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Project

Calculating and Comparing Ecolabels for Popular Passenger Aircraft

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Abstract

This project produces Ecolabels for the most flown aircraft to compare their environmental impact. For this matter, different aircraft types, cabin layouts from various airlines and several engine configurations are taken into account. The general buildup of an Ecolabel is described, and its criteria elements are highlighted. It is based on existing methods, algorithms, rating scales and a basic architecture of an Excel calculation tool. In this project, functions to automatically create and print the Ecolabels have been added to the Excel tool. The usage of Ecolabels is demonstrated on using the example of four significant case examples covering a variety of comparison possibilities. The performed evaluations show the potential of Ecolabels by comparing low cost with legacy carriers, two different airline fleets, three engine configurations on the same aircraft type and two manufacturers with a similar aircraft size. One major result of the calculation of Ecolabels in aviation in this project is the better rating of aircraft with a higher seating density of passengers. The usage of the Ecolabel should support the airline passenger to make him aware of his own environmental impact.

Calculating and Comparing Ecolabels for Popular Passenger Aircraft

Task for a *Project* according university regulations.

Background

It can be observed that new passenger aircraft are advertised with many claims about their environmental advantages compared to a reference model and compared to the competition. These advertisement claims are often not verifiable, not based on any reporting standards (due to a lack of such standards), and generally not backed up by any scientific work. For this reason an "Ecolabel for Aircraft" has been defined by students in Bachelor and Master Theses at the University of Applied Sciences Hamburg. The idea was also presented at the German Aerospace Conference 2017 (http://bit.ly/2HSTOoj). The goal is to enable the travelling passengers to make an educated choice among different airline offers (with a certain aircraft and a certain seating arrangement) such that the selected (direct) flight is the least damaging to the environment. The "Ecolabel for Aircraft" quantifies energy consumption and pollution by way of index scores or units of measurement. The final result is an overall rating (0 to 1) illustrated by a letter between A (best, green) to G (worse, red).

Task

The task is to calculate all required parameters for the "Ecolabel for Aircraft" (see previous work at University of Applied Sciences Hamburg) for many popular passenger aircraft and to compare and discuss the results. Following subtasks have to be considered:

- Review and finish the definition of the "Ecolabel for Aircraft" as presented by Lynn Van Endert. Take note of her chapter "Recommendations".
- Automate the Excel tool by Van Endert for the Ecolabel calculation.
- Include a chapter in the project report that serves as a User Guide for the software.
- Calculate and print Ecolabels for the most popular aircraft.
- Compare and discuss the created Ecolabels and draw conclusions for an environmentally friendly air transport.

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

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List of Symbols

AR	Airline rating
m	Mass
$N_{A/C}$	Number of aircraft type in fleet
$O_{A/C}$	Overall aircraft rating
R	Range
$S_{A/C}$	Number of seats per aircraft

List of Abbreviations

CO	Carbon monoxide
EASA	European Aviation Safety Agency
HC	Hydrocarbon
ICAO	International Civil Aviation Organisation
LTO	Landing – Take-Off Cycle
MTOW	Maximum Take-Off Weight
NMVOC	Non-Methane Volatile Organic Compound
NO_x	Oxides of Nitrogen
OEM	Original Equipment Manufacturer
PM	Particular Matter
SAR	Specific Air Range
TCDSN	Type-Certificate Data Sheet for Noise

List of Definitions

Aircraft Data Set
An aircraft data set contains all relevant values for the calculation of one Ecolabel. In the excel tool it can be found in a row within the "Database" sheet.

Cabin Layout
The cabin layout defines the cabin sections in which passengers travel. It defines the separation of the cabin in several zones such as different travel classes, galleys and areas for flight attendants. The cabin layout differs from one airline to another. (**Wikipedia 2018a)**

Ecolabel

An Ecolabel marks products or services by rating the most important environmental factors to give the consumer an overview of the environmental impact of the product. In comparison to a detailed technical specification, an Ecolabel visualizes the most important product properties at a glance. (**EuroCom 2018**)

Ecological Footprint

The Ecological Footprint describes the impact of human activities measured in terms of the area of biologically productive land and water required to produce the goods consumed and to assimilate the wastes generated. More simply, it is the amount of resources necessary to produce the goods and services necessary to support a particular lifestyle (**WWF 2018**).

Fleet consumption

The fleet consumption describes the average fuel consumption per passenger of the whole fleet of an airline. Usually it is given in l per km (or hundred km) per seat. (**BdL 2018**)

Fuel consumption

Fuel is the product of refining fossil oil. It is used to release energy or heat through combustion. In aviation context, fuel is a phrase for kerosene, which is used to power the aircraft engines. Consumption describes the burned fuel during a flight. (**BdL 2018**)

Landing and Take-off cycle

The LTO cycle is defined by ICAO to limit or reduce the impact of aircraft engine emissions on local air quality. It covers four modes of engine operation, which are named idle, take-off, climb out and approach. Each of them is associated with a specific engine thrust setting and a time in mode. For each mode measured and/or calculated values have to comply with defined limits. (**EASA 2018c**)

Legacy carrier

The original definition of a legacy carrier describes airlines, which have been founded early in aviation history and have undergone the economic, technological and social evolution of air transportation. Today's definition has expanded; it may also include newer airlines which provide a high-class travel service and have a good reputation. (**Wikipedia 2018b**)

Low cost carrier

Low cost carriers offer low priced airplane tickets. These flights are offered by renouncement of the usual comfort aspects like a reduced seat pitch and additional services, such as drop-off baggage or catering services. (**Stainton 2019**)

Oxides of Nitrogen (NOx)

NO_x is produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures. The occurrence of NO_x can result in smog and acid rain, which may cause adverse health effects. (**DAS 2018**)

Rating scale category

A rating scale category is defined by two values (upper and lower limit). Ratings which lie between the limits belong to the corresponding category. The aim of this categorization is to simplify the recognition whether a value is good or bad without precise inspection and comparison of other values. (**Wikipedia 2018c**)

Seat pitch

The seat pitch is the distance in flight direction between a defined point on the seat (usually the back rest) and the identical point on a successive seat. (**Skytrax 2018**)

Seat width

The seat width is the distance between the armrests of a seat. (**Walton 2018**)

1 Introduction

1.1 Motivation

Nowadays the environmental awareness has gained attention in many aspects and has become an important role within our society. Energy consumption has become a significant criterion of the ecological footprint. Buying household aids like a TV or refrigerator, the customer is shown a short visual information about some basic data of the device. The overall performance of a device is illustrated in energy efficiency classes from A (very good) to G (bad). The classes are encoded in colors for convenience. Additionally, specific information is given. Consequently, features for e.g. a refrigerator like annual power consumption and volumetric capacity are accessible without any deeper research or technical understanding. It is easier for the customer to make a purchase decision from the ecological point of view since extensive research to collect all information is not necessary anymore.

In aviation this labeling is not common. Mostly known is the fleet consumption, which had a value of 3,64 l per head per 100 km for German airlines in 2016 (**BdL 2017**). However, this indication is not helpful for a single passenger as the per-head-consumption differs between individual aircraft models. As well there is no information about the fuel consumption within different travel classes. This information cannot be found as easily as for a household aid. Therefore, the passenger has no other choice as to trust the assertions of airlines.

1.2 Objectives

In this project, results from preceding theses (with their focus on theoretical development) are used to create Ecolabels in an easy and efficient way. The objective is to create a digital "printer" for Ecolabels and to show how they could be used to compare the environmental impact of single passenger seats, different travel classes, various aircraft types or even whole fleets.

1.3 Literature

This project is based on the bachelor thesis of **Haß 2015**, where the first definition of an Ecolabel was made. This bachelor thesis can be read for additional information; however, it is not fundament of this project.

This definition was intensified in the research of **Van Endert 2017**, where methods for a calculation of an Ecolabel are created and algorithms, rating scales and the basic architecture of the Excel tool have been specified. This project carries forward the results of the master thesis.

