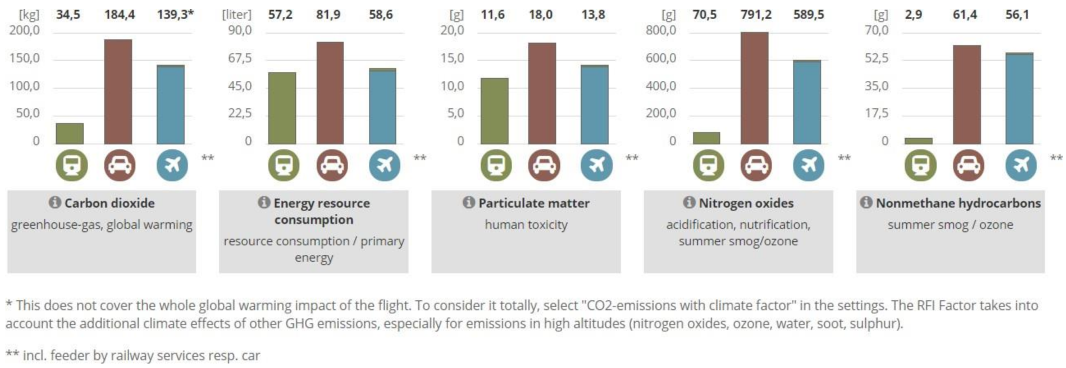


Figure 7.23 Graphs of journey emissions by transport mean. Extracted from (Eco Passenger, 2020)

			incl. transport to and from the airport		
COMPONENT	Train	Car	Train	Aircraft	Sum
Carbon dioxide *kilograms*	34,5	184,4	0,78	138,5	**139,3**
Energy resource consumption *liter gasoline equivalent*	57,2	81,9	0,46	58,2	**58,6**
Particulate matter *grams*	11,6	18,0	0,17	13,6	**13,8**
Nitrogen oxides *grams*	70,5	791,2	1,4	588,2	**589,5**
Nonmethane hydrocarbons *grams*	2,9	61,4	0,06	56,1	**56,1**

Source: ifeu (except railway mix including Green Certificates)
Source railways mix: Sustainable Development Foundation based on UIC data

Print

Figure 7.24 Table of journey emissions. Extracted from (Eco Passenger, 2020)

Although several metrics are shown, for the Eco Table, the ones that have to be looked at are the Energy Consumption and Nitrogen oxides emissions

Noise Considerations

As it can be observed in the Eco Table when it comes to the noise, just between aircraft comparisons and calculations are provided. Even in the case of the overall efficiency an hypothetical future comparison is proposed if an Ecolabel under a common standard was designed for all vehicles. However in the noise is more difficult. At Section 2.2 the several noise sources of different vehicles were described. There it was seen how different they were: the noise of aircraft just is relevant if the flight path crosses a city, whereas the noise of cars and trains although being quieter is more constant since their infrastructures are built inside cities, finally, in case of ships, horns are not the biggest problem, but the noise pollution inside water that animals suffer. Since the context where the noise pollution in each case happens is so different a common calculation standard is difficult to be reached. However, there have been different articles written that try to address this difficult comparison. They will be now just briefly reviewed.

– **Noise annoyance of airplanes and high-speed trains:** in (Soeta et al., 2009) a comparison between the perceived noise of these two means of transport when the passenger is travelling inside them was made. Although this is not the most common definition that is given to noise pollution, the results extracted from this article can be interesting, because this noise annoyance is actually lived by the passenger. High-speed trains are one of the most popular alternatives to flying and one of the most equivalent ones in terms of journey duration. After several calculations it was determined that the noise of high-speed trains could be more annoying than the one coming from aircraft.

– **Sleep disturbance by airplanes, railways and roadways noise:** in (Perron et al., 2016) was studied the sleep disturbance linked to these noise sources. The study was carried out in Montreal, and it was determined that this is a serious health problem in the city. It concluded that those who were exposed to more than one noise source tended to present worse sleep problems, as it could have been expected. The results of the comparison between noise sources can be seen at the following image.

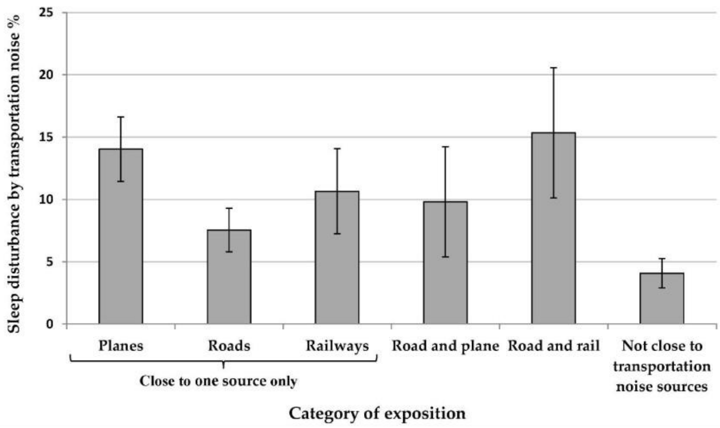


Figure 7.25 Graphic of level of noise annoyance depending the source. Extracted from (Perron et al., 2016)

After running several models, calculations and surveys the past results were found. The noise pollution is focused on sleep disturbance because it is one of its most serious effects in the life quality of a community. The results are pretty self explanatory: airplanes stand as the most disturbing individual noise source followed by railways. This result can seem to differ from the previous article, but (Soeta et al., 2009) did not talk about sleep disturbance, but as noise annoyance when passengers are inside of the vehicles.

– **Annoyance differences in front of continuous and intermittent noises of airplanes, railways and roadways:** in (Brink et al., 2019) a study was performed to study how people responded in front of the noise of airplanes, railways and roadways in terms of annoyance, focusing of the intermittent or continuous character of these noises. A sample of Swiss population was used to perform the study, in which surveys were asked to be answered. It was found that aircraft noise was the most annoying noise, followed by railway and roadway noise. However, it was also determined that railway noise was more annoying than is usually considered. Moreover, intermittent noises were concluded to be less annoying, even if a very loud noise happened, as long as it was followed by a calm period.

After reviewing these three articles it can be determined that aircraft are probably the most annoying sources of sound. However, the studies where always carried out in the framework of proximity to the noise source. It is true that when someone lives near an airport or under the flight path of aircraft suffers the consequences more severely. However, it is not that common to live in such conditions, but to reside near a railway or a busy road is. This is why no firm conclusion can be extracted, since as it was explained before, the contexts where the different means of transport are found are very different.

The explanation of the functioning of the two proposed systematics has already finished. With the use of the CO_2 Flowchart and the Eco Table the passenger is pretended to be best informed about the environmental impacts of their journey. It has to be remarked the practical application these tools have, since until now if someone tried to compare their travelling options based on the environmental impacts they would have found a huge disordered amount of options on the internet. This is a problem that is seen more and more over the years: although the information is online, is difficult to filter what is important and what is not. These two tools are so useful because a selection of the most efficient options has been made

7.2.3 Fleets Comparison

As a last tool proposal, methods to compare airline fleets will be explained. Actually some of them could conform a systematic on its own at the same level of the CO_2 Flowchart and the Eco Table. There are some proposals with a high degree of maturity, such as the Atmosfair Index, which will be the one on which the section will be focused. The philosophy in all of them is different compared to the previous ones. They do not allow to make specific flight or aircraft comparisons, since they compare airlines fleets between each other. It has been taken advantage of this characteristic to make it appear in bigger tools, such as in the CO_2 Flowchart and in the Ecotable in the case of the Atmosfair Index or inside the Ecolabel in the case of the Overall Fleet Grading of (Sokour et al., 2018), although this last one is just a future recommendation.

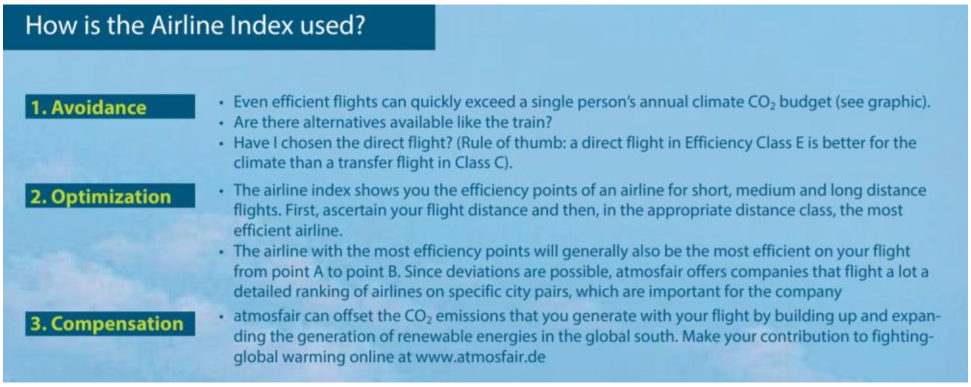
It has to be born in mind that the actual tool systematic proposal is consulting the Atmosfair Index. The Overall Fleet Grading of the Ecolabel will be shown as well due to belonging to the same field of interest, but it is neither as big nor as mature as the Atmosfair Index.

Atmosfair Index

The tool that will be reviewed will be the Atmosfair Airline Index (Atmosfair, 2018b). This tool was included in bot the CO_2 Flowchart and in the Eco Table as a tie breaking method when two aircraft or flights are graded equally: then it is advised to use the one that belongs to a more environmentally friendly airline. However, this Index is mature enough to be reviewed and proposed as an individual tool if general and quick criteria for taking a decision is wanted. Although it can work inside a bigger system, it can be proposed as an independent system for the passenger to be informed about the environmental of their flight. The passenger could decide which flight to take based on the environmentally evaluation of the whole fleet of the airline which they fly: it might not be the most accurate argument, but it is still better than to considering the environmental impacts at all.

This is why it has been presented separately and not in the same level of the CO_2 Flowhcart and the Ecolabel. As it is inside other systematics it can not be on the same level, but at the same time is more important than the other smaller tools, because it can work as a comparison systematic on its own.

The actual index can be found in a document provided in Atmosfair website, (Atmosfair, 2018b), which is called "Atmosfair airline index 2018 English (Atmosfair, 2018a). There, a very brief explanation of the Index functioning can be read. Therefore, instead of rephrasing it, the actual description provided by Atmosfair will be shown in form of screenshot of the document section where it appears.



How is the Airline Index used?

1. Avoidance
- Even efficient flights can quickly exceed a single person's annual climate CO_2 budget (see graphic).
- Are there alternatives available like the train?
- Have I chosen the direct flight? (Rule of thumb: a direct flight in Efficiency Class E is better for the climate than a transfer flight in Class C).

2. Optimization
- The airline index shows you the efficiency points of an airline for short, medium and long distance flights. First, ascertain your flight distance and then, in the appropriate distance class, the most efficient airline.
- The airline with the most efficiency points will generally also be the most efficient on your flight from point A to point B. Since deviations are possible, atmosfair offers companies that flight a lot a detailed ranking of airlines on specific city pairs, which are important for the company

3. Compensation
- atmosfair can offset the CO_2 emissions that you generate with your flight by building up and expanding the generation of renewable energies in the global south. Make your contribution to fighting-global warming online at www.atmosfair.de

Figure 7.26 Summary of the Airline Index instructions. Extracted from (Atmosfair, 2018a)

The advantage of this index is that it is very complete. Several rankings are shown to allow the passenger to have different perspectives. The different ways in which the information is displayed will be reviewed.

Firstly, Atmosfair shows three main classifications: one with the biggest airlines that perform short haul flights (up to 800km), medium haul flights (from 800km up to 3800km) and long haul flights (more than 3800km). Each of this three categories is split in 7 ranks, ordered from A (the best rank) to G (the worst one). Each of them shows a maximum of 5 airlines, which correspond to the five largest ones of the given rank; This is why it has been said that each classification corresponds to the biggest airlines of each of the three distance hauls. An example of the short haul classification will be provided in the form of screenshot of (Atmosfair, 2018a). In this case, as it can be seen in the cite, the Index of 2018 will be displayed, as it is the most recent one.

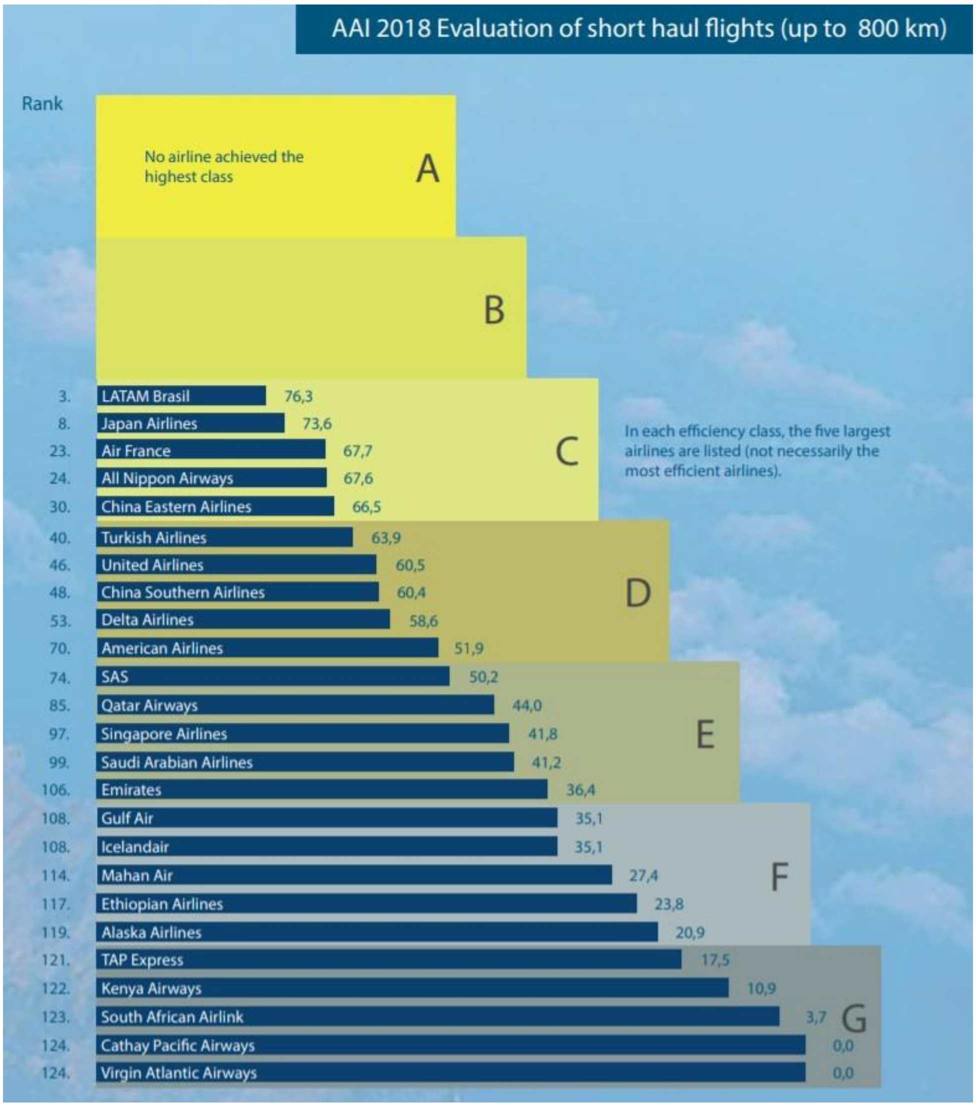


Figure 7.27 AAI 2018 Evaluation of short haul flights (up to 800km). Extracted from (Atmosfair, 2018a)

It can be seen how next to every airline name there are two numbers: the one on the right corresponds to the overall airline rank (this rank will be explained later) and the one on the left corresponds to the efficiency points that are used to evaluate each aircraft. It has to be noted that higher efficiency points means higher efficiency.