1.4   Structure of the Project

Chapter 2   Introduction into calculations, relevant data and their origin, the origin of applied scales and the general design structure of the Ecolabel

Chapter 3   Description of the basic Excel tool and the added functions, relations and databases, including a handbook how to implement new aircraft data sets and finally, how to export an Ecolabel

Chapter 4   Comparison of produced Ecolabels of selected cabin configurations, engine and aircraft types and fleets, followed by a short interpretation

Chapter 5   Critical discussion of achieved results, source reliability and potential improvements

Chapter 6   Conclusions of the project

2 Fundamentals

To understand the various parameters, which are necessary to calculate an Ecolabel, this chapter gives an overview about the most significant properties of the Ecolabel. An example of the design of the Ecolabel by **Van Endert 2017** is given below. Be advised that a comma is used as decimal separator.
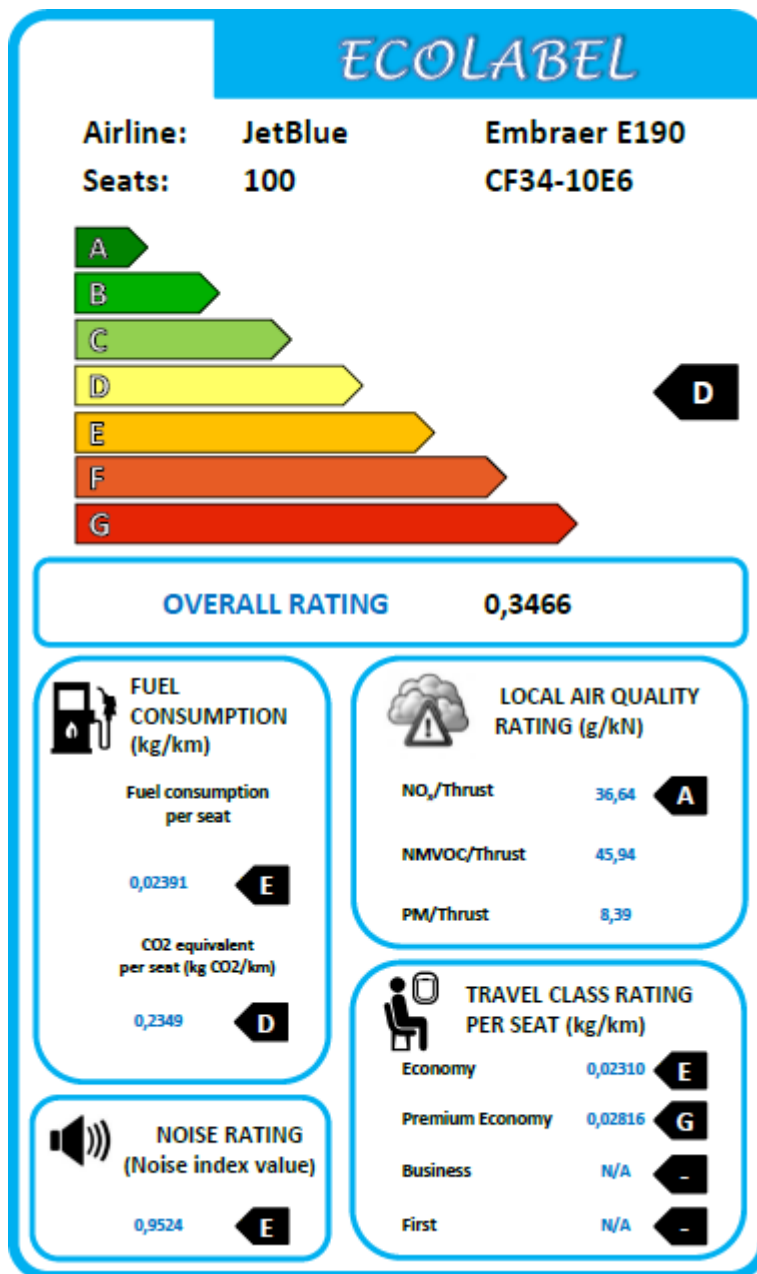
Figure 2.1   Design example of an Ecolabel (**Van Endert 2017**)

At the top of the Ecolabel information about the airline, specific aircraft type, total number of seats and engine type is given. It is followed by the seven rating scales from A to G which are colored from green to red. The overall rating gives a summary of the fuel consumption per

seat, CO_2 equivalent per seat, noise rating and overall air quality rating. As the chosen travel class influences the relative impact by the passenger, an additional travel class rating is calculated.

The categories will be explained in the following chapters.

2.1   Relevant Data for Ecolabel Calculation

The Ecolabels are calculated according to **Van Endert 2017** by considering climate impact according to the produced CO_2-equivalent, fuel consumption, local air quality and noise pollution.

To determine the overall rating, weighting factors for the different indicators are introduced based on the life cycle assessment by **Johanning 2016**. In his work, Johanning discovered that climate change and resource depletion are the main contributors to negative environmental impacts. Both values are determined by the aircraft's fuel consumption. Van Endert choses a rounded ratio of 2,0 between the two categories, leaving 20% for both the local air quality and noise pollution.

$$
\begin{aligned}
& Overall\ rating \\
&= 0{,}4 \cdot (CO_2\ equivalent) \\
&+ 0{,}2 \cdot (fuel\ consumption) \\
&+ 0{,}2 \cdot (local\ air\ quality) \\
&+ 0{,}2 \cdot (noise)
\end{aligned}
\tag{2.1}
$$

The following subchapters provide an overview about meaning, origin and application of the data used.

2.1.1   Fuel Consumption and CO_2-Rating

To evaluate the fuel consumption, the Specific Air Range (SAR) is used. The SAR describes the distance that can be covered with one kg of fuel. The needed values for our work to calculate the SAR are taken manually from the Payload Range diagram (Figure 2.2) since the SAR data is not publicly available.
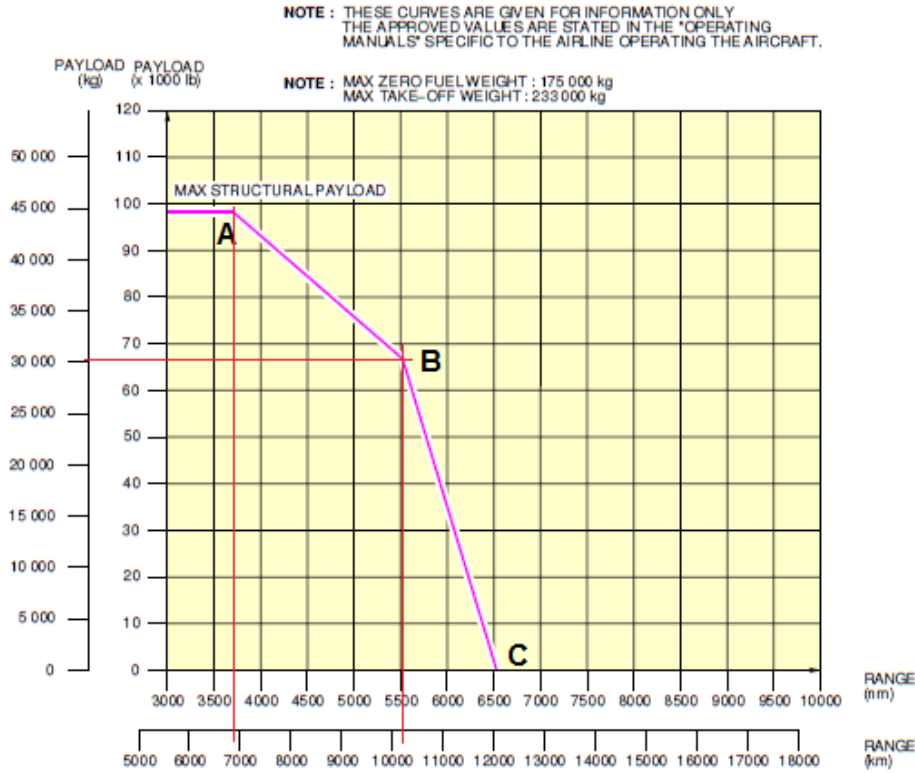
Figure 2.2   Payload Range diagram for A330-300 with PW 4000 Series Engine (**Airbus 2017a**)

Point A marks the range at maximum payload. The MTOW is reached; no more fuel can be taken on board. To increase the range further, the payload has to be reduced or in other words changed into fuel. Point B marks the configuration with reduced payload and full fuel tanks. A higher range can only be achieved by further reduction of payload. The greatest range is marked at point C with zero payload, the so-called ferry range. Between point A and B, so to speak a switch from payload to fuel is performed. This creates a direct dependence between mass of fuel and reachable range.

The gradient of the graph between point A and B is interpreted as SAR. It shows a direct dependence between the fuel mass and the range. In other words, it delivers a value of how far you can travel with a certain amount of fuel. The SAR is used to calculate the fuel consumption per km per seat, depending on the travel class. As well the CO_2 equivalent per seat is considered and gives a rating about the climate impact, which depends on many aspects and is given in the amount of CO_2 in kg per km. The values are only average for the seats which does not give specific information about the travel classes. The fuel consumption per seat is explained more detailed in Chapter 2.1.4.

The gradient is calculated by Formula 2.2. As depicted in Figure 2.2., R_A and R_B are the derived ranges, m_A and m_B the derived payloads at point A and B respectively.

$$SAR = \frac{R_B - R_A}{m_B - m_A}$$

(2.2)

2.1.2 Local Air Quality Rating

For the air quality rating, the acquisition of smoke number and fuel flow during take-off, climb, approach and idle is necessary, as well as the mass of emitted CO, HC, NOx and the consumed fuel during a LTO cycle. These numbers are extracted out of ICAO Engine Exhaust Emissions Databank (**ICAO 2017**).

The local air quality values consist of NMVOC-equivalents (non-methane volatile organic compound or ozone formation potential) and PM-equivalents (particulate matter formation potential), which are calculated by converting relevant emission products and by NOx-emissions.

The NOx-emissions during the LTO cycle represent the effects of aircraft movement on the local air quality in the Ecolabel and have a more significant impact then the other two equivalents, which are included on the Ecolabel for additional information. To ensure a fair comparison between different engine thrust categories, these three parameters are set into relation to the generated thrust. For example, the emitted NOx-emissions are given in grams per kilonewton.

2.1.3 Noise Rating

Noise information is taken from the TCDSN (**EASA 2018a, EASA 2018b**). Noise level is measured in three different flight phases or positions, named lateral, flyover and approach. A limit is defined for each measurement by authorities, depending on aircraft type and engine. The published document contains both level and limit for each existing combination of engine and aircraft. For further calculations, the actual noise level is divided by the limit; they are set into relation. This percentage is used to determine the noise index value according to Chapter 2.2. The higher the noise index value, the worse is the rating category.

Noise pollution can have a direct impact on our environment and an effect on the health of people who live near airports. Hearing loss is the most common and often discussed health effect, but research has shown that exposure to constant or high levels of noise can cause countless adverse health effects. These could be a higher blood pressure, sleep disruption and stress related illnesses. Therefore, it is important to keep the noise pollution and hence also the noise index value low (**Spector 2018**).

2.1.4 Travel Class Rating per Seat

The cabin layout is important for calculating the environmental impact of a single passenger seat, depending on the travel class. Therefore, the number of seats per travel class is needed as passenger comfort is expressed in leg room and space. To compare seats of different travel classes, the required area of one seat is calculated out of the seat dimensions. For this value, the seat pitch must be multiplied with the seat width. All data is taken from www.SeatGuru.com, which features seat maps for all major airlines and aircraft on the market (see Appendix A for references). As a result, the fuel consumption in kg per km per seat can be extracted from the Ecolabel and gives more information about differences between travel classes. The travel class rating does not participate in the overall rating.

2.2   Scaling

To enable an easy assignment of the intended categories from A to G, each calculated range of values is normalized from 0 to 1. The steps between the categories are related to the World Airliner Census 2016 (**Flight International 2016**). The aim is to have the same number of aircraft in each category; this means every category must contain roughly 14% of the number of all aircraft in service. Considering the fact that the number of all Boeing 737-800 and Airbus A320 together exceeds 30% of all aircraft in service and that these aircraft types are quite modern, the consequence is a smaller value range within a rating category. The rating scale is defined from A (the best) to G (the worst). They are marked in colours from green to red, green as an indication for very good and red as an indication for very bad.

The scaling consists of values that represent the status of July 2016 (publication of World Airliner Census 2016). It may happen that more efficient aircraft will be introduced and so the achieved values are located out of the range (better than the best). A similar situation was with European Union's Ecolabels for household aids; they first introduced category A+, later A++ and so on. To avoid an obscure category adaption, the convention is to just extend category A to the best achieved value. This does not falsify the result, because the percentage of newly introduced aircraft compared to the number of (worldwide) all aircraft in service is very low. However, after a certain period of time (maybe every 10 years), it is recommended to update the scaling.

From **Van Endert 2017**, two rating scales for noise pollution have been developed (jet and turboprop). This project aims for a comparability of all aircraft, so a new rating scale has been derived, considering both jet and turboprop engines. The result of the new calculation is shown in Table 2.1. A description of the calculation algorithm and a visualization of the value range is given in Appendix B.

Table 2.1   New calculated rating scale for noise pollution

Category	Min	Max	Normalized	Min	Max
A	0,8175	0,9278	A	0,0000	0,6027
B	0,9278	0,9396	B	0,6027	0,6676
C	0,9396	0,9466	C	0,6676	0,7060
D	0,9466	0,9519	D	0,7060	0,7346
E	0,9519	0,9564	E	0,7346	0,7595
F	0,9564	0,9643	F	0,7595	0,8026
G	0,9643	1,0004	G	0,8026	1,0000

3 Excel Tool

3.1 Preexisting Tool

Part of the thesis of **Van Endert 2017** is a tool created with Microsoft Excel to calculate Ecolabels. The tool contains sheets with revised data from **EASA 2018a** as well as **EASA 2018b** ("TCDSN_Jets/Props") and **ICAO 2017** ("PM"). All needed values for the calculation have to be searched in these tables, depending on the aircraft to be evaluated, and entered manually in the sheet "ECOLABEL". Additionally, the cabin configuration must be extracted from the Internet. Putting all those values in the right place, the necessary calculations are executed automatically and updated in the Ecolabel graphic nearby. The small flags to mark all the rating categories from A to G have to be added manually.

3.2 Motivation for a More Usable Tool

The first try to create an Ecolabel took roughly two hours. All the necessary data had to be extracted manually from data sheets within the Excel file and with the help of the Internet for specific seat configurations. This may be acceptable for one label, but for a decent basis to compare multiple aircraft, fleets and variants, this is not an appropriate timeframe. As well it was not possible to save calculated Ecolabels in one file. Each saving of an Ecolabel involved a whole Excel file with information, which was not relevant for the evaluated Ecolabel. Furthermore, there was no possibility for further use of the calculated Ecolabel to illustrate it for example on a travel website. Consequently, the decision to automatize the tool was made.

3.3 Ecolabel Printing Tool

First, an additional data sheet named "Database" was introduced to structure data appropriately. In this sheet, several VLOOKUP-functions are implemented to complete entries from all the other sheets which hold information for noise rating, air quality rating etc. Depending on aircraft and engine type selected in the "ECOLABEL"-sheet, the VLOOKUP-function is now able to search the other sheets for the needed values. It is a lot more time saving to fill the database-sheet with this function than scrolling manually through many columns in order to find the correct value. The "SAR"-sheet is used to file data about SAR (extractions from Payload Range diagrams) and the MTOW. The cabin layout still has to be entered manually; it would be a big effort to store all cabin configurations of all airlines in a database.

	General Information	
AircraftType	**Thrust (kN)**	**MTOW (kg)**
Airbus A319	=VLOOKUP("*"&C4&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A4&"*";SAR!A:G;7;FALSE)
Airbus A319	=VLOOKUP("*"&C5&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A5&"*";SAR!A:G;7;FALSE)
Airbus A319	=VLOOKUP("*"&C6&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A6&"*";SAR!A:G;7;FALSE)
Airbus A320	=VLOOKUP("*"&C7&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A7&"*";SAR!A:G;7;FALSE)
Airbus A320	=VLOOKUP("*"&C8&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A8&"*";SAR!A:G;7;FALSE)
Airbus A320neo	=VLOOKUP("*"&C9&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A9&"*";SAR!A:G;7;FALSE)
Airbus A321	=VLOOKUP("*"&C10&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A10&"*";SAR!A:G;7;FALSE)
Airbus A321	=VLOOKUP("*"&C11&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A11&"*";SAR!A:G;7;FALSE)
Airbus A330-200	=VLOOKUP("*"&C12&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A12&"*";SAR!A:G;7;FALSE)
Airbus A330-200	=VLOOKUP("*"&C13&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A13&"*";SAR!A:G;7;FALSE)
Airbus A330-200	=VLOOKUP("*"&C14&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A14&"*";SAR!A:G;7;FALSE)
Airbus A330-200	=VLOOKUP("*"&C15&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A15&"*";SAR!A:G;7;FALSE)
Airbus A330-300	=VLOOKUP("*"&C16&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A16&"*";SAR!A:G;7;FALSE)
Airbus A330-300	=VLOOKUP("*"&C17&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A17&"*";SAR!A:G;7;FALSE)
Airbus A330-300	=VLOOKUP("*"&C18&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A18&"*";SAR!A:G;7;FALSE)
Airbus A340-300	=VLOOKUP("*"&C19&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A19&"*";SAR!A:G;7;FALSE)
Airbus A340-600	=VLOOKUP("*"&C20&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A20&"*";SAR!A:G;7;FALSE)
Airbus A340-600	=VLOOKUP("*"&C21&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A21&"*";SAR!A:G;7;FALSE)
Airbus A350-900	=VLOOKUP("*"&C22&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A22&"*";SAR!A:G;7;FALSE)
Airbus A350-900	=VLOOKUP("*"&C23&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A23&"*";SAR!A:G;7;FALSE)
Airbus A380-800	=VLOOKUP("*"&C24&"*";PM!C:S;4;FALSE)	=VLOOKUP("*"&A24&"*";SAR!A:G;7;FALSE)

Figure 3.1:   VLOOKUP-functions in the newly introduced "Database"-sheet

Next, several macros have been programmed. The one named "Tabelle16.Overall_Rating" is responsible for updating the markers of the matching rating category. For this function, a rating scale table was created to store the limits of each category, derived from **Van Endert 2017**. The macro must be triggered by the adjacent button ("Calculate Ecolabel") every time the aircraft data set is changed in order to have a correct indication.