The numbers that are located on the right next to each airline label are the ones used to build the overall rankings. These overall rankings are displayed in form of tables. It has been said rankings in plural and not in singular because again, three classifications are provided. The first one is the main one, where the majority of airlines are found. Most of the airlines that appear in this classification perform short, medium and long haul flights, and they perform differently in each flight type: therefore, a different ranking is assigned each of them. Furthermore, an overall ranking that takes all the parameters into account is also displayed. In the second table, carriers are found. Finally, the third one is composed by regional carriers.

It is important to remark that not only letter-based overall rankings are shown: since the tables show more detailed rankings than the first indexes, other parameters can be seen. Apart from this A-F grade, the country where the airline is based, points used for evaluating the efficiency of the aircraft, the airline type and the number of passengers in millions are shown; all this information is presented together with an overall ranking position. Moreover, as it has been already commented, distance-based ranking information is also given, where specific parameters such as the efficiency points, the A-F grade (which is called efficiency class) and the distance-specific ranking position. Is this ranking position which is used for ordering the airlines in the first three index. A fragment of this table will be shown for improving its understanding.

Ranking in detail (1)

Overall ranking								Distance-based ranking: <800 km			800-3800 km			>3800 km		
Rank	Airline	Country	EP* '18	EP* '17	EK*	Type*	Pax (in Mio.)*	EP*	EK*	Rank	EP*	EK*	Rank	EP*	EK*	Rank
1	TUI Airways	UK	79,3	78,9	B	Charter	10,9	69,1	C	17	79,4	B	2	79,2	B	1
2	LATAM Airlines Brasil[1]	Brasilien	78,8	72,3	B	Net Carrier	33,8	76,3	C	3	82,2	B	1	66,0	C	18
3	China West Air	China	77,8	78,6	C	Regional	7,2	76,7	C	2	77,9	C	4			
4	TUIfly	Deutschland	77,6	78,2	C	Charter	4,6	72,9	C	10	77,7	C	5	76,3	C	3
5	Transavia.com France	Frankreich	76,3	-	C	Charter	5,1	77,8	C	1	76,3	C	7	73,8	C	4
6	SunExpress	Türkei	74,9	-	C	Charter	6,3	39,8	E	101	74,9	C	9			
7	Thomas Cook Airlines	UK	74,7	72,9	C	Charter	6,6	54,5	D	64	78,6	B	3	68,8	C	9
8	Air Europa Express	Spanien	73,4	-	C	Regional	0,2	73,4	C	9						
9	Condor Flugdienst	Deutschland	71,8	72,9	C	Charter	7,3	42,9	E	92	77,6	C	6	65,7	C	20
10	Juneyao Airlines	China	70,9	61,6	C	Net Carrier	13,3	69,4	C	15	71,0	C	15			

Figure 7.28 Ranking in detail of the Atmosfair Index airlines. Extracted from (Atmosfair, 2018a)

Similar type of information is provided in the second and third table, without having distance-specific parameters. The efficiency points are also shown for several years.

Finally, low cost carriers are presented in a different table, without any parameters, just the alphabetical classification.

Apart from indexes and the tables use for classifying and rating the airlines, other information is provided. A list with some airlines and the specific points that make them win or lose efficiency points and the reasons why this happens. This reasoning is based on the used aircraft models, the seat layout configuration or the route type.

In order to use this tool, the passenger only needs to find the airline with which wants to fly and see what position has in the ranking. One main advantage of this index is the fair treatment is given to compare short and long haul flights. It is logic that if just the metric CO_2/km is compared, short haul flights see themselves in a worse position: both short and long haul ones have to emit the same amount of carbon dioxides during the LTO cycle, but long distance flights make more of this situation, since for the same amount of emissions during take-off and landing, they end up flying more. This is why a curve is used to compensate the situation: qualitatively speaking, short flights have it easier to achieve higher efficiency points. This can be seen at the following image:

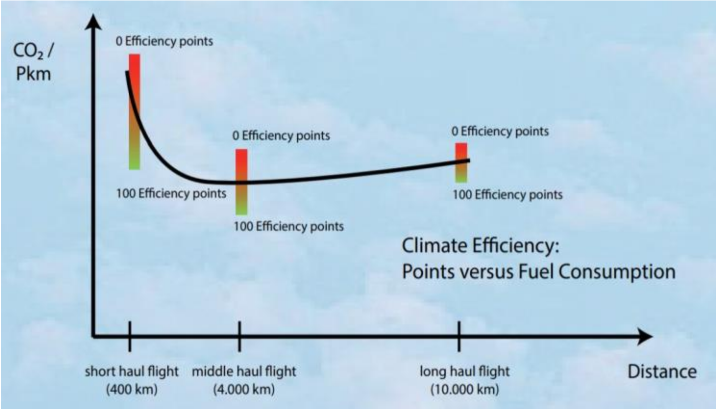


Figure 7.29 Curve correction for unbiasedly compare short and long haul flights. Extracted from (Atmosfair, 2018a)

Although being the Atmosfair Index the main source of fleet comparison, and probably one of the most reliable ones, since as it is stated in its website, it uses ICAO calculation methods, there is another one. In (Sokour et al., 2018) a comparative study of the airline fleets was also performed. This will be addressed in the following point as a closure of the section

Ecolabel Airline Rating

The Atmosfair Index was not the only initative to evaluate an airline as a whole. At (Sokour et al., 2018), once the ecolabels were calculated and the aircraft grades obtained, an average was computed to evaluate the whole fleet. Considering the aircraft that belonged to the airline, an overall evaluation was obtained. The quantity of aircraft of each model and their numbers of seat are used to calculate the average grade. This has sense, since an aircraft that transports more people should have a higher weight in the average than other with less.

If the Ecolabel was a tool mature enough this grade could be added as well. However this should only be made when the scheme was well established and mandatory to follow by all airlines. Then they would use the exact data of their fleet and all of them would have a grade, because it might happen nowadays that the exact fleet of an airline is not known.

Fleets Age

Although this is neither a systematic nor a tool, is a calculation that has been gaining more importance as the importance of the environmental awareness in the airline sector grows. A new aircraft could be thought to imply a greater overall efficiency, which is translated into less environmental impacts. Considering that it is easy to understand why the relevance of this factor. It signifies other things, such as more comfort for the passenger and new entertainment systems, but in this case this escapes from the interest of this thesis.

In (Loh, 2019) the age overall age of some airlines was presented. For example, the fleet of Norwegian Air is said to be 2.8 years old, and Emirates, 6.2 years old. However, this is not a parameter that can be considered in any ways for evaluating the environmental efficiency of an airline. It is not being said that in the article this was advised, this is just a warning for the reader in case they thought about it. Although at the beginning was said that new aircraft could mean more efficient aircraft this is not always the case. It is obvious that aircraft 30 years older than others should be less efficient, but when smaller age gaps are considered the higher or not efficiency can not be assured. This is why when comparing airlines, the evaluation of specific environmental metrics have to be considered, such as the carbon dioxide emissions in the Atmosfair Index or an average of carbon dioxide and nitrogen oxide emissions, fuel depletion and noise levels in the Ecolabel Airline Rating.

As a final conclusion, if the the environmental value of a fleet is willing to be consulted, it is recommended to use the Atmosfair Airline Index due to its maturity and bigger data sample. (Sokour et al., 2018) has deficiencis in both aspects, however this is normal, since a industrial project cannot be compared with an academic one. Although it is true that the Ecolabel Fleet Rating takes into consideration more factors than just carbon dioxide, since this (together with fuel depletion) its the most important metric, together with the maturity of the scheme makes it the best option.

8 Public Perception of Initiatives of Environmental Information

During all this thesis several analysis have been performed about different topics. How the public treatment that has been given to environmental impacts has evolved through the years has been reviewed from the perspective of society in general, in form of the public opinion. Moreover, several tools focused on this matter has been closely looked at: offsetting mechanisms, the ecolabel, the main tool that exists currently, and other environmentally informative methods. Regarding these tools, their functioning, their flaws and how they can be improved were reviewed. Exposing its deficiencies has been a very important point during this work, but doing this has not been enough.

It is important to remember that the goal of this thesis is to create something that informs the passenger about the environmental impacts of their flight. The opinion of the author of any of the thesis that have been written or that will be written on the subject will never be definitive if the general public does not approve it, because eventually they will be the ones that need to use these tools. This is why knowing the opinion of passengers that are non-experts on the matter about it is necessary to design the most efficient tool possible. Arrived at this point two paths are found: the first one is to search surveys about it on the internet, and the first one is to design one.

It is clear that the surveys that there might be on the internet are not specific enough. The energy label topic is very wide, and although it could cover some aspects, there will not be any survey that goes directly to the points that could answer the questions that have appeared thorugh this thesis. Moreover, the aviation ecolabel is a very recent topic and it has not spread enough yet. Although the concept of an energy label for the aviation industry has been introduced in some ocasions, the ecolabel developed in (Van Endert, 2017) is so new that there has not been sufficient time for being analysed by specialised journals. However, it is true that some publications carried out in the beginning some analysis of the ecolabel of the aviation industry. These are interesting and their results will be in the following point shown before introducing the survey designed specifically for this thesis.

8.1 Literature Review of Existing Surveys

Two main journal articles were found where the idea of the aviation energy label was first introduced. Some interviews and surveys were carried out where several aspects of the ecolabel were asked. It will be useful to analyse their results, since mainly, they were targeted at professionals of the aviation sector, which means their opinion has an added value. Nevertheless, by looking at them will be also proved that a specific survey is also needed.

8.1.1 Reasons for an Ecolabel for the Airline Industry

This first article, An Ecolabel for the Airline Industry? (Baumeister; Onkila, 2017), has as its main objective to set the first step towards the creation of an aviation ecolabel. This was achieved by doing twelve interviews with airline industry experts and then analysing the results together with some prior research. This section will be focused on studying the results of the interviews the investigators run. These interviews were done with experts of the aviation sector that were involved in developing a sustainable future for the industry, such as people involved in airlines, airports, airline management consultant companis or business travel companies. According to (Baumeister; Onkila, 2017), in these interviews the ecolabel of Flybe and the eco value of CheapTickets.nl [5] were shown and then the questions asked.

Questions

The interviews are said to be conducted mainly face-to-face at the workplaces of the already said experts in Germany, Finland and Spain. The duration of the conversations varied between 40 and 120 minutes. In the following article, (Baumesiter, 2017) this articles is studied. There the exact questions that were shown. This is going to be used to show them before reviewing the actual article:

1. **Do you consider the environment when booking a flight?**
   - Which of the three flight options displayed would you choose and why?
   - Do you consider the environment when booking a flight?
   - Do you think that there is a difference between the environmental performances of individual airlines?
   - How can these differences been measures, where do you personally see the main differences?
2. **How would you distinguish a responsible airline?**
   - How would you distinguish airlines according to their environmental performance?
   - Do you think an eco-label could help distinguish airlines according to their environmental performance?
   - What do you think about Flybe's eco-label?
3. **How could more awareness been built among air travelers?**
   - Do you think the average air traveler is aware of these differences?
   - What do you think could help to build more awareness among air traveler in this content?
   - Do you think air travelers would consider an aviation eco-label and that this would influence their booking decision?
4. **How could an industry wide eco-label be realized?**
   - Could you imagine that something similar to the shown eco-labels could be introduced industry wide?
   - What should be the criteria for an aviation eco-label? Age of fleet? Fuel consumption? CO_2-Emissions? Noise rating? Waste handling?
   - Who should introduce and control such a kind of eco-label? The IATA? The ICAO?
5. **Is there still something you would like to tell or something you would like to add to the former discussions?**

Figure 8.1 Interview carried out at (Baumeister; Onkila, 2017). Extracted from (Baumesiter, 2017)

[5] Unlike the Flybe scheme, the one from CheapTickets.nl was impossible to be reviewed in this thesis because the company ereased it from its website

Results Analysis

The results presented in the article will be now summarised:

- There is a difference between the environmental performance of airlines.
- Choosing a flight according to environmental aspects can make a difference.
- Making flights environmentally comparable through ecolabels could lead to more competition between airlines; currently there is hardly no competition.
- Nowadays, environmentally speaking, airlines just do the minimum.
- The general public has a negative environmental image of airlines. Therefore, an initiative as the ecolabel might be perceived as greenwashing.
- The message should be easy to understand for everyone and integrated during the booking process.
- Some participants declared that an energy label would be sufficient.
- Others thought that more detailed information about the methodology was needed to ensure transparency. However, several warned that excessive complex information might result in disinterest in passengers.
- The experts emphasised that the ecolabel should not by given to the airline but to each flight
- It was agreed that the aircraft type, its configuration, the average load factor and the route haul had be considered.
- There was wide agreement to take into account all greenhouse gases, not only carbon dioxide.
- It was stated that just one ecolabel should exist, which should result from the agreement of all involved parties. A standard has to be created.
- It was said that using symbols easier to understand, such as a scale from A to E, might be a good idea.
- An independent authority should be responsible of developing the ecolabel, in order to find a common agreement. ICAO was thought to be the most suitable option.
- Credibility, comparability, clarity, transparency and participation were identified as five very important criteria for the ecolabel.

It is important to remark that during the article (Baumeister; Onkila, 2017) the explanations of the conclusions obtained from the interviews are shown together with the cited statements of the experts that helped to arrive to these conclusions. Moreover, a part from interviews, in the article is also said that during the Air Transport World 5th Annual Eco-Aviation Conference (in Washington D.C in June 2012) discussions took place during breaks. These conversations were established with several professionals of the airline industry that attended to the convention. They were shown samples of the ecolabels of Flybe and CheapTickets.nl and asked for they opinion. The candidates for the interviews that later took place were chosen based on recommendations given during these conversations.

8.1.2 Changes of Behaviour in Airline Industry due to Ecolabels

This project, An Eco-Label for the Airline Industry: Instrument for Behavioral Change? (Baume-siter, 2017), has been chosen to appear in this thesis due to the vast amount of information that it provides. Its main advantage is that one of the tasks that was carried out was to review other articles were the results of surveys, interviews and othery analysis were analysed. Specifically, four articles were reviewed in the project, but given that one of them is (Baumeister; Onkila, 2017), which was already reviewed in the previous section, just 3 will be considered to analyse.

Two of them did surveys relative to the ecolabel topic, (Baumeister, 2015) and (Baumesiter; Hoffendahl, 2017). However, the third one what made in fact was to analyse fuel and flight data for 118 flights for which carbon dioxide emissions were calculated. Although this could be interesting, it falls out from the scope of this section. As a consequence, just the surveys that the first two ones designed will be studied. They will be presented in different sections to not diminish its relevance, since (Baumesiter, 2017) is just a compilation, but the two that will be reviewed now are the ones that actually extracted conclusions.

The article found that an Ecolabel is translated into many benefits. Firstly, an introduction of an scheme like that can change the behaviour of passengers in the booking process, which eventually reduces the carbon emissions, as they will end up choosing mostly the greenest options. At the same time the environmental consciousness would rise, making the population more aware about the not reliability of other informative strategies, such as airline marking campaigns. Finally, a competition for being the most efficient airline would appear, which would benefit the sustainability of the sector. However, all these aspects will be seen in more detail in the individual reviews of both articles. As it could be seen, the changes of behaviour will be analysed from two points of view: the airlines, in the first article, and passengers, in the second.

8.1.3 Environmentally Responsibility as Competitive Advantage in the Airline Industry

The objective of the article, Environmentally Responsibility as a Factor in Gaining Competitive Advantage in the Aviation Industry (Baumeister, 2015), was to study how the pro-environmental initiatives of airlines were seen by passengers. A survey was designed, and the data of 148 responses analysed.