Two macros ("Tabelle16.AirlineReset", "Tabelle16.EngineReset") in combination are responsible for the selection menu. They assure that only valid combinations of aircraft type, airline and engine can be selected as prescribed in the database. To get a proper basis for the selection menu, an additional data sheet was created, named "Auxiliary Data Sheet". In this sheet, the lists for the following drop-down menus are created. One macro implemented in this sheet (named "AuxiliaryFilter") executes the so-called "FilterCopy". Result of this function is a listing of all aircraft types without duplicates. Provided with a dynamic function to define the list length, this list is the basis for the aircraft type selection menu in the sheet "ECOLABEL". According to the selection, a formula searches for matching airlines who operate the aircraft type, and out of this combination, another formula searches for available engine types. This information is displayed in the columns B and C of the Auxiliary Data Sheet and also provides the basis for the selection menus. Two macros are implemented to reset the engine type when the airline selection is changed, or to reset both engine type and airline after changing the selected aircraft type. With this function, it is ensured that only valid combinations of aircraft type, airline and engine type are selectable. The last macro ("PDF_Print") is used to create a PDF-file of the Ecolabel with the selected values.

Figure 3.2:   „Auxiliary Data Sheet" to feed the selection menus on the main "ECOLABEL"-sheet

3.4   Creation of a New Aircraft Data Set

To create your own custom aircraft data set which has not already been entered by the developer, click on "Database" on the Excel worksheet tabs bar.
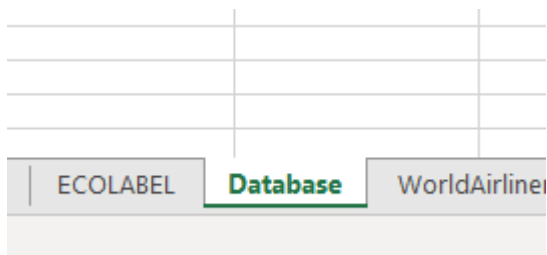
Figure 3.3   Selected „Database"-sheet

Scroll down to the bottom of the table until you reach an empty row. Insert the name of your aircraft into the column "Aircraft Type"

	A	B	C	
1	**General Information**			
2				
3	*AircraftType*	*Airline*	*Engine type*	*Th*
43	**Boeing 777-300ER**	KLM	GE90-115B	
44	**Boeing 777-300ER**	Air France	GE90-115B	
45	**Boeing 787-8**	Norwegian	Trent 1000-A	
46	**Boeing 787-9**	Air New Zealand	Trent 1000-H	
47	**Boeing 787-9**	KLM	GeNx-1B	
48	**Boeing MD-90**	Delta Airlines	V2525-D5	
49	**Bombardier CRJ100**	Air Canada	CF34-3B	
50	**Bombardier CRJ700**	Air France - HOP!	CF34-8C1	
51	**Bombardier CRJ900**	Lufthansa	CF34-8C5	
52	**Embraer ERJ-145**	American	AE3007A1	
53	**Embraer E170**	Egyptair	CF34-8E5	
54	**Embraer E175**	LOT	CF34-8E5	
55	**Embraer E190**	JetBlue	CF34-10E6	
56	**Embraer E195**	Lufthansa	CF34-10E5	
57	**Embraer E195**	Lufthansa	CF34-10E5	
58	**Airbus A320**			
59				
60				

Figure 3.4   Entering a new aircraft into the "Database"-Sheet

With entering the aircraft type, the VLOOKUP-function searches the depending tables for all information concerning noise. If the lookup has been successful, the corresponding columns are automatically filled with the numbers of your aircraft. The same happens with air quality data after entering the engine identification. Be advised that the entries must match the names in the corresponding sheets. If it is not working, the spelling and the availability in the depending sheet must be checked.

For the travel class rating, information for seat pitch, seat width and number of seats need to be entered manually. The necessary data for your aircraft-airline combination can be taken from www.SeatGuru.com.

Figure 3.5   Seating details on SeatGuru

If the aircraft type is not listed in the database yet, two more steps are necessary. First, an entry in the "SAR"-sheet must be made, containing extracted data from the Payload Range diagram (see Chapter 2.1.1) and MTOW.

Figure 3.6 "SAR"-sheet to enter new aircraft data

Next, "CopyAircraft" must be executed to update the list corresponding to the drop-down menu. This is done by clicking on the button "Copy Aircraft List" in the "Auxiliary Data"-sheet.

After all entries are made, your new data set can be selected in the drop-down menus on the "ECOLABEL"-sheet in the general information block (upper left area on the sheet).

Figure 3.7 Selecting the new aircraft data set

3.5 Printing of an Ecolabel

The first sheet in the excel file is named "ECOLABEL". There, Ecolabels can be calculated and printed into a PDF-file. To print your Ecolabel:

1. Select aircraft type from Cell B5 in the general information block.
2. Select airline from Cell B6.
3. Select engine from Cell B7.

4. Click Button "Calculate Ecolabel" to refresh the overall rating marker.
5. Enter file path in Cell Y60.
6. Click Button "Print PDF" to print the Ecolabel into a PDF-file.

If in the general information block aircraft type, airline and engine type are selected in this order, the "Calculate Ecolabel"-button needs to be pushed to refresh the calculation and the design of the label. Because of the VLOOKUP-function with three criteria, the entries in cells B5 to B7 must be made before any value will appear. Also, the macro for the rating marker does not work with entries missing. The new Ecolabel is shown on the right side of the sheet. In order to compare the printed Ecolabels, a PDF-button was added to the tool, which makes it possible to save the Ecolabel in a selected memory location in PDF-format. Therefore, it is necessary to enter the path address of the selected memory location in cell Y60. It is important to add a backslash ("\") to the end of the path address to save the file to the correct memory location. Once the memory location has been entered correctly, the PDF-button can be pushed. The created Ecolabel is saved as a PDF-file and immediately opens in the standard PDF-viewer.

Figure 3.8   General information block for Ecolabel calculation

Figure 3.9   Printing the Ecolabel into a PDF-file

4   Ecolabels

As part of this project, a substantial number of Ecolabels for various popular passenger aircraft and airlines have been calculated and created. A list of all chosen aircraft can be found in Appendix A.

The following selected Ecolabel comparisons are chosen considering various aspects. The World Airliner Census from 2016, in which the number of all flying aircraft in the world is listed, shows the Boeing 737 and the Airbus A320 family as the most operated ones. This puts down the question which one of them is eco-friendlier. Since Boeing and Airbus are the biggest aircraft manufacturers (OEMs) in the world an Ecolabel comparison for them is done by taking a closer look at the fleets of two airlines which represent the aircraft of an OEM more than the other OEM. In this case KLM as a more Boeing oriented operator and Lufthansa as a more Airbus oriented operator are chosen. The third question considers the engine manufacturers which can only be ecologically compared by looking at the same type of aircraft with three different engine types. For the last comparison, the current trend is considered, where low cost carriers such as Ryanair and Easy Jet have become more popular with the sale of comparatively cheap airplane tickets. How do they impact the environment compared to legacy carriers like Lufthansa?

4.1   Same Aircraft Size from Different Manufacturers –
Boeing 737 Family vs. Airbus A320 Family

The Boeing 737-700 with a length of 33.63 meter and a diameter of 3.76 meter (**Boeing 2013)** is comparable to the Airbus A319 with a length of 31.45 meter and a diameter of 3.95 meter (**Airbus 2018a**). The 737-700 has a total number of 132 seats, whereas the A319 has 138 seats. Table 4.1 shows the outcome of the printed Ecolabel comparison of the Boeing 737-700 (Figure 4.1) with the Airbus A319 (Figure 4.2).
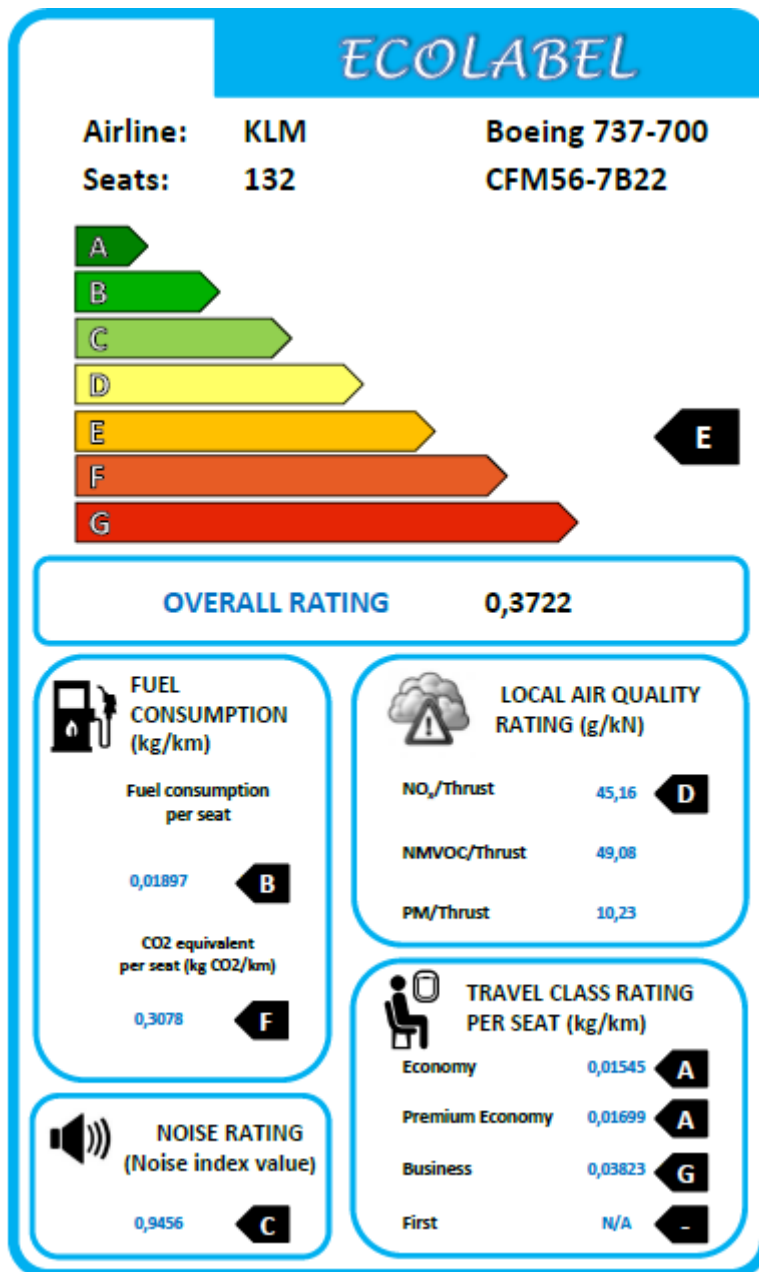
Figure 4.1   Ecolabel for KLM Boeing 737-700

ECOLABEL

Airline:	Eurowings	Airbus A319
Seats:	138	V2524-A5

A
B
C ◄ C
D
E
F
G

OVERALL RATING   0,3146

FUEL CONSUMPTION (kg/km)

Fuel consumption per seat

0,01666   **A**

CO2 equivalent per seat (kg CO2/km)

0,2526   **E**

NOISE RATING (Noise index value)

0,9377   **B**

LOCAL AIR QUALITY RATING (g/kN)

NOₓ/Thrust	48,40	**D**
NMVOC/Thrust	49,74	
PM/Thrust	10,93	

TRAVEL CLASS RATING PER SEAT (kg/km)

Economy	0,01596	**A**
Premium Economy	0,02395	**F**
Business	N/A	**-**
First	N/A	**-**

Figure 4.2   Ecolabel for Eurowings Airbus A319

Table 4.1   Comparison of Boeing 737-700 vs. Airbus A319

Aircraft type Airline	Boeing 737-700 KLM		Airbus A319 Eurowings	
Engine type	CFM56-7B22		V2524-A5	
Overall rating	0.3722	(E)	0.3146	(C)
Fuel consumption				
Fuel consumption per seat	0.01897	(B)	0.01666	(A)
CO_2 equivalent per seat (kg CO_2 / km)	0.3078	(F)	0.2526	(E)
Local air quality				
NO_X / thrust (g / kN)	45.16	(D)	48.40	(D)
NMVOC / thrust (g / kN)	49.08		49.74	
PM / thrust (g / kN)	10.23		10.93	
Noise rating				
Noise index value	0.9456	(C)	0.9377	(B)
Travel class rating				
Economy (kg / km)	0.01545	(A)	0.01596	(A)
Premium economy (kg / km)	0.01699	(B)	0.02395	(F)
Business (kg / km)	0.03823	(G)	-	

The overall rating for the A319 is C and the B737-700 two categories lower with E. For the fuel consumption per seat the A319 is rated with A and the B737-700 with B. Another difference can be found in the CO_2 equivalent per seat, where the B737-700 is rated with F and the A319 one category higher with E. For the local air quality both aircraft are rated with D. The A319 is one category better with the noise index value, but the values of both aircraft do only differ by 0.0079, which means that both of them are pretty similar and the values are located at the limit of two rating categories. A look at the travel class rating shows that the economy classes of both aircraft types are rated with A. For the premium economy class the aircraft types differ by four categories in the rating. The B737-700 is rated with B and the A319 with F. Unlike the A319 the B737-700 includes a business class with a rating of G.

Taking a closer look into the calculation of both Ecolabels and especially at the reciprocal SAR value, which differs by 0,2 kg per km per seat, the A319 has a smaller value and therefore a better fuel consumption than the B737-700. As well the A319 has six more seats in the cabin layout, which gives the aircraft a better rating than the B737-700 in the fuel consumption per seat. The calculated area for an economy seat is for both aircraft nearly the same, which is another reason for the same rating category. The B737-700 includes fewer economy seats than the A319 and has instead more premium economy and business class seats. This is one of the reasons for a lower overall rating for the B737-700, since more area of the available cabin is used for fewer passengers, who choose to fly in a more comfortable travel class with more leg room and space. The area of one business class seat within the B737-700 is in size comparable to the premium economy class of the A319, which also explains the poor rating concerning the fuel consumption per seat in both travel classes. The

premium economy class of the B737-700 has a small increase in the seat pitch and therefore still deserves a good rating with B.

Looking on the values which are not affected by the number of passengers (NO_x / Thrust and noise), both aircraft have only small differences. Regarding the fuel consumption per seat and the CO_2 emissions per seat, the A319 is rated one category better in both disciplines. This is the outcome of narrowly 10% less fuel consumption (calculated from the SAR) and a higher seating density in the cabin. The A319 can be seen as friendlier for the environment.

4.2 Fleet Comparison – KLM vs. Lufthansa

As shown in Table 4.2 and Table 4.3, KLM's fleet currently consists of 118 aircraft and is mostly operated with Boeing aircraft types, whereas Lufthansa has a fleet of 281 aircraft mostly consisting of Airbus aircraft. To determine which airline has a friendlier fleet towards the environment with the help of the Ecolabels a value needs to be found which represents all overall ratings for each fleet. To compare different fleets with different types and numbers of aircraft, a common basis is needed. Therefore, the decision was made to use one seat as a unit and its overall rating as a weighting factor. With variables defined as

- AR: airline rating
- $N_{A/C}$: number of aircraft type in fleet
- $S_{A/C}$: number of seats per aircraft
- $O_{A/C}$: overall aircraft rating
- i: ID according to Table 4.2 and Table 4.3,

the mathematical operation can be expressed as followed:

$$AR = \frac{\sum N_{A/C,i} S_{A/C,i} O_{A/C,i}}{\sum N_{A/C,i} S_{A/C,i}} \tag{4.1}$$

This equation puts the number of seats used to calculate the individual overall aircraft ratings in relation to the total number of seats of an airline fleet. The result is an average rating per seat of an airline independent of its fleet size. Table 4.2 and Table 4.3 show the number of aircraft types each airline operates and the result of the equation calculation.