Questions

The questions that were asked in the survey will be now shown:

1. Introduction

Dear participant!

In the field of environmental responsibility, airlines are currently playing a particularly important role in the climate change debate. Finnair wants to be the choice for environmentally conscious travelers and is seeking for new ways how to reduce its emissions.

Taking care of the environment is a very crucial issue and your views are highly valued. Taking part in the questionnaire should not take more than 10 minutes.

This web interview is part of a Master's Thesis research project and is carried out by the University of Jyväskylä, the School of Business and Economics.

The information provided by you will only be used for data analysis within the University of Jyväskylä, individual participants cannot be identified from the report and your responses are absolutely confidential.

Thank you for taking part in this questionnaire!

2. How often do you usually fly with Finnair?

□ Once a year □ 2-3 times per year □ Every month
□ I never flew with Finnair so far

3. When booking a flight how important are the following aspects for you?

a. **Price**
□ Very important □ Important □ Less important □ Not important

b. **Total flight time (including transfers)**
□ Very important □ Important □ Less important □ Not important

c. **Non-stop flight to final destination**
□ Very important □ Important □ Less important □ Not important

d. **Suitable departure and arrival time**
□ Very important □ Important □ Less important □ Not important

e. **Finnair's new identity as a design airline**
□ Very important □ Important □ Less important □ Not important

Figure 8.2 Extract a of the survey of (Baumeister, 2015). Extracted from (Baumesiter, 2017)

4. Do you take environmental aspects into consideration when booking a flight?

□ Yes
□ No

If yes please specify what kind of environmental aspects you are taking into consideration when booking a flight:

5. In the following section we will present you several statements and ask you kindly to respond whether you agree or you not agree.

6. Finnair has a leading role in Europe when it comes to environmental responsibility.

□ I fully agree □ I agree □ I don't know □ I disagree □ I fully disagree

7. Operating a modern fleet (that means flying new planes) is better for the environment.

□ I fully agree □ I agree □ I don't know □ I disagree □ I fully disagree

8. I accept stopovers on my way to my final destination if the ticket prices are therefore much lower (e.g. flying from Helsinki to Frankfurt with changing planes in Riga or Copenhagen).

□ I fully agree □ I agree □ I don't know □ I disagree □ I fully disagree

9. I am ready to pay more for a flight that is producing less emissions.

□ I fully agree □ I agree □ I don't know □ I disagree □ I fully disagree

10. I am interested in donating some of my Finnair Plus-Points to projects aiming the recovery of our nature e.g. to the Baltic Sea Action Group or the Finnish Association for Nature Conservation / Suomen Luonnonsuojeluliitto.

□ I fully agree □ I agree □ I don't know □ I disagree □ I fully disagree

11. I think paying for carbon offset has a positive effect on the environment.

□ I fully agree □ I agree □ I don't know □ I disagree □ I fully disagree

12. Finnair should offer the possibility to pay for carbon offset as well.

□ I fully agree □ I agree □ I don't know □ I disagree □ I fully disagree

Figure 8.3 Extract b of the survey of (Baumeister, 2015). Extracted from (Baumesiter, 2017)

13. Have you ever paid for carbon offset while you booked a flight?

□ Yes
□ No

14. Have you heard about Finnair's new emissions calculator? (that is based on actual cargo, passenger and fuel consumption figures, not averages or assumptions and is certified by PricewaterhouseCoopers.)

□ Yes
□ No

15. Have you tried the new Finnair emissions calculator?

□ Yes
□ No

16. Do you think that the Finnair emissions calculator will have any impact when you make travel plans in the future?

□ Yes
□ No

Please specify in which way the results of Finnair's emissions calculator could influence your decision making about further travelling plans:

17. The following section contains questions about background information. The information provided by you will only be used for data analysis, individual participants cannot be identified from the report and your responses are absolutely confidential.

18. What is your gender?

□ Female
□ Male

19. What is your current age?

□ under 25 □ 26-39 □ 40-59 □ over 60

20. Are you a Finnair Plus member?

□ Yes
□ No

Figure 8.4 Extract c of the survey of (Baumeister, 2015). Extracted from (Baumesiter, 2017)

21. What is your Finnair Plus member status?

□ Finnair Plus Basic □ Finnair Plus Silver □ Finnair Plus Gold
□ Finnair Plus Platinum □ Finnair Plus Junior

22. Do you have any comments or notes?

Figure 8.5 Extract d of the survey of (Baumeister, 2015). Extracted from (Baumesiter, 2017)

Results Analysis

The analysis that were extracted in (Baumesiter, 2017) from the answers of the previous questions will be now summarised.

- Passengers see as something positive and valuable environmental initiatives of airlines.
- The operation of a more modern fleet was agreed by the majority of answers that was more environmetally-friendly.
- Passengers said that although airlines did different environmentally-friendly actions, if they are not informed about it, they will not see airlines as environmental leaders: a better communication has to be found to make them aware.
- The price sensitivity is high: it will be difficult for airlines to find willingness among passengers to pay higher prices although flights being more environmentally respectful.
- Although carbon offsetting was seen positively, not all of them were willing to pay for it.
- The amount of passengers that considerate the environment when booking a flight is "small but considerable".
- Airlines with a differentiation regarding the environmental aspect should work on identifying a target that values that. They should also use it as a selling point even though for passengers that do not value this that much.

8.1.4 Effects of an Ecolabel on the Booking Decisions of Airline Passengers

The objective of this article, The Effect of an Ecolabel on the Booking Decisions of Air Passenger (Baumesiter; Hoffendahl, 2017), was to analyse the effects of an airline ecolabel on the booking decisions of air passengers. A survey was designed, and the data of the 554 responses analysed.

Questions

The questions that were asked will be now shown. It is important to say that before presenting the questions an introduction on the topic was given. However, since during the whole thesis all the explanations have been revolving around it, now just the questions will be displayed.

4. Choice Experiment

Select the flight you like to book by clicking on it. Please select only **one** flight. Your selection will be highlighted in **green**. Press "Next" to continue.

Flight Option	Flight 1	Flight 2	Flight 3
Ticket price	$225	$205	$225
Total time	7hr 50min	5hr 20min	5hr 20min
Eco-label	B	A	C

Figure 8.6 Extract a of the survey of (Baumesiter; Hoffendahl, 2017). Extracted from (Baumesiter, 2017)

Select the flight you like to book by clicking on it. Please select only **one** flight. Your selection will be highlighted in **green**. Press "Next" to continue.

Flight Option	Flight 1	Flight 2	Flight 3
Ticket price	$245	$205	$205
Total time	6hr 35min	5hr 20min	7hr 50min
Eco-label	B	C	A

Select the flight you like to book by clicking on it. Please select only **one** flight. Your selection will be highlighted in **green**. Press "Next" to continue.

Flight Option	Flight 1	Flight 2	Flight 3
Ticket price	$245	$225	$245
Total time	7hr 50min	6hr 35min	6hr 35min
Eco-label	A	C	A

Figure 8.7 Extract b of the survey of (Baumesiter; Hoffendahl, 2017). Extracted from (Baumesiter, 2017)

Select the flight you like to book by clicking on it. Please select only **one** flight.
Your selection will be highlighted in **green**. Press "Next" to continue.

Flight Option	Flight 1	Flight 2	Flight 3
Ticket price	$245	$245	$225
Total time	7hr 50min	5hr 20min	6hr 35min
Eco-label	B	A	A

Select the flight you like to book by clicking on it. Please select only **one** flight.
Your selection will be highlighted in **green**. Press "Next" to continue.

Flight Option	Flight 1	Flight 2	Flight 3
Ticket price	$205	$225	$225
Total time	7hr 50min	5hr 20min	7hr 50min
Eco-label	B	B	C

Figure 8.8 Extract c of the survey of (Baumesiter; Hoffendahl, 2017). Extracted from (Baumesiter, 2017)

Select the flight you like to book by clicking on it. Please select only **one** flight.
Your selection will be highlighted in **green**. Press "Next" to continue.

Flight Option	Flight 1	Flight 2	Flight 3
Ticket price	$205	$245	$225
Total time	6hr 35min	7hr 50min	5hr 20min
Eco-label	C	C	A

Select the flight you like to book by clicking on it. Please select only **one** flight.
Your selection will be highlighted in **green**. Press "Next" to continue.

Flight Option	Flight 1	Flight 2	Flight 3
Ticket price	$205	$205	$245
Total time	6hr 35min	5hr 20min	5hr 20min
Eco-label	A	B	B

Figure 8.9 Extract d of the survey of (Baumesiter; Hoffendahl, 2017). Extracted from (Baumesiter, 2017)

Select the flight you like to book by clicking on it. Please select only **one** flight. Your selection will be highlighted in **green**. Press "Next" to continue.

Flight Option	Flight 1	Flight 2	Flight 3
Ticket price	$205	$205	$245
Total time	7hr 50min	6hr 35min	6hr 35min
Eco-label	C	B	C

Select the flight you like to book by clicking on it. Please select only **one** flight. Your selection will be highlighted in **green**. Press "Next" to continue.

Flight Option	Flight 1	Flight 2	Flight 3
Ticket price	$245	$225	$225
Total time	5hr 20min	6hr 35min	7hr 50min
Eco-label	C	B	A

5. Demographics

What is your gender?

- Male
- Female

Figure 8.10 Extract e of the survey of (Baumesiter; Hoffendahl, 2017). Extracted from (Baumesiter, 2017)

What is your age?

under 18	18-24	25-34	35-44	45-54	55-64	65-74
	75-84	85+				

What is your household's annual income?

- Less than $10,000
- $10,000-$14,999
- $15,000-$24,999
- $25,000-$34,999
- $35,000-$49,999
- $50,000-$74,999
- $75,000-$99,999
- $100,000-$149,999
- $150,000-$199,999
- $200,000 or more

What is the highest level of formal education that you have completed?

- Below Grade 12
- High School Diploma
- Associate's Degree
- Bachelor's Degree
- Graduate / Professional Degree
- Doctorate Degree

In which country do you reside?

→Dropdown menu with all countries

In what state do you currently reside?

→Dropdown menu with all states

6. Testing environmental mindedness

How strongly would you rate the importance of the eco-label for the booking choices you made above?

- Unimportant
- Of little importance
- Moderately important
- Important
- Very important

Figure 8.11 Extract f of the survey of (Baumesiter; Hoffendahl, 2017). Extracted from (Baumesiter, 2017)

How frequently do you purchase organic products?

- Never
- Sometimes (once every 10 trips to the grocery store)
- Occasionally (once every 5 trips to the grocery store)
- Often (every other trip to the grocery store)
- Always (every trip to the grocery store)

How often do you purchase voluntary Carbon Offsets when booking a flight?

- Never
- Sometimes
- Occasionally
- Often
- Always
- I don't know what Carbon Offset is

How concerned are you about the future state of our environment?

- Not at all concerned
- Slightly concerned
- Moderately concerned
- Very concerned
- Extremely concerned

Are you a member of an environmental organization?

- Yes
- No

7. Comments and payment

Please provide any comments you might have about this survey.

Thank you for participating in our survey!

Figure 8.12 Extract g of the survey of (Baumesiter; Hoffendahl, 2017). Extracted from (Baumesiter, 2017)

Results Analysis

The analysis that were extracted in (Baumesiter, 2017) will be now summarised.

- Airline ecolabels were proved to affect the booking decision of passengers.
- It was seen that not only environmentally aware passengers reacted positively to ecolabels, other passengers with a lower degree of interest reacted satisfactorily too if additional information was provided. This was tested through showing new eco-labels in the survey: they were unknown for all passengers, but environmentally minded passengers showed an immediately sense of trust towards it, even with few information, probably due to past experiences, argues (Baumesiter, 2017).
- It is argued that, on the one hand, a more environmentally efficient flight should be cheaper due to its higher level of efficiency, which implies saving costs. On the other hand, this higher environmentally efficiency can be also seen as an added value, which implies a higher cost. Be that as it may, if a willingness to pay is wanted to be achieved, additional information to the passenger has to be provided.
- It was shown that the price had a much stronger relation with the environmentally

respect of a flight that time: passengers interpret higher prices as an sign of an added value due to being the flight greener, but no interaction between time and the green character of the flight was found.
- It was demonstrated that when having to choose flights, passengers tend to avoid the ones labelled with red tags. It was thought that they would tend to opt for yellow labeled ones, as green ones would be seen as premium. However, green tickets were the one preferred by users. This indicates that airlines should pay special attention to make their flights fall in this category.
- It was shown again that providing additional information about the ecolabel, during the purchase process, while still being new, it is crucial for its success among buyers.

Arrived to this point, the revision of the three articles has been finished. The conclusions that their authors obtained have been analysed. This has helped to understand better how the ecolabel is able to change the behaviour of passengers during the booking process.

The general idea that has to be extracted from the three last articles is the clear philosophy that all passengers seem to expect: transparency, information and reasons for trust. The majority of interviewees saw the ecolabel as something very valuable, which however should be presented with the right auxiliary information in order to help passengers understand what they read. Other idea that was repeated several times was the choice of the correct target: already environmentally-aware passengers were keen on using the ecolabel scheme, but the ones who were not, did not present a closed position towards it. Moreover, the general image of airlines should be changed somehow, since experts said that due to the bad reputation of airlines, even action with good intentions such as the ecolabel might be misunderstood by greenwashing.

8.2 New Specific Survey

After seeing the surveys and interviews that were performed by experts on the matter about the aviation ecolabel, it has been understood why it is necessary to design a survey that specifically suits the necessities of this thesis. Although reviewing the questions and the answers about the ecolabel has been very constructive for knowing the opinion of workers of the industry, the real target of the ecolabel is the plain public with no knowledge on the matter. Moreover, these interviews and surveys were not centered on the aviation ecolabel around which the work of this thesis has been revolving. This is why it is concluded that an specific survey is needed. Other topics will be targeted as well, such as offsetting or the general view of aviation and the environment. The survey was designed using the Google web application Google Forms and spread via Whatsapp and email.

8.2.1 Questions

The questions that were decided to ask will be presented now. Screenshots of the Google Forms survey will be displayed, in order to show to the reader how the format of the survey was. If the survey is wanted to be seen online, it can be accessed through the following link: `https://forms.gle/ysVrggCH9aJwpEry7`

How to inform the passengers about the environmental impacts of their flight

Survey carried out as a part of Alejandro Ridao Velasco Bachelor Thesis; written at the university HAW Hamburg and supervised by professor Scholz. The responses are completely anonymus.

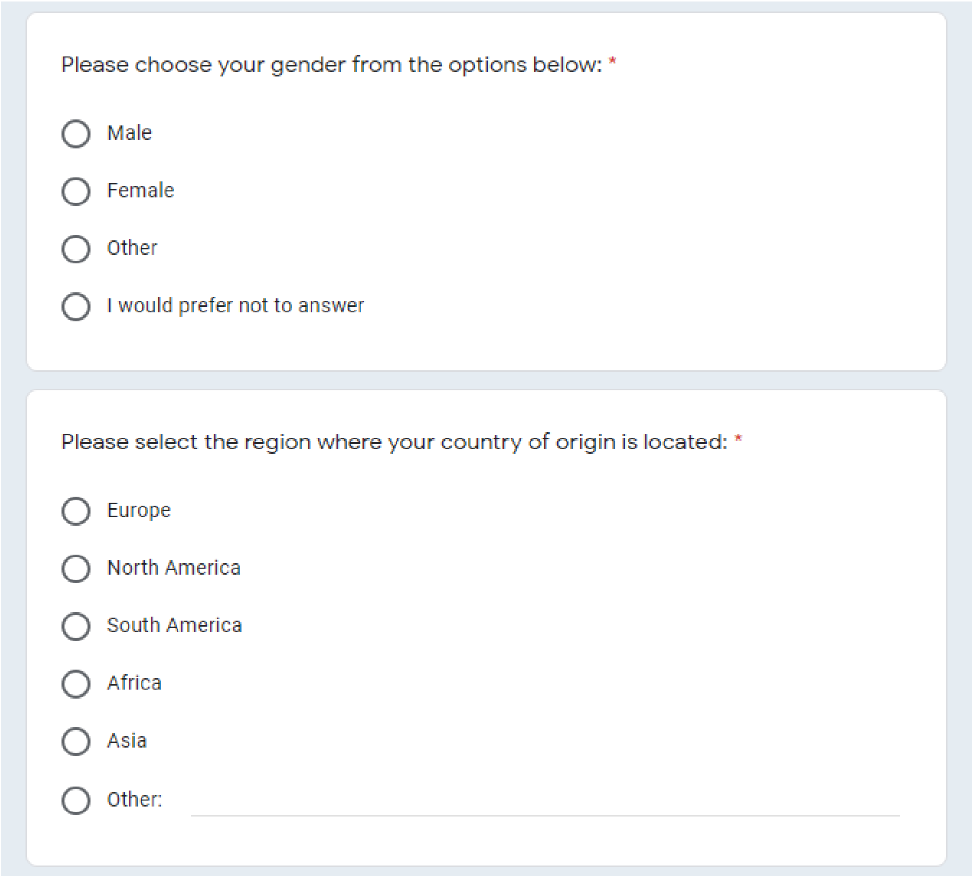
*Required

PERSONAL INFORMATION

Please select your age range: *

- ○ 1 - 10
- ○ 11 - 20
- ○ 21 - 30
- ○ 31 - 40
- ○ 41 - 50
- ○ 51 - 60
- ○ +61

Figure 8.13 Extract a of the survey about travelling behaviour and environmental informative tools. Airplane heading image extracted from (Bühler Motor, n.d.)



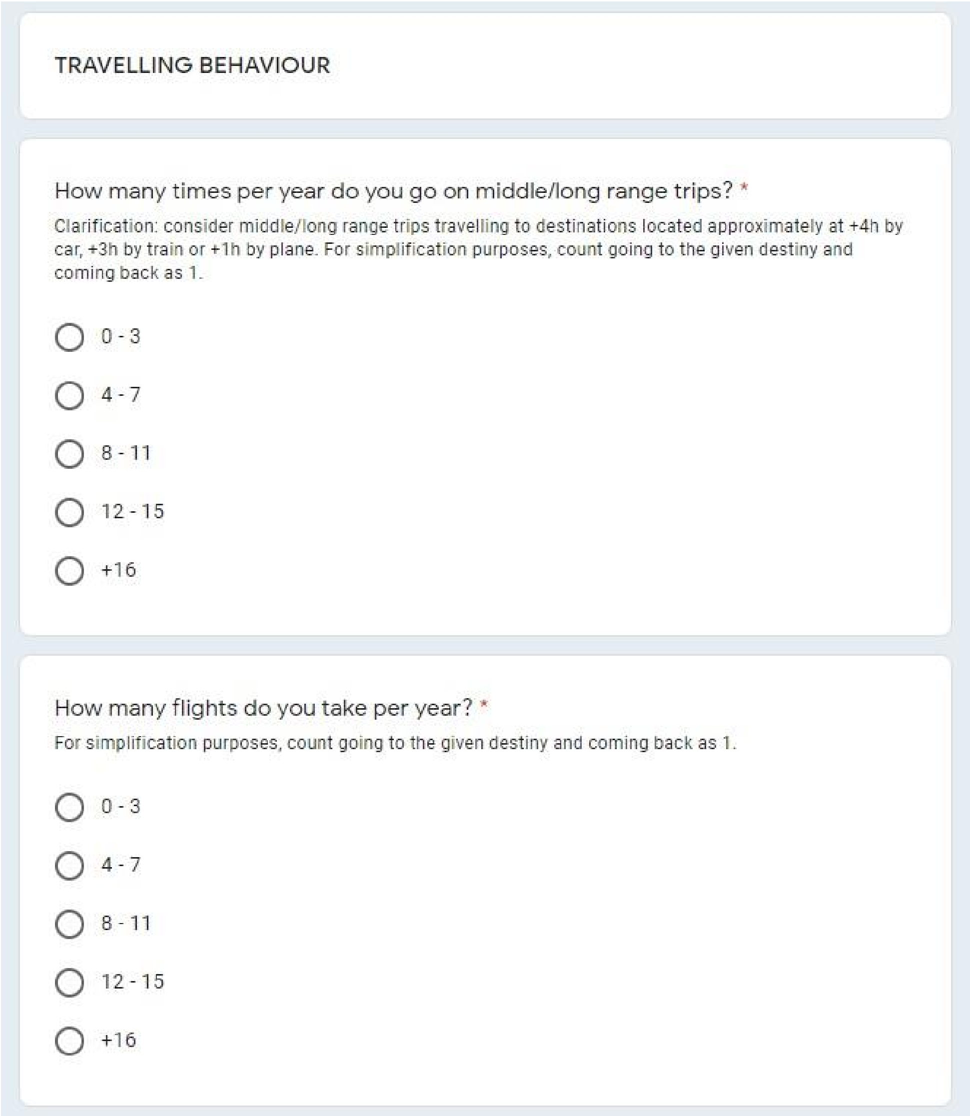
Please choose your gender from the options below: *

- Male
- Female
- Other
- I would prefer not to answer

Please select the region where your country of origin is located: *

- Europe
- North America
- South America
- Africa
- Asia
- Other: ______

Figure 8.14 Extract b of the survey about travelling behaviour and environmental informative tools



TRAVELLING BEHAVIOUR

How many times per year do you go on middle/long range trips? *

Clarification: consider middle/long range trips travelling to destinations located approximately at +4h by car, +3h by train or +1h by plane. For simplification purposes, count going to the given destiny and coming back as 1.

- 0 - 3
- 4 - 7
- 8 - 11
- 12 - 15
- +16

How many flights do you take per year? *

For simplification purposes, count going to the given destiny and coming back as 1.

- 0 - 3
- 4 - 7
- 8 - 11
- 12 - 15
- +16

Figure 8.15 Extract c of the survey about travelling behaviour and environmental informative tools

For the previously asked trips, when not done by flying, which is your most used mean of transport? *

This question still refers to travelling middle/long range distances.

- ○ Train
- ○ Car
- ○ Bus
- ○ Ship
- ○ Other: ____________

Because of which of the following reasons have you ever chosen planes over other means of transport? *

This question still refers to travelling middle/long range distances. You can select more than one option.

- ☐ Shorter travel time
- ☐ Money
- ☐ Comfort
- ☐ Lack of alternatives
- ☐ Other: ____________

Figure 8.16 Extract d of the survey about travelling behaviour and environmental informative tools

Because of which of the following reasons have you ever chosen other means of transport instead of flying? *

This question still refers to travelling middle/long range distances. You can select more than one option.

- ☐ Pollution
- ☐ Comfort
- ☐ Price
- ☐ Other: ____________

Figure 8.17 Extract f of the survey about travelling behaviour and environmental informative tools

THE AVIATION ECOLABEL

The following image corresponds to the energy label developed by the European Union. The example shown corresponds to a label of a fridge.

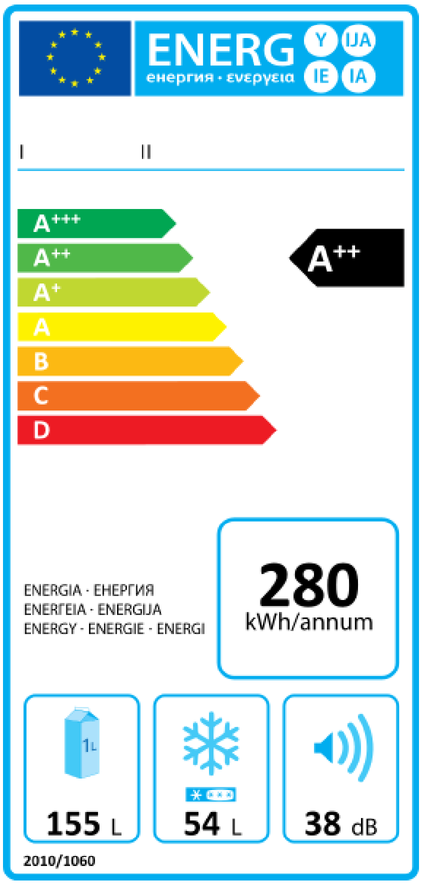


Figure 8.18 Extract g of the survey about travelling behaviour and environmental informative tools

Would you find useful to be informed about how environmentally efficient an aircraft is with a method such as the one presented in the last image? *

The image corresponds to the EU energy efficiency label that most household appliances display.

- ◯ Yes
- ◯ No
- ◯ Do not know / No answer

Figure 8.19 Extract h of the survey about travelling behaviour and environmental informative tools

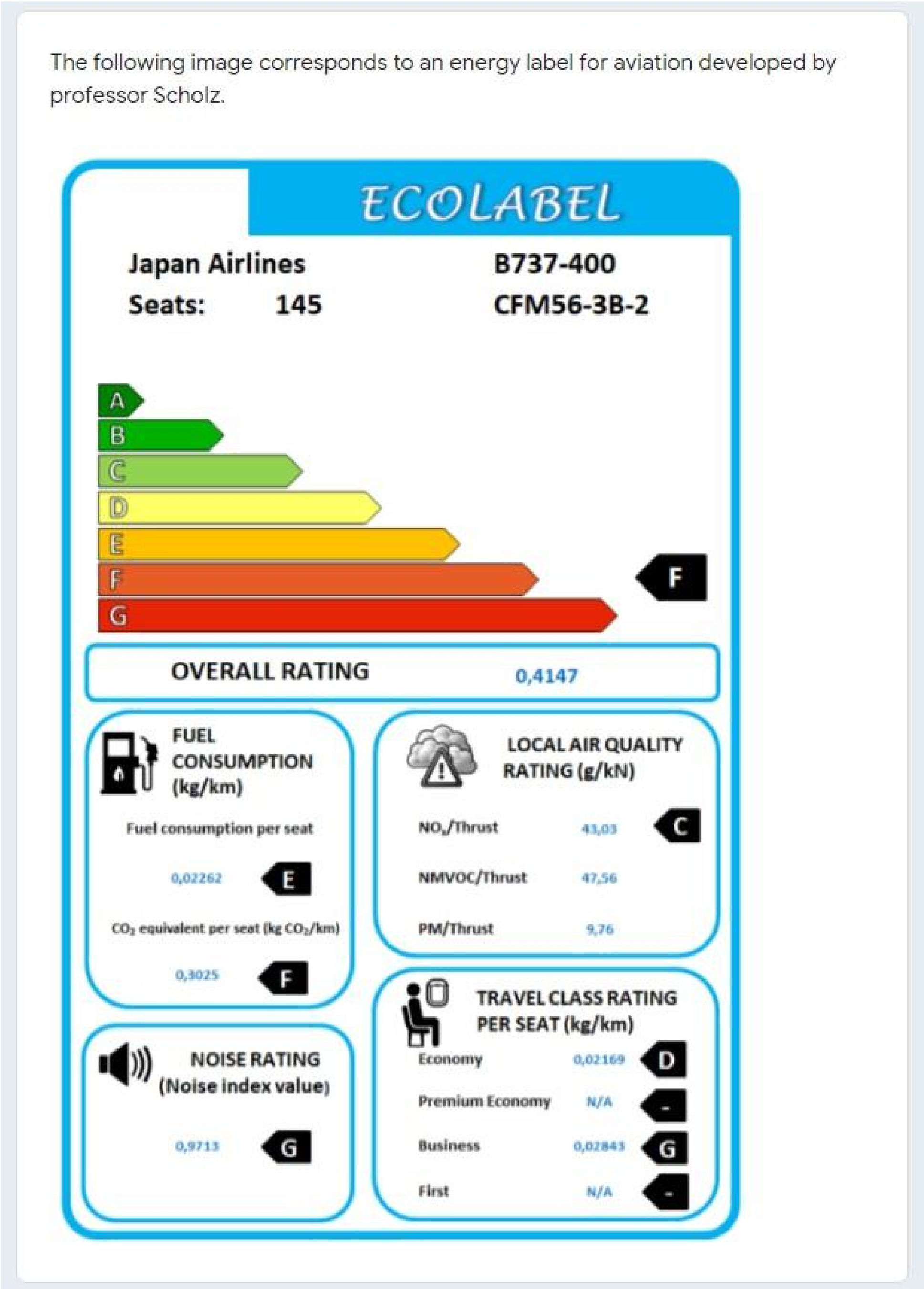
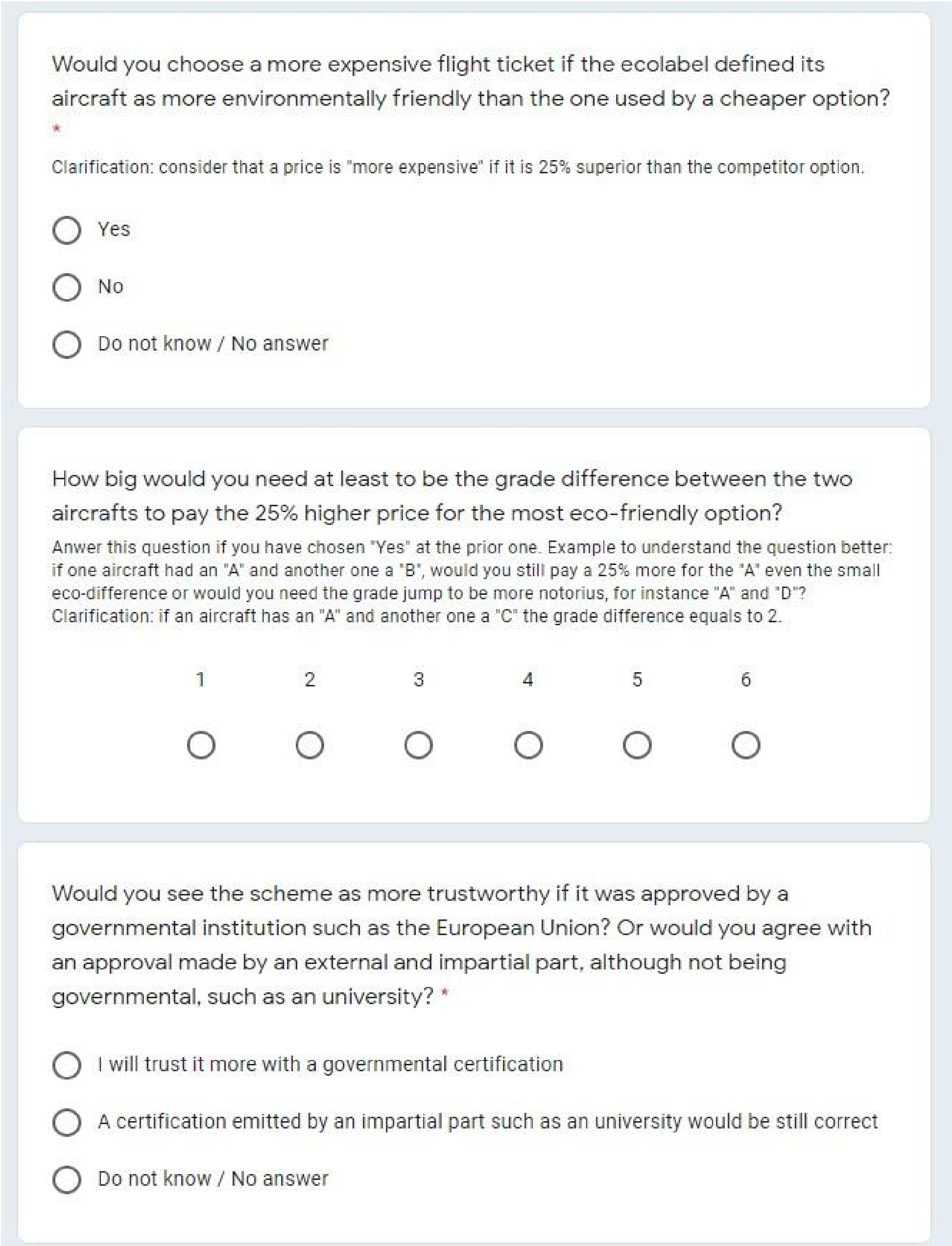


Figure 8.20 Extract i of the survey about travelling behaviour and environmental informative tools



Would you choose a more expensive flight ticket if the ecolabel defined its aircraft as more environmentally friendly than the one used by a cheaper option? *

Clarification: consider that a price is "more expensive" if it is 25% superior than the competitor option.