Table 4.2   Lufthansa aircraft fleet (**Planespotters 2018a**)

ID (I)	Aircraft type	No. of A/C (N)	Seats per A/C (S)	Overall rating (O)	N S	N S O
1	Airbus A319	30	122	0.3601	3660	1317.97
2	Airbus A320	68	166	0.3121	11288	3522.98
3	Airbus A320neo	10	166	0.2201	1660	365.37
4	Airbus A321	63	190	0.3342	11970	4000.37
5	Airbus A330-300	19	255	0.2998	4845	1452.53
6	Airbus A340-300	17	298	0.3067	5066	1553.74
7	Airbus A340-600	20	281	0.4425	5620	2486.85
8	Airbus A350-900	8	319	0.2303	2552	587.73
9	Airbus A380-800	14	509	0.3117	7126	2221.17
10	Boeing 747-400	13	371	0.3457	4823	1667.31
11	Boeing 747-8	19	364	0.3093	6916	2139.12
				$\sum$:	65526	21315.14
				Average Rating		**0.3253 (D)**

Table 4.3   KLM aircraft fleet (**Planespotters 2018b**)

ID (I)	Aircraft type	No. of A/C (N)	Seats per A/C (S)	Overall rating (O)	N S	N S O
1	Airbus A330-200	8	268	0.3217	2144	712.88
2	Airbus A330-300	5	292	0.2810	1460	410.26
3	Boeing 737-700	18	132	0.3722	2376	835.64
4	Boeing 737-800	27	170	0.3008	4590	1381.13
5	Boeing 737-900	5	178	0.3382	890	300.99
6	Boeing 747-400	15	408	0.3198	6120	2003.69
7	Boeing 777-200ER	15	316	0.3327	4740	1471.29
8	Boeing 777-300ER	14	408	0.3042	5712	1699.32
9	Boeing 787-9	11	294	0.2160	3234	641.95
				$\sum$:	31266	9637.04
				Average Rating		**0.3082 (C)**

By using the equation for every fleet of an airline, the results are shown in the tables. Lufthansa's fleet is rated with D, whereas KLM is rated with C. Several reasons have to be considered to explain this result. As explained in Chapter 2.1, the overall rating consists of differing weighting factors, which are 20% of the fuel consumption per seat, 40% of the CO_2 equivalent per seat, 20% for the noise index value and 20% for the air quality rating. So, 60% of the overall rating depends directly on the number of seats within the aircraft. For the remaining 40% the cabin layout has no impact. Consequently, the more seats an aircraft has, the better its overall rating category is. KLM has 27 business class seats in average for all of their cabin layouts, whereas Lufthansa has 45 business class seats in average. These numbers are not representative because of neglecting the sizes of the different aircraft types; however, it shows a significant difference in the class allocation. As well KLM does not include any

first class in their cabin layouts, Lufthansa does. The first-class seat takes up a huge area of the total available cabin area compared to one single economy seat. On account of this, fewer seats can be integrated into the cabin if the space is needed for first and business class seats. Since Lufthansa transports more first and business class seats, they have less space for more economy seats and get a lower overall rating because of the weighting factors explained above.

4.3   Engine Comparison on Same Aircraft – TAP Airbus A330-200

TAP Portugal operates the Airbus A330-200 with three different engine types. All three aircraft have the same cabin layout with the same total number of 273 seats. Therefore, TAP Portugal's A330-200 is suitable for an engine comparison. Table 4.4 summarizes the outcome of the Ecolabel values of Figure 4.3, Figure 4.4 and Figure 4.5.

ECOLABEL

Airline: **TAP Air Portugal Airbus A330-200**
Seats: **273** **CF6-80E1A4**

A
B
C
D
E
F
G

◀ C

OVERALL RATING 0,3148

FUEL CONSUMPTION (kg/km)

Fuel consumption per seat

0,01955 B

CO2 equivalent per seat (kg CO2/km)

0,1836 B

LOCAL AIR QUALITY RATING (g/kN)

NOₓ/Thrust 60,70 F

NMVOC/Thrust 68,86

PM/Thrust 13,67

TRAVEL CLASS RATING PER SEAT (kg/km)

Economy 0,01723 A
Premium Economy N/A -
Business 0,03589 G
First N/A -

NOISE RATING (Noise index value)

0,9562 E

Figure 4.3 Ecolabel for TAP Portugal A330-200 with engine type CF6-80E1A4

ECOLABEL

Airline: TAP Air Portugal Airbus A330-200
Seats: 273 PW4168A

A
B
C
D
E
F
G

◀ D

OVERALL RATING 0,3222

FUEL CONSUMPTION (kg/km)

Fuel consumption per seat

0,01955 ◀ B

CO2 equivalent per seat (kg CO2/km)

0,1836 ◀ B

NOISE RATING (Noise index value)

0,9587 ◀ F

LOCAL AIR QUALITY RATING (g/kN)

NOₓ/Thrust 65,14 ◀ G

NMVOC/Thrust 68,38

PM/Thrust 14,53

TRAVEL CLASS RATING PER SEAT (kg/km)