- Yes
- No
- Do not know / No answer

How big would you need at least to be the grade difference between the two aircrafts to pay the 25% higher price for the most eco-friendly option?

Anwer this question if you have chosen "Yes" at the prior one. Example to understand the question better: if one aircraft had an "A" and another one a "B", would you still pay a 25% more for the "A" even the small eco-difference or would you need the grade jump to be more notorius, for instance "A" and "D"?
Clarification: if an aircraft has an "A" and another one a "C" the grade difference equals to 2.

1 2 3 4 5 6

Would you see the scheme as more trustworthy if it was approved by a governmental institution such as the European Union? Or would you agree with an approval made by an external and impartial part, although not being governmental, such as an university? *

- I will trust it more with a governmental certification
- A certification emitted by an impartial part such as an university would be still correct
- Do not know / No answer

Figure 8.21 Extract j of the survey about travelling behaviour and environmental informative tools

Would you trust the system transparency? Or do you think you could end up misunderstanding it as a form of greenwashing? *

Clarification: greenwashing is defined as the action of making a company seem more environmentally friendly than it really is by using certain marketing strategies

- ◯ Yes, I would trust it
- ◯ No, I would think of it as a greenwashing method
- ◯ Do not know / No answer

By looking at the image that corresponds to the aviation ecolabel, would you say you understand completely all the displayed parameters? *

- ◯ Yes
- ◯ No
- ◯ Do not know / No answer

Would you find useful to have the aviation ecolabel accompanied by a second page with a description of the displayed parameters? *

- ◯ Yes
- ◯ No
- ◯ Do not know / No answer

Figure 8.22 Extract k of the survey about travelling behaviour and environmental informative tools

At a first glance, what is your opinion about the number of parameters the aviation ecolabel shows? *

Clarification: although possible aclarations of the displayed data could be added in the future, do not count them as parameters; just consider the currently shown variables (fuel consumption per seat, NOx/Thrust, etc.)

- ◯ Too many
- ◯ Adequate
- ◯ Too few

Figure 8.23 Extract l of the survey about travelling behaviour and environmental informative tools

EMISSIONS OFFSETTING

Offsetting is defined as the act of paying a sum of money that helps to compensate the carbon dioxide emissions that a human activity produces. This compensation is performed through programs that reduce or not use the equivalent amount of carbon dioxide that the human action created.

The following image corresponds to the carbon dioxide calculator the airline Virgin Atlantic displays at its website. It allows to offset the emissions. The example shows a flight between Hamburg and Barcelona airports.

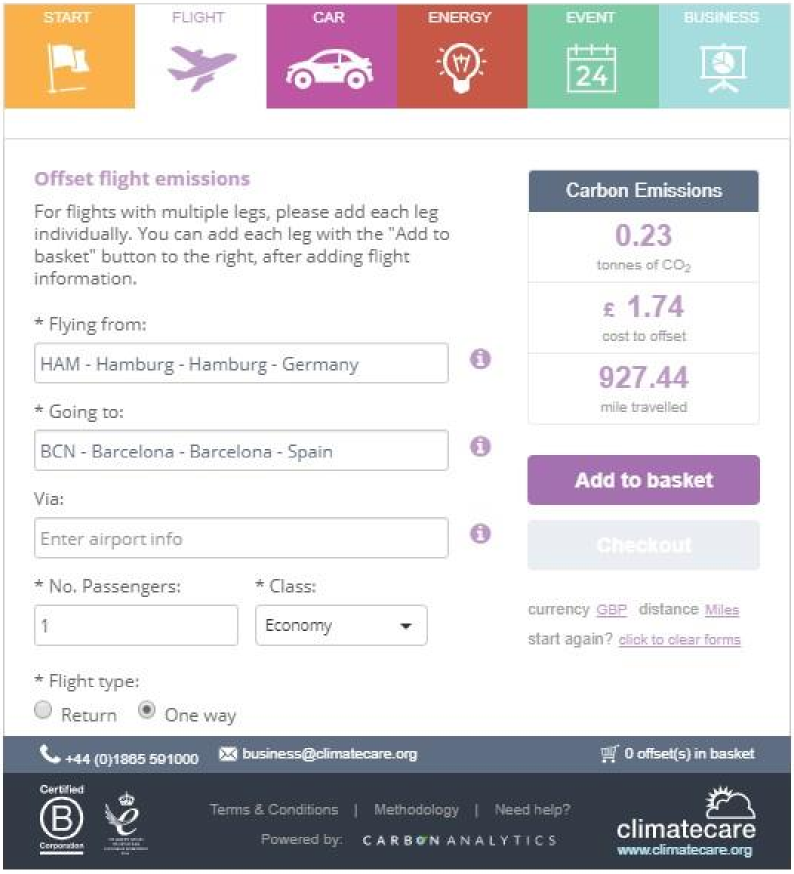


Figure 8.24 Extract m of the survey about travelling behaviour and environmental informative tools

Would you be willing to offset the emissions you produce when you flight? *

Clarification: the definition of "emission offsetting" can be found under the title of the section over the last picture

- ○ Yes
- ○ No
- ○ Do not know / No answer

Because which of the following reasons would you offset your flight emissions?

Answer this if you chose "Yes" in the last question. You can select more than one option.

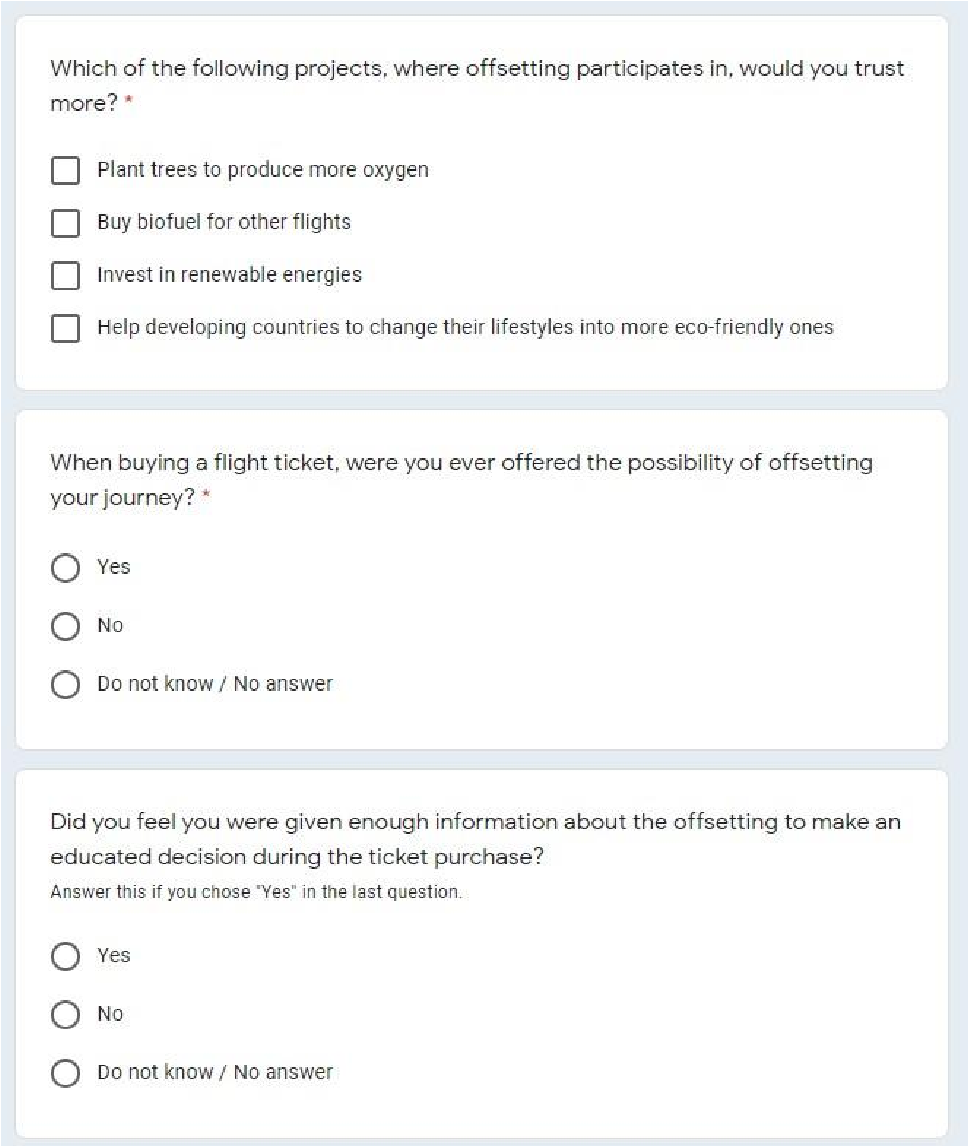
- ☐ To feel good for doing a good action
- ☐ To clear my conscience for polluting because of flying
- ☐ Because of believing in the positive effects of the projects impulsed by offsetting

Because which of the following reasons would you not offset your emissions?

Answer this if you chose "No" in the penultimate question. You can select more than one option.

- ☐ I do not trust this offsetting system
- ☐ I do not care about the environment
- ☐ I am not willing to pay more for a flight ticket
- ☐ It is not my function as an individual to fight climate change in such a way
- ☐ Airlines should offset their own emissions, not passengers

Figure 8.25 Extract n of the survey about travelling behaviour and environmental informative tools



Which of the following projects, where offsetting participates in, would you trust more? *

- [ ] Plant trees to produce more oxygen
- [ ] Buy biofuel for other flights
- [ ] Invest in renewable energies
- [ ] Help developing countries to change their lifestyles into more eco-friendly ones

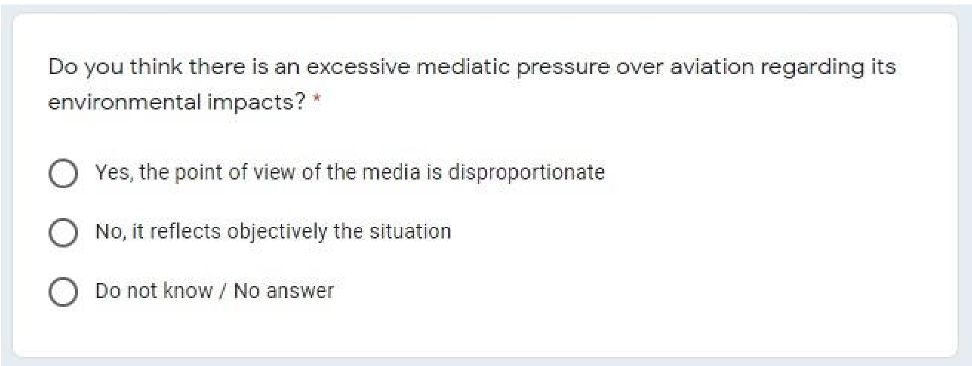
When buying a flight ticket, were you ever offered the possibility of offsetting your journey? *

- Yes
- No
- Do not know / No answer

Did you feel you were given enough information about the offsetting to make an educated decision during the ticket purchase?
Answer this if you chose "Yes" in the last question.

- Yes
- No
- Do not know / No answer

Figure 8.26 Extract o of the survey about travelling behaviour and environmental informative tools



Do you think there is an excessive mediatic pressure over aviation regarding its environmental impacts? *

- Yes, the point of view of the media is disproportionate
- No, it reflects objectively the situation
- Do not know / No answer

Figure 8.27 Extract p of the survey about travelling behaviour and environmental informative tools

8.2.2 Answers

Now that the questions have been seen, the answers to each one of them will be attached. The responses will be presented in form of graphics, which will have different formats depending on the question type. They are automatically generated by Google Forms. A total of 306 answers were registered.

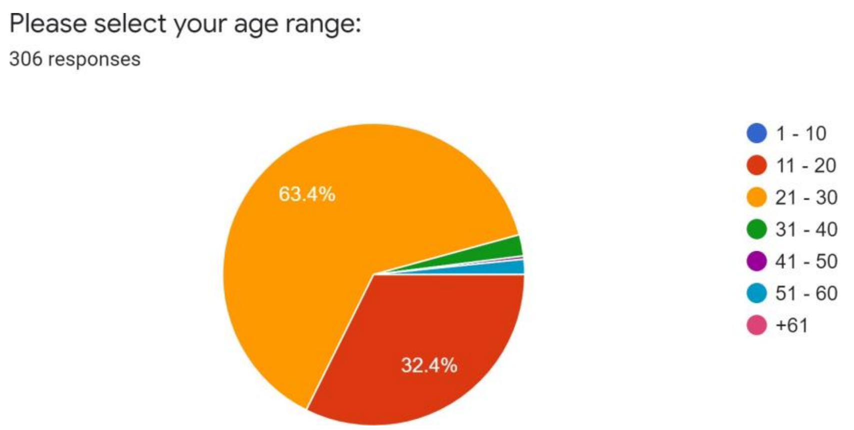


Figure 8.28 Answer to the question number 1 of the survey

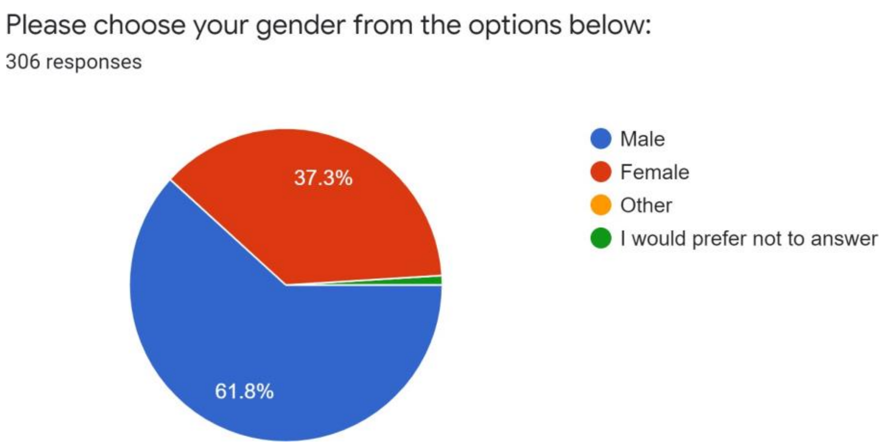


Figure 8.29 Answer to the question number 2 of the survey

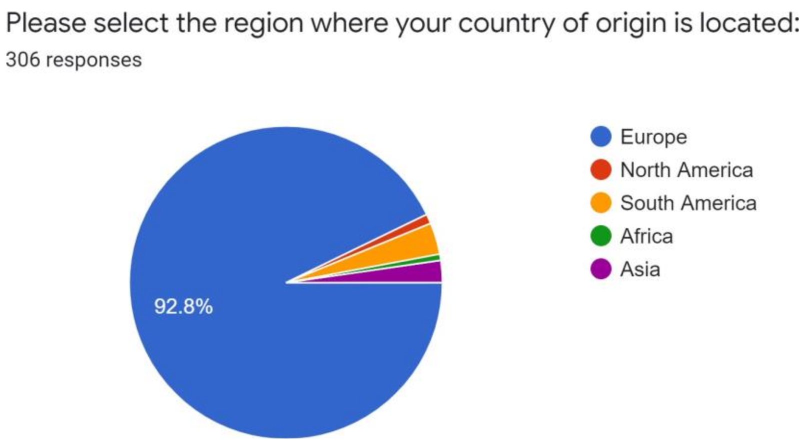


Figure 8.30 Answer to the question number 3 of the survey

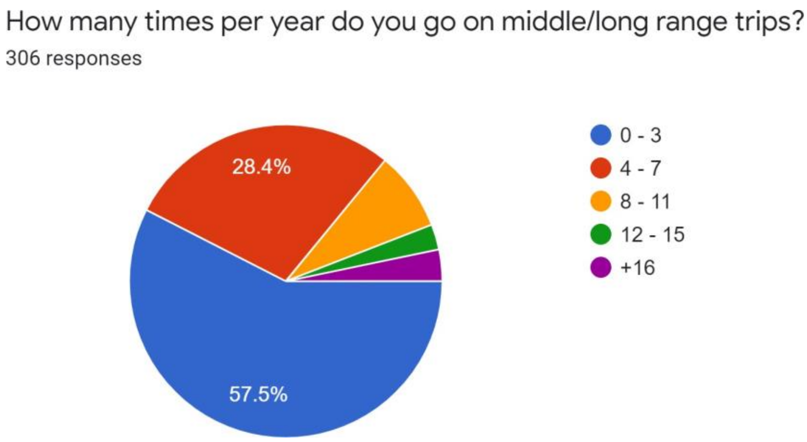
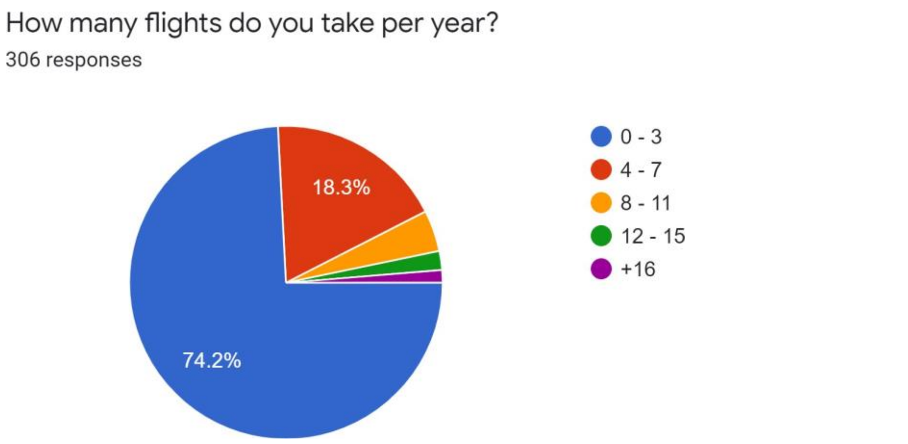


Figure 8.31 Answer to the question number 4 of the survey



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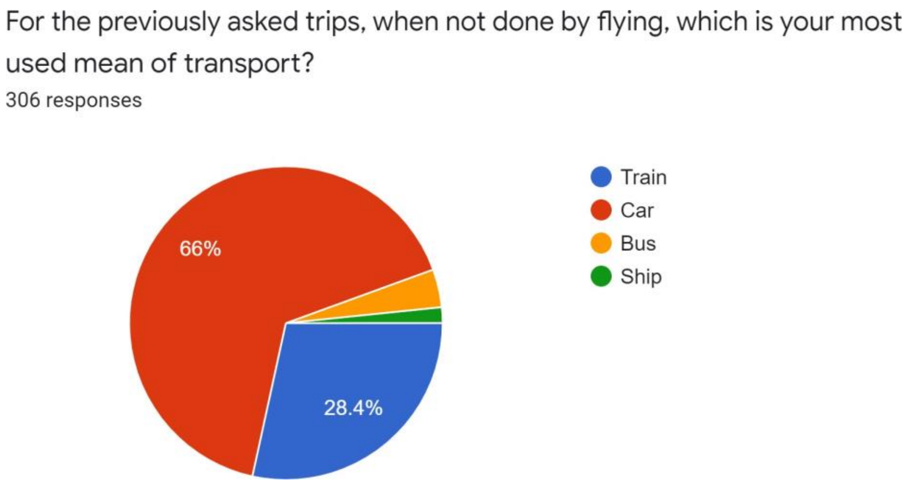

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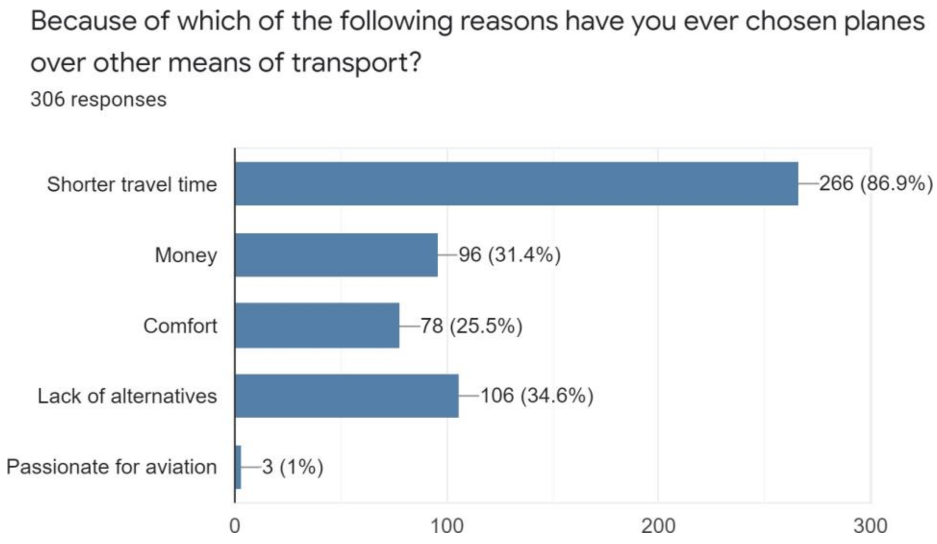

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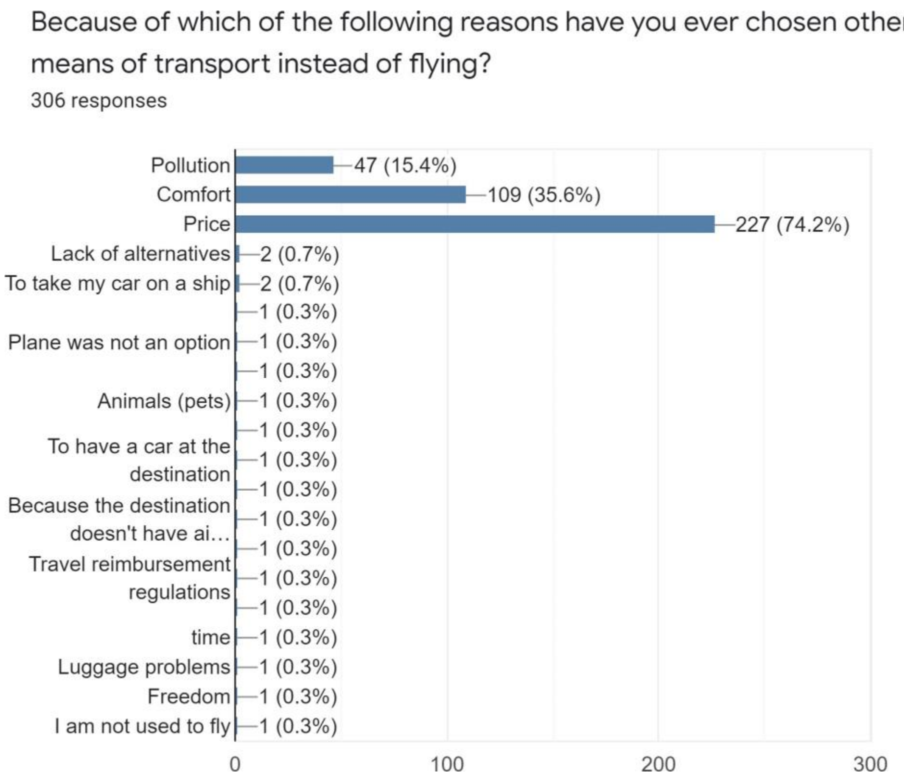

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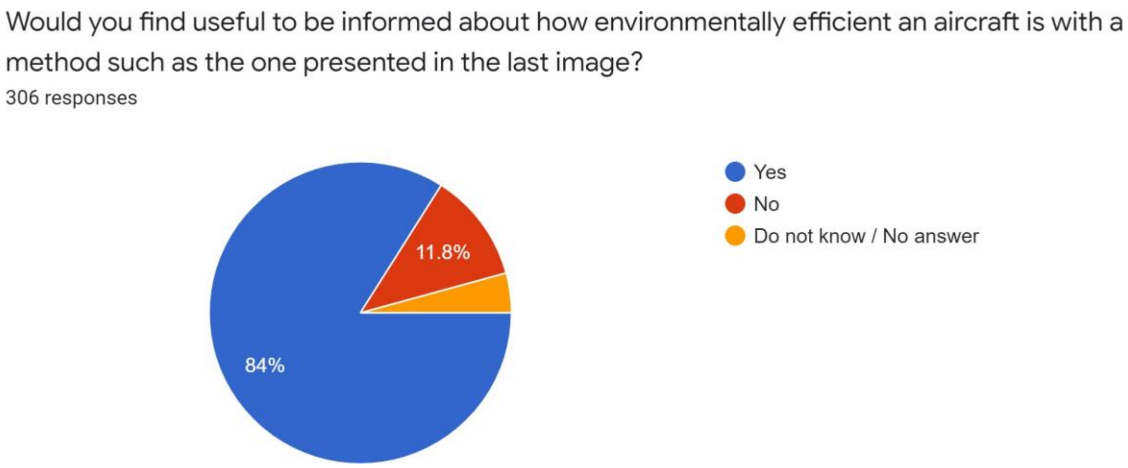

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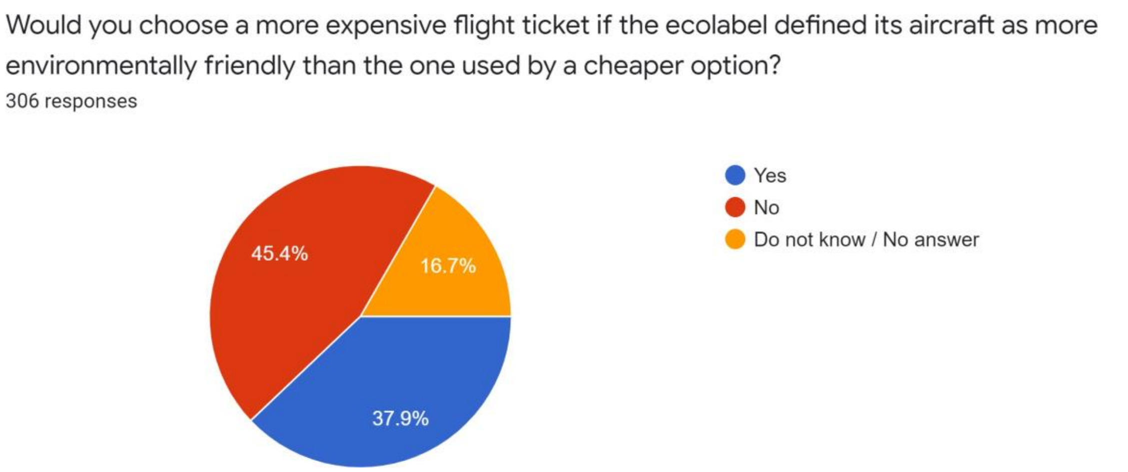

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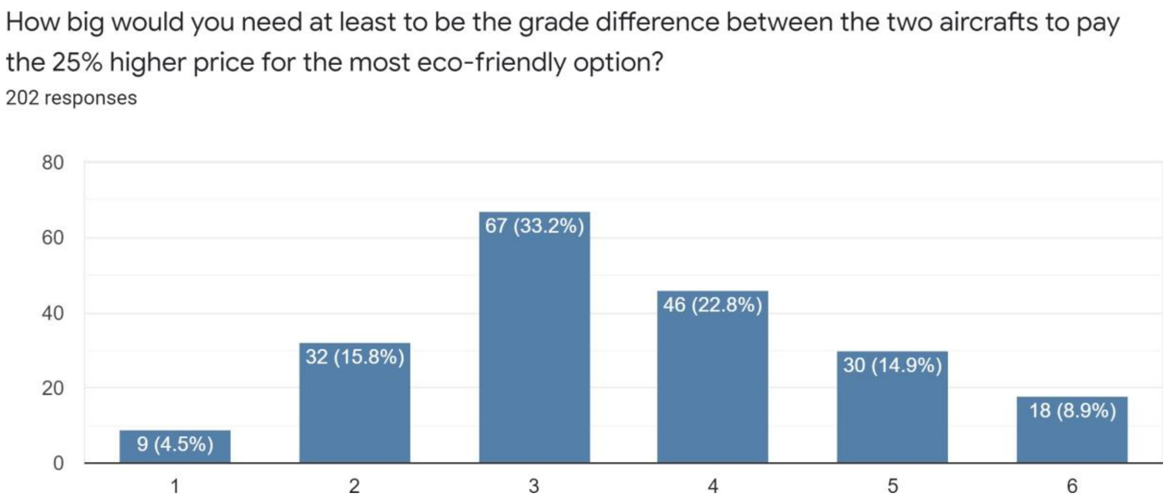

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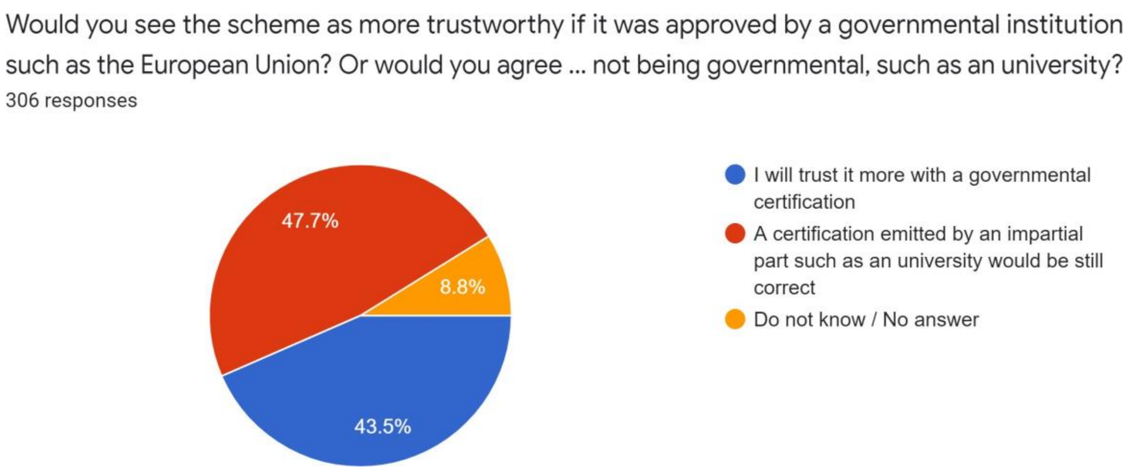