Economy 0,01723 ◀ A

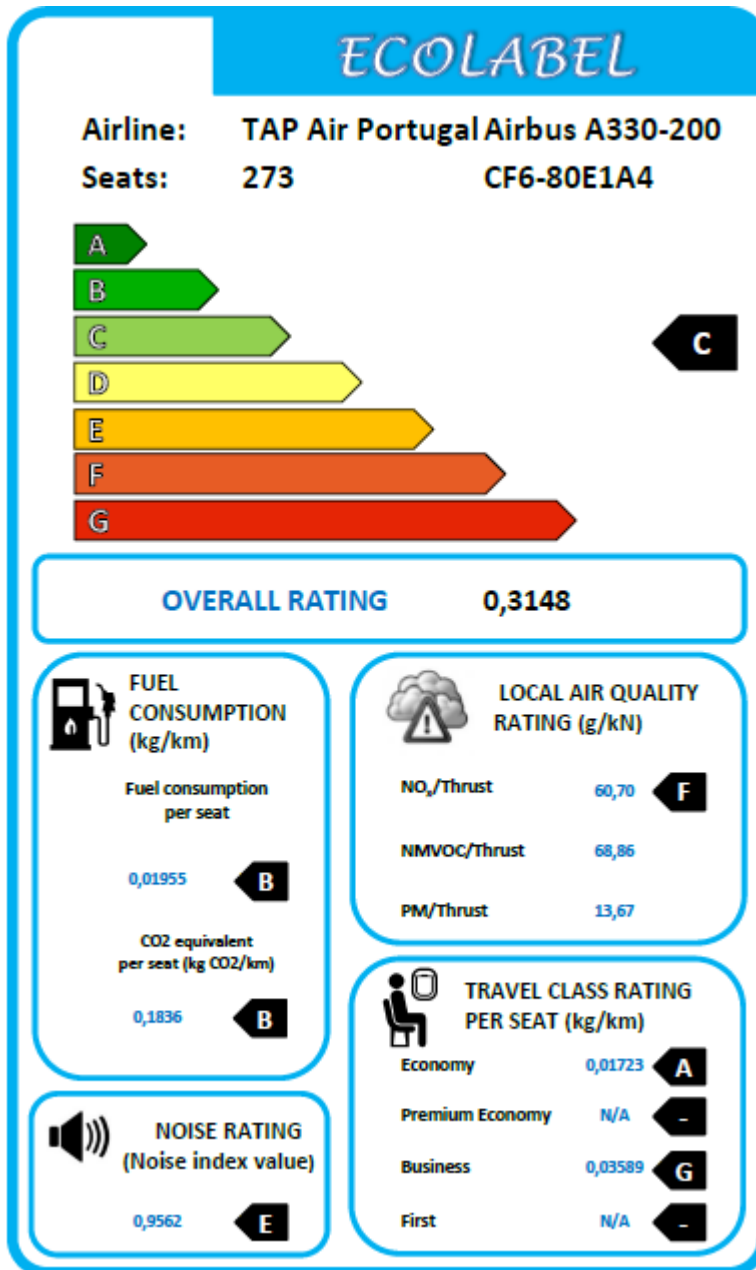Premium Economy N/A ◀ -

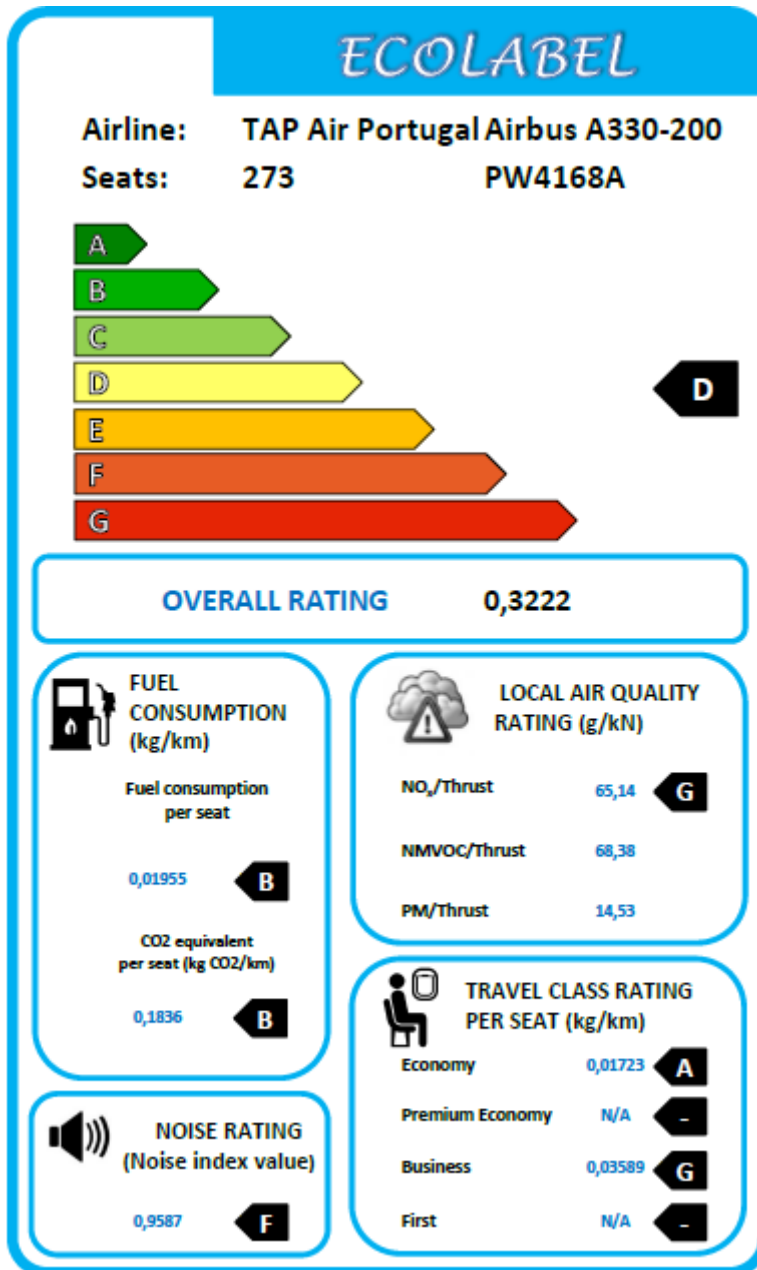Business 0,03589 ◀ G

First N/A ◀ -

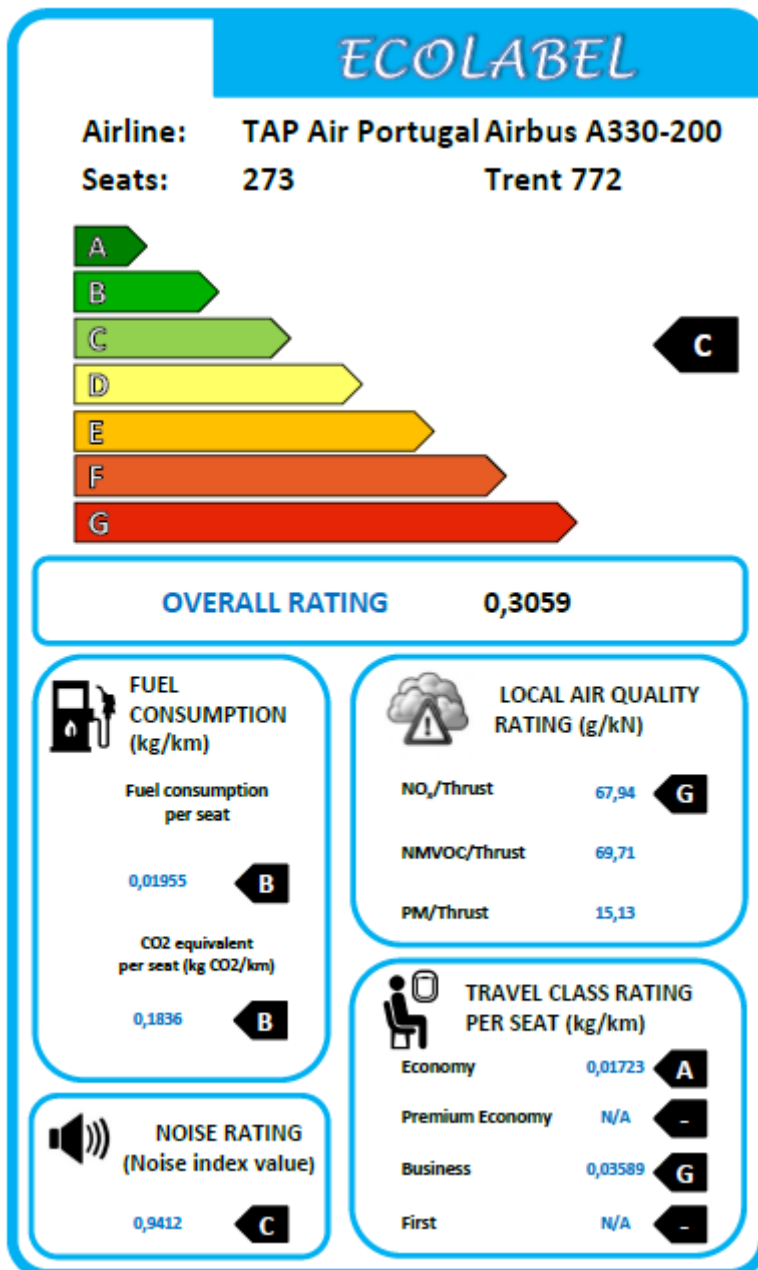**Figure 4.4** Ecolabel for TAP Portugal A330-200 with engine type PW4168A

Figure 4.5   Ecolabel for TAP Portugal A330-200 with engine type Trent 772

Table 4.4   Ecolabel comparison on A330-200 TAP Portugal with three different engine types

Engine type	CF6-80E1A4 (1)		PW4168A	(2)	Trent 772	(3)
Overall rating	0.3148	(C)	0.3222	(D)	0.3059	(C)
Fuel consumption						
Fuel consumption per seat	0.01955	(B)	0.01955	(B)	0.01955	(B)
CO_2 equivalent per seat (kg CO_2 / km)	0.1836	(B)	0.1836	(B)	0.1836	(B)
Local air quality						
NO_X / thrust (g / kN)	60.7	(F)	65.14 (G)		67.94 (G)	
NMVOC / thrust (g / kN)	68.86		68.38		69.71	
PM / thrust (g / kN)	13.67		14.53		15.13	
Noise rating						
Noise index value	0.9562	(E)	0.9587	(F)	0.9412	(C)
Travel class rating						
Economy (kg / km)	0.01723	(A)	0.01723	(A)	0.01723	(A)
Business (kg / km)	0.03589	(G)	0.03589	(G)	0.03589	(G)

The engine types 1 and 3 show besides the local air quality rating and the noise rating the same results in each category with an overall rating of C. They differ from the engine type 2 with the overall rating category of D. The fuel consumption per seat is rated for all three engine types with B and for the CO_2 equivalent per seat all of them are rated with B. A closer look on the local air quality category shows, that all three engine types are rated in the lowest third of the scale. Type 1 is rated with F, whereas type 2 and 3 are rated with G. The noise rating shows E and F as a result for type 1 and 2. In comparison type 3 is rated with C. Looking at the travel class rating, all of them are rated the same. The economy class is rated with A and the business class is rated with G.

All three A330-200 with different engine types have an overall rating, which lie very close to each other. The Rolls Royce Trent engine has a remarkable better noise rating than the ones manufactured by Pratt & Whitney and General Electric. With this better noise rating it reaches a higher overall rating category. Since the number of seats is the same in all three variants, the travel class rating was expected to be the same. Only in the noise rating and in the local air quality, differences can be detected. 40% of the overall rating depend directly on engine data like noise and local air quality. Since the engines have the same thrust class, the values for the overall rating are expected to be all in the same range without major differences.