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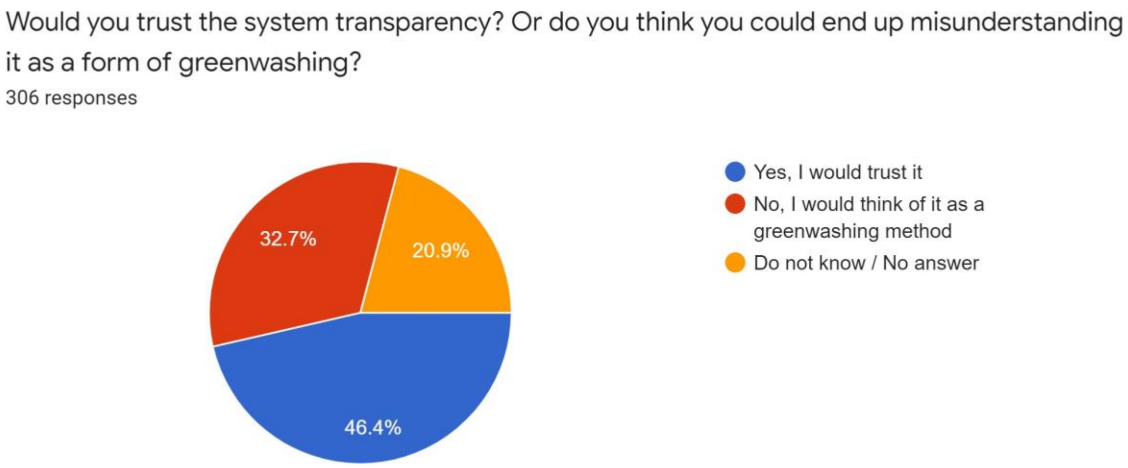

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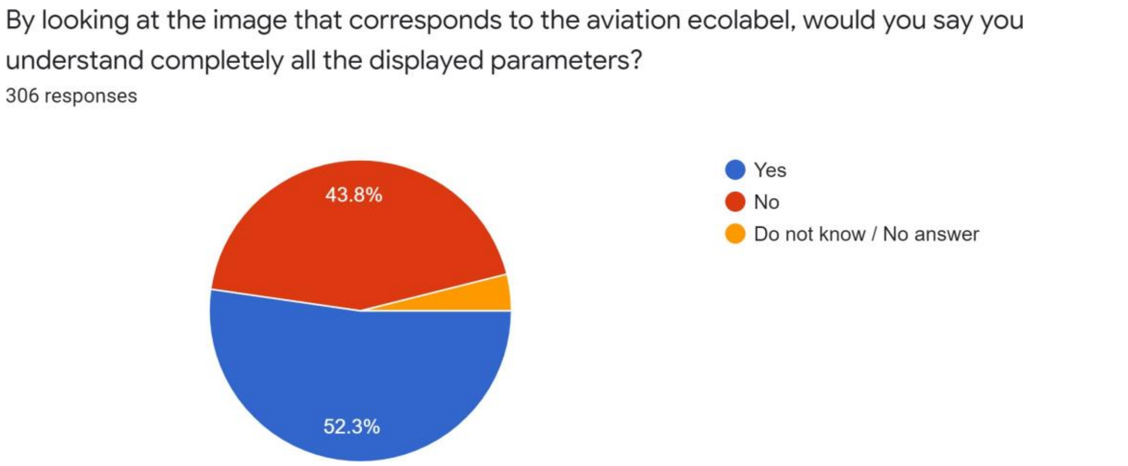

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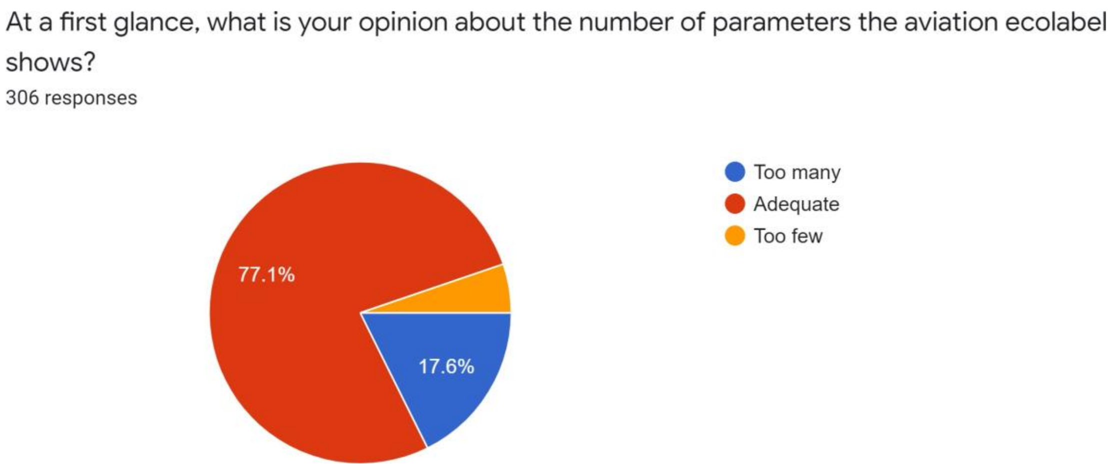

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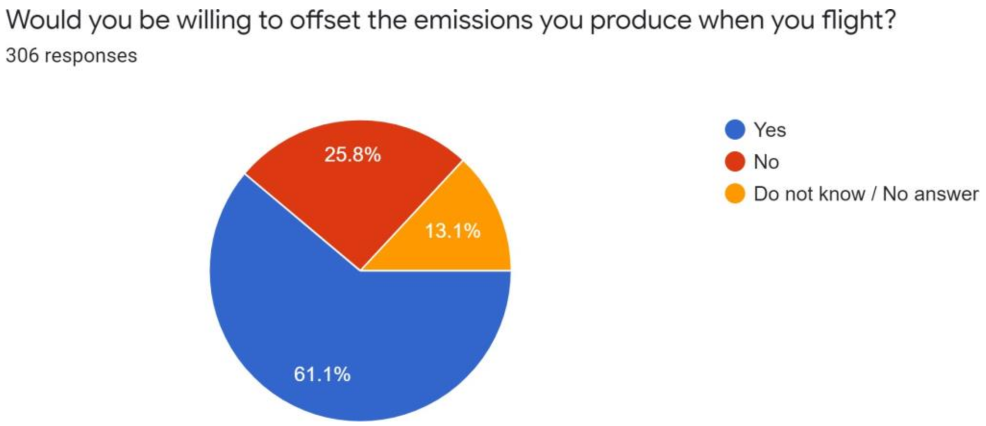

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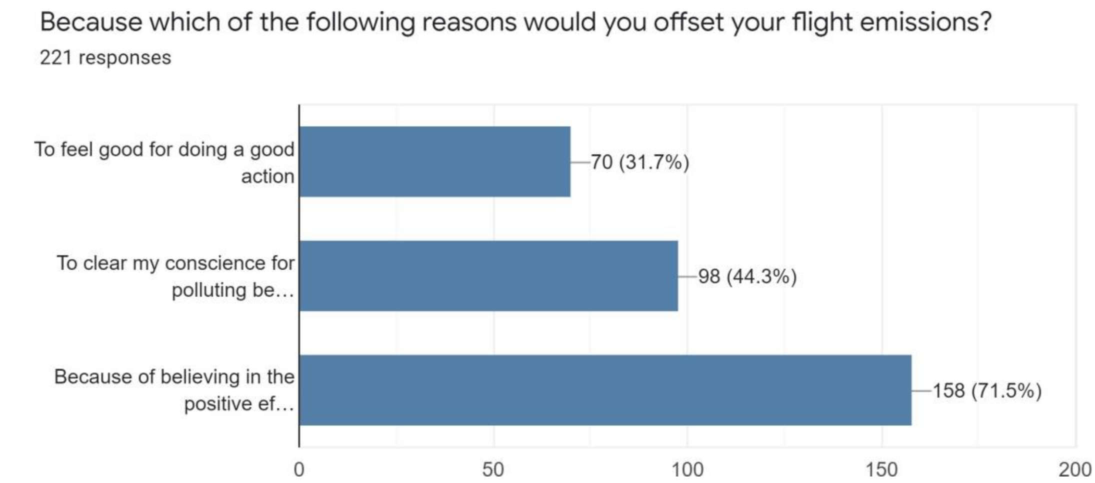

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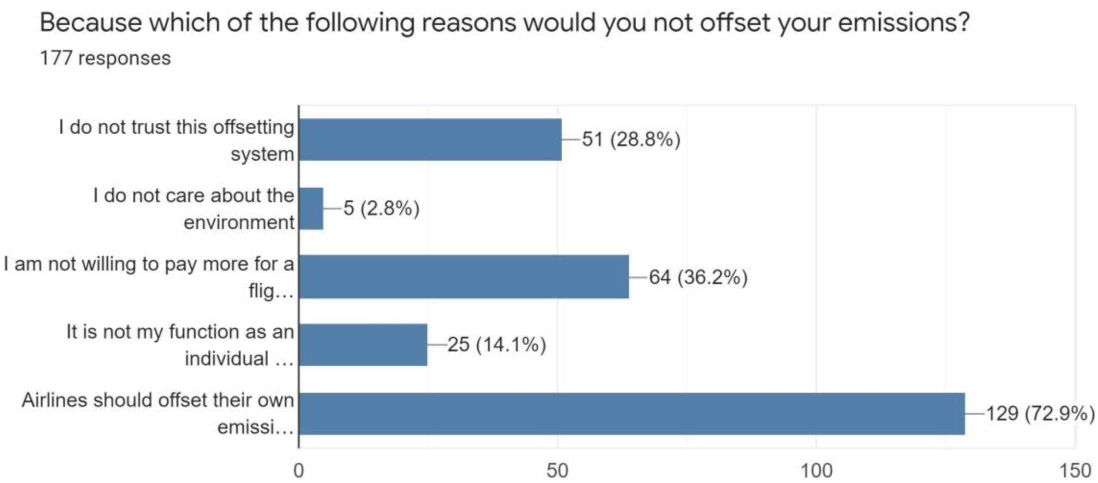

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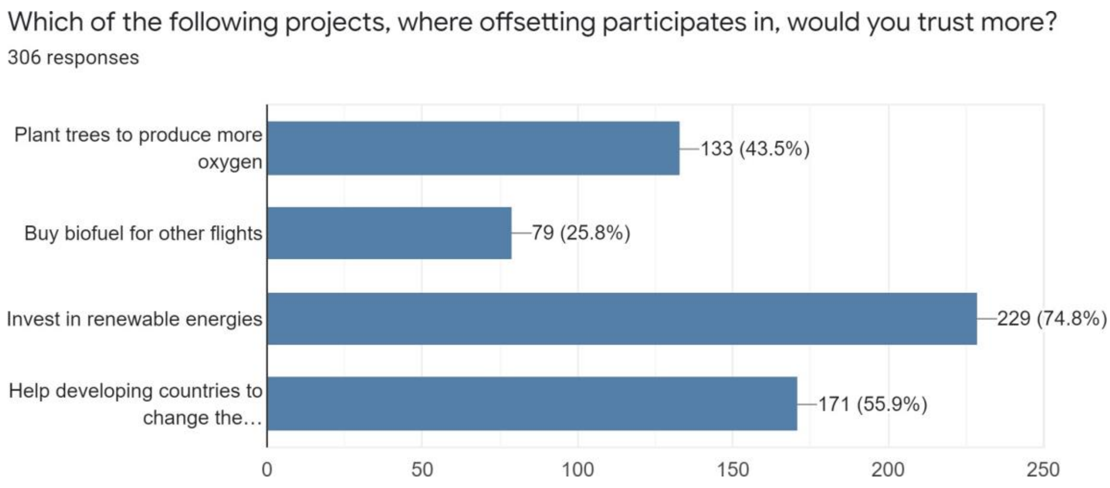

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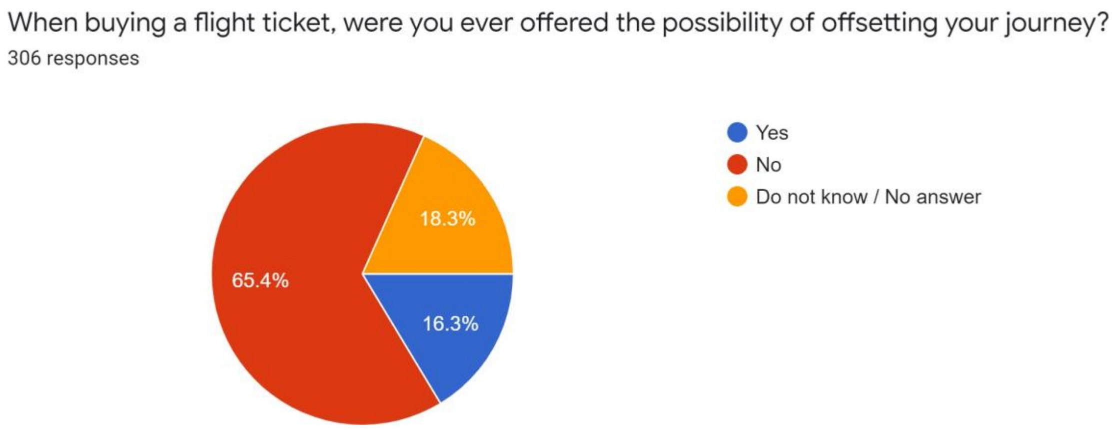

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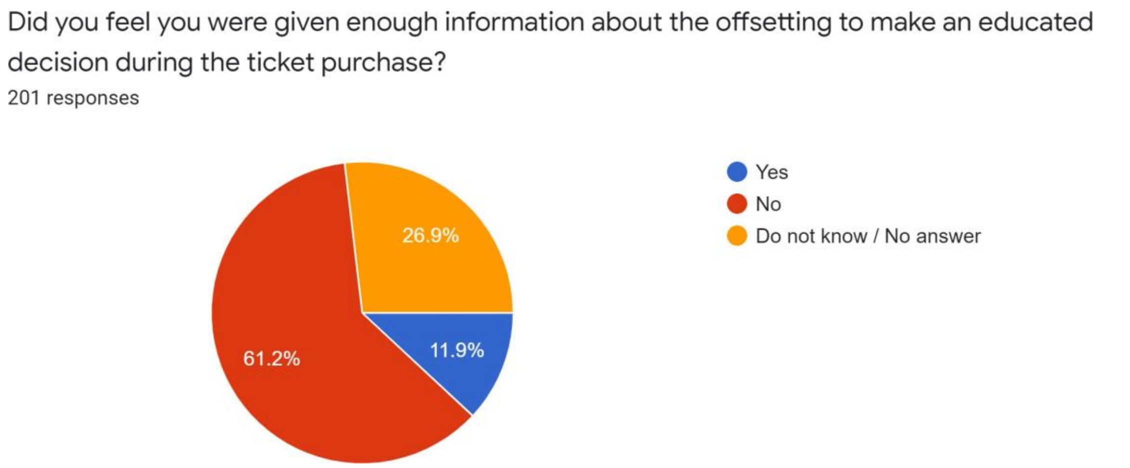

Figure 8.48 Answer to the question number 22 of the survey

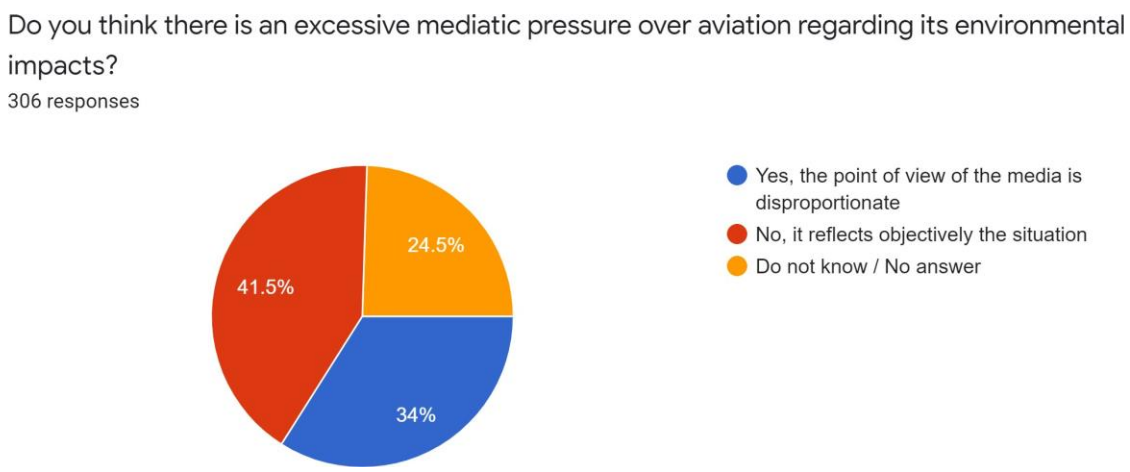

Figure 8.49 Answer to the question number 23 of the survey

8.2.3 Results Analysis

In previous sections some articles have been reviewed to extract conclusions of the surveys and interviews they carried out. Now the same will be done, but this time analysing the results of the specific survey designed for this thesis. This will allow to see if the doubts that appeared while working on it has been confirmed by the eventual users of the informative tool: the passengers. A total of 306 answers were obtained; this is a decent number of responses that assures a high level of accuracy in the results, if it was too small it will not be representative.

As it can be seen in the graphics, the majority of the people that answered the survey are young European males. This was not intentionally searched, but came out like this due to the nature of the type of population that could be reached.

The questions of the section called "Travelling behaviour" set the base to understand how important travelling by flying was in comparison to other transport means. As it was expected, long-mid range travels were not a daily thing: the majority of the respondents said to do a maximum of three of these kind of travels in a year. Moreover, as it was also thought beforehand, the majority of these journeys where performed by plane. If the total percentage of people that go on between 0 and 7 middle/long range trips in a year it can be seen how is just slightly smaller than the people that take a total of between 0 and 7 planes in a year. This confirms that currently, flying is the most popular way of going to distant locations. In order to see where does the remaining percentage come from, the next answer has to be considered. The majority of long trips, when not done by flying, it was because they were performed mainly by car or alternatively by train. These results meant no surprise.

When thinking about the advantages of flying over other transports, its speed is one of the first things that comes to one mind. This was clearly proved in the seventh question. This is why although there has been movements such as flightshaming to try to make people fly less, the time convenience that flying implies it is very difficult to counteract although its high pollution. This however comes at the cost of a higher price, which in the next question is stated as the reason that some respondents have had for not flying. It is interesting to see how some said that the high pollution levels was what prevent them from flying, it was just a minority. With these section the attitude of passengers in front the act of travelling was clarified. No surprises were found. Despite the idea that was repeatedly seen after analysing articles, surveys and interviews that because of environmental friendliness, people were willing to stop flying if needed, the assimilated conception of taking planes for going far from home is difficult to change.

In the next groups of answers, focused on the creation of an aviation ecolabel, the contrast between active and passive environmental awareness showed up again. In the previous question it was seen how a minority found environment a reason for stop flying, but the vast majority of them saw positively to be provided with an Ecolabel, something that not requires giving up personal privileges. This was again demonstrated because when asking if they would pay more for a "greener" flight, although tied up, there were more negatives than positives answers. To pay the higher price (an example with a 25% difference was set) a notoriously big ranking gap was needed for them: specifically of 3 grades. This shows that although there is a predisposition in population for taking care of the environment, if this invades important topics such as money without firm and clear advantages, no sacrifices are likely to be taken.

One of the main objectives repeated in the previous thesis that focused on creating an Ecolabel was the need of the qualification of the ecolabel by a scientific organisation. Since that it was seen complicated that in the beginning an institution such as the European Union did this, the Hamburg University of Applied Sciences was proposed several times as a possibly leader in this matter. In the survey it was seen how this was perceived positively by the respondents: the preference for an governmental institution or an external impartial non-governmental one was tied up. This shows that HAW could lead the spread of the Ecolabel without any problem. As it was seen in all the previously analysed surveys, the airline sector has not the best reputation and some of its practices are sometimes considered untrustworthy. Although the majority of people said that they would trust on the transparency of the Ecolabel, a considerable high percentage thought that they could end up misunderstanding it by greenwashing. This, together with the big amount of people that said to not understand completely all the displayed parameters and the and that agreed with the utility of providing information about the shown metrics, indicates that being honestly informed is one of the most demanded things by users of these kind of tools. They need to understand what they really consist on to, on the first hand, be able to make educated decisions about how to travel, and, on the second hand, be able to trust them. Schemes with a lack of clarity can not be successful in any way.

The final section asked about how passengers perceived the carbon offsetting emissions. This time, the difference between actively and passively tackling environmental impacts was again seen. The majority of passengers were willing to offset their emissions because they believed in the positive effects it implied, but hardly any of them were neither offered the possibility to offset the emissions of their flight nor given information about what offsetting consists on. It would be interesting to see how they would have answered to the first question if offsetting were a more common thing that they were offered on a regular basis. It has been already seen that the Ecolabel is seen as a positive idea, but when the time of paying comes, very few respondents are willing to pay more for a more environmentally friendly flight.

Not only this conclusion can be extracted from the offsetting section. The ones that said that they would not offset their emissions, the main reason was that airlines should be responsible for offsetting what they emit. Answers like this, together with the main idea of that the mediatic pressure that exists over the aviation sector is justified, helps to understand the bad reputation that airlines have in the environmental topic. It was seen how flying was kept from the Kyoto Protocol, and this was not until the Paris Agreement that some actions started to be demanded. The years of inactivity of the sector towards the environmental matter can imply very serious consequences if no immediate improvements are made.

9 Conclusions and Recommendations

9.1 Conclusions

During this thesis it has been possible to see a complete overview of the best tools that allow the passenger to understand the environmental impacts of not only their flight, but they trip, regardless of the chosen mean of transport. Not only existing tools have been examined, but new systematics have been created to improve how they can make an educated decision considering the environmental consequences of travelling. Some other conclusions have been extracted from the research that was done.

On the first hand, how the environmental awareness in passenger aviation has evolved has been understood by analysing it from the institutional point of view and the passengers perspective. It has been seen that the lack of initiatives of the sector regarding the environmental issue has had serious consequences in terms of reputation. Since airlines did not start taking measures until 2016 with the Paris Agreement, the industry began to gain an image of being excessively polluting and non reliable. Movements like "Fridays for Future" or "Fligthshaming" have campaigned for it. Airlines tried to tackle it by showing the passengers their improvements, but it has been discovered that due to their preexisting bad fame it was most of the times seen as greenwashing strategies.

Through the revision of several articles it has been understood that trustworthiness and fairness are the two main things that passengers ask airlines in terms of environmental impacts management. It has been concluded that most people are willing to take individual measures, such as fly less, choose greener options or pay higher taxes when booking a flight. However, they feel that if they are going to make these sacrifices, they need reasons to trust that they are not giving up privileges for nothing. They also want to feel a sense of proportionality: in case of taxes for example, by tackling frequent flyers more than sporadic ones. This is only achieved by openly informing them about any action of their concern. It was surprisingly seen at the specific survey designed for this thesis that although most of the participants wanted to offset their flight emissions, they were rarely given the option or they were not given enough information. This reflects the lack of transparency of the industry, something that really needs to change.

Giving the possibility to passengers of offsetting their carbon emissions is a strategy whose relevance has been growing over the years. Therefore it was essential to analyse it. Few conclusions could be taken about the basis of its calculations, since it is important to remember that they are private and voluntary initiatives. However, it was noticed again a sense of unreliability. Out of the several usages of the money collected with the offsetting, the reforestation of green areas is the most popular one. Considering the long term effect of this strategy; its volatility, since it is very difficult to make sure that trees last enough for covering the planned carbon emissions and the fact that it usually takes place in countries with complex political situations, again a sense of inconsistency is felt. The offsetting effect of trees can not be quantified, which not helps airlines to improve their image of opacity.

This idea of passengers offsetting their own emissions did not came out from scratch. It was an idea of airlines after they were forced to participate in such schemes but in bigger company levels. One of the most criticised ones is CORSIA, a market where participants buy the allowance of polluting. However, unlike other offsetting schemes, CORSIA does not work under an emission cap that gets lower every year. This has been the main source of critique: paying for what ones pollutes does not help to grow carbon free, it is just a way of cleaning one conscience, which is the same reason why offsetting in passenger has been widely disapproved. It is easy to see after all these blurry initiatives why the sector does not have the best reputation.

After understanding why the image of the sector is so damaged it was seen that informing the passenger about the environmental impacts of their flight was essential. It was determined that the existing Ecolabel for aircraft could be improved. By studying the EU Energy label, a successful and mandatory scheme for household appliances, it was concluded that for being effective, the Ecolabel had to be compulsory as well. Moreover, a new designed was proposed: the way in which the environmental metrics were displayed was modified and a second page that included explanatory information about how these metrics were obtained was added. Since it was discovered that the lack of transparency was a very serious problem, providing this was indispensable.

By taking a step back it was realised that when the passenger was willing to be informed about the environmental impacts of travelling, the only systematic he was offered to follow was to consult the Ecolabel, which was determined to be insufficient. With just it, it was impossible to compare one flight that follows the most route with other that needs to perform a considerably big deviation. This was solved by computing the approximate distance of both flights with the help of Flight Route Calculator and multiplying it by the CO_2 Equivalent Emissions metric. On the other hand, since with just the ecolabel flights could not be compared with other transport means, a solution had to be found. It was determined that gathering small existing tools was the most efficient idea, and this was how the CO_2 Flowchart and the Eco Table were born. The two of them solved the problems previously stated but by following different philosophies: one by exclusively comparing carbon dioxide emissions trough forcing the user to follow a guided path, and the other by providng an all-metrics comparison where the user could check metrics individually.

It can be finally concluded that the resolution of the study has been satisfactory. By studying the interaction of the aviation and the environmental awareness from different perspectives it has been possible to understand which are the needs of the informative tool that people demand to know the environmental consequences of travelling.

9.2 Recommendations

Although it has been already said that the outcome of this thesis has been satisfactory and the established objectives have been fulfilled it is obvious that there is still work to to and room for improvement. The recommendations that will be given will be mostly centered on the informative tools and systematics and the offsetting schemes, which are the points still under development, as well as the study of the changes the sector is performing to advance towards a more sustainable future.

On the first hand, regarding the informative systematic, there is a lot of work to do. Before this thesis there were already two models of Ecolabels and a huge task of research behind by various students and even airlines, which makes the third generation of Ecolabel created in this tehesis a very polished and refined product. However, this is the first time that it has been aimed to create an informative and comparative tool that encloses different transport means. This means that this first proposal can be widely improved, in terms of design, operativity, used sources and even its concept itself. For instance, instead of a Flowchart, where the user has to manually follow a path and enter in the online links one by one, a smartphone app that ease this task could be programmed.

It could consist on a simple but clear system where in the screen the questions asked in the flowchart would appear. Depending on the answer of the passenger, in the screen would appear then another question. It would be useful that in these screens the user introduced the same metrics they would do in each of the websites provided in the flowchart, but in a more appealing interface. The app could have running these websites beneath, so they could take advantage of already existing tools. The system could save all the answers to finally show the user a summarise of the consequences of their travel and an automatic outcome of the comparison, advising them which transport to take. By linking it to Google Maps, the time of the journey and exact locations of origin and departure could be also displayed. In these way, not only the environmental costs, but the travelling distance and the duration of the travel would be provided to the passenger. Moreover, it is pretty sure that with the years new and better tools would appear. The problem that exists currently is the lack of standardisation: the majority of the proposed tools that conform the Flowchart and the Eco Table are not official sources, which does not allow to perform strict calculations, just approximated comparisons. This is why a continued research has to be carried out in this matter. However, this is not a worrying topic, since with the increasing awareness that the climate change is arising, constant advances are made.

The other problem that both tools have, which has been commented several times, is the fact that although they allow to do a global comparison where all transport means are taken into account, it is clearly performed by an aviation-centered point of view. It can not be forgotten that this thesis exists in the framework of the department of aeronautical engineering. The complete tool is born having the Ecolabel as the basis, which is purely an aviation tool. If a higher level of accuracy wants to be achieved a cooperation with other departments would be highly recommended. If the same work of the aviation Ecolabel was performed with cars, buses, ships and trains, creating new ecolabels under the same standards, transversely comparisons could be performed. Furthermore, students specialised in other means of transport are very likely to know different and better tools for computing metrics for the vehicles of their fields, which will undoubtedly improve the quality of the conclusion extracted after the comparison.

Regarding the the Ecolabel itself, which has been one of the most important tools, there are some improvements that could be made with the years. One of the main steps is to make the Ecolabel be a scheme accepted by an institution such as the EASA, ICAO or IATA to spread its use among airlines. If this happened a standard could be created. Moreover, with the power institutions like these have, airlines could be forced to share intern data. This would improve the quality of the sources of information used until the date, such as flight plans. This would help to avoid to use approximated applications such as the Flight Route Calculator. If not, the actual flown distance if a deviation has to be performed is impossible to be known.

On the other hand, although seeming a less important point, the use of plastic onboard can be the protagonist of following investigations. Currently, most of airlines use a lot of plastics in form of cups, cutlery, dishes or different bags. By addition it turns out to be a huge amount of unnecessary plastic as it has already been warned, such as in articles like (Pepper, 2018). If these were changed to recyclable paperboard a big step would be made. There are some airlines that claim to have reduce the use of plastic, such as SAS at (SAS, 2019b), but there is very few information. With the rise of environmental consciousness this topic is very likely to win relevance. If this happens, the metric "Amount of plastic per person" could be included in the Ecolabel. If the paperboard was certified by institutions such as the FSC, that guarantees that the paper used in a product is environmentally responsible, it could be said as well.

Secondly, there is still room for studying how the offsetting schemes evolve. In 2021 the fourth phase of the EU ETS scheme will begin, as well as the CORSIA scheme will officially do. Interesting studies could be made to see the consequences of the coexistance of these two emissions trading systems as well as the change or not of behaviour of the evolution of carbon emissions.

It is also advised to analyse how the perception of tools such as the Ecolabel or the offsetting methods that airlines offer change when they settle more firmly in the sector. It is important to remember that the Ecolabel is a quite recent tool, and the possibility of offsetting the emissions as well (so much recent that most of passengers do not know about their existence). The review of articles that analyse how these two methods are seen by passengers via surveys should be repeated in some years to see if the perception has changed substantially. If the Ecolabel was taken by an official institution to set an standard this comparison would be even more interesting.

Finally, as it has said in some occasions, this thesis was written in the middle of the pandemic of covid-19. Currently the airline sector is living a strange moment where several limitations are imposed for health reasons. Some airlines are having financial problems due to the sudden reduction of activity. Some people are starting to accept the fact that currently flying is not possible due to the lack of offer and other means of transport have to be taken. It will be very interesting to analyse if with the years these situation changes and goes back to normal or, together with the before-covid though flying restrictions (for environmental reasons), the demand of flight tickets fall. On the other hand, before the pandemic, making the airline industry a more sustainable sector was one of the most relevant topics on the agenda, but now priorities have changed for obvious reasons towards making fly safe for health. It will have to be seen if making the sector more environmentally friendly gains again the importance that it used to have.

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