4.4   Low Cost Carrier vs. Legacy Carrier – Easy Jet vs. Lufthansa

Easy Jet as a low-cost carrier operates the Airbus A319 with a total number of 156 seats, whereas Lufthansa operates the same aircraft type with 122 seats including a business class. Table 4.5 shows the comparison of the Ecolabels between Easy Jet (Figure 4.6) and Lufthansa (Figure 4.7).
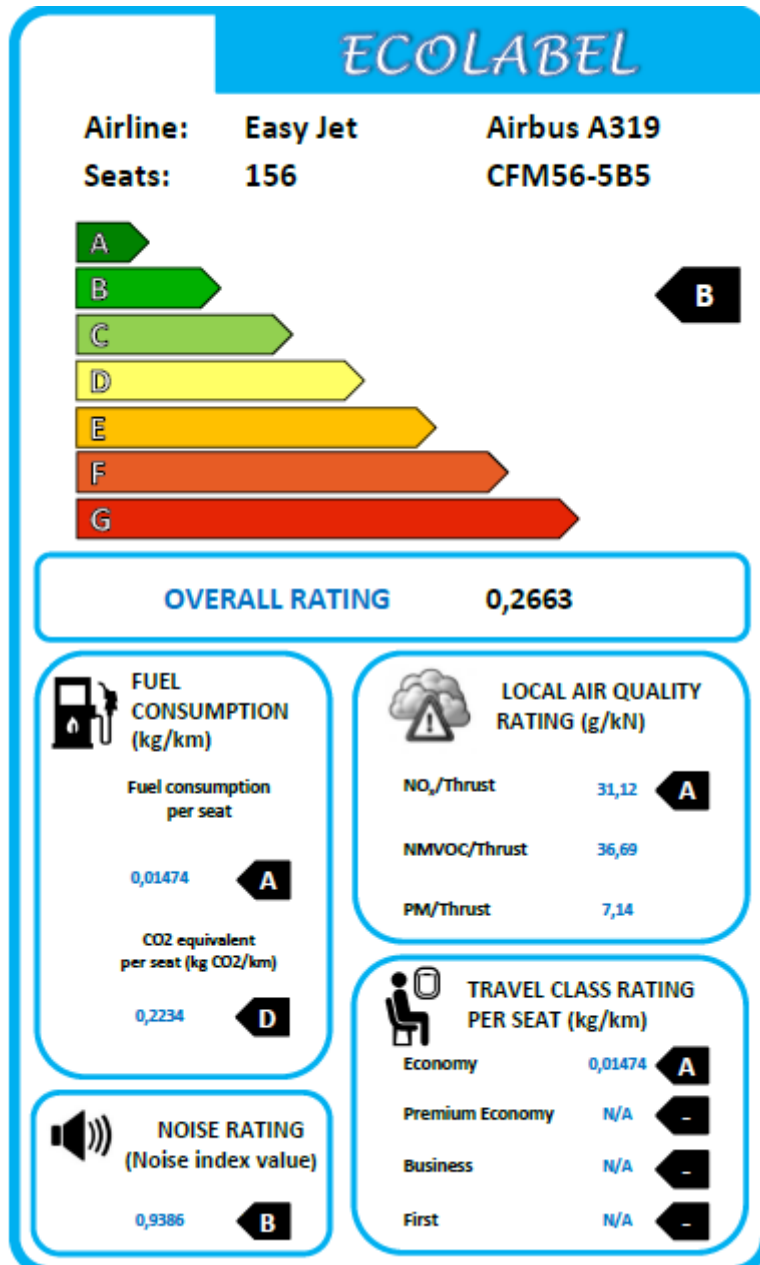

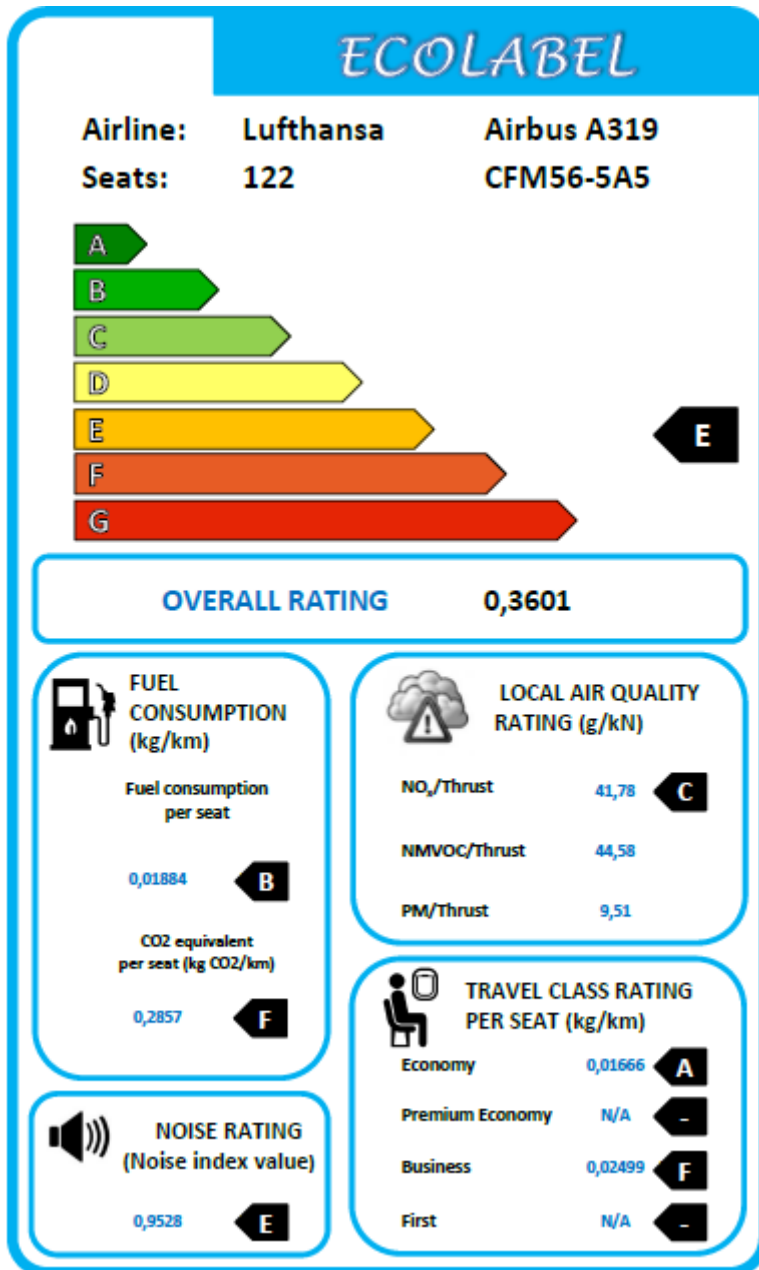**Figure 4.6**   Ecolabel for EasyJet Airbus A319

Figure 4.7 Ecolabel for Lufthansa Airbus A319

Table 4.5   Low cost carrier vs. Legacy carrier - Ecolabel comparison

Aircraft type	Airbus A319		Airbus A319	
Airline	**Easy Jet**		**Lufthansa**	
Engine type	CFM56-5B5		CFM56-5A5	
Overall rating	0.2663	(B)	0.3601	(E)
Fuel consumption				
Fuel consumption per seat	0.01474	(A)	0.01884	(B)
CO_2 equivalent per seat (kg CO_2 / km)	0.2234	(D)	0.2857	(F)
Local air quality				
NO_X / thrust (g / kN)	31.12 (a)		41.78 (c)	
NMVOC / thrust (g / kN)	36.69		44.58	
PM / thrust (g / kN)	7.14		9.51	
Noise rating				
Noise index value	0.9386	(B)	0.9528	(E)
Travel class rating				
Economy (kg / km)	0.01474	(A)	0.01666	(A)
Business (kg / km)	-		0.02499	(F)

Easy Jet's overall rating of B and Lufthansa's overall rating of E fall into two different rating categories irrespective of the same aircraft type. The fuel consumption per seat is rated for Easy Jet with A and for Lufthansa with B. For the CO_2 equivalent per seat Easy Jet is rated with D and Lufthansa with F. Looking at the local air quality, again the low-cost carrier earns an A-rating, whereas the legacy carrier gets a C-rating. For the noise rating Easy Jet is placed in the upper half rating category with B and Lufthansa in the lower half with E. For the travel class rating Easy Jet is rated with A in their economy class, just like Lufthansa is also rated with A for their economy class. However, in their business class the rating category is F.

All in all, Easy Jet has a better rating in almost all categories. On one hand, this result is the consequence of the higher number of seats on the Easy Jet aircraft. The more seats an aircraft has, the better the overall rating will be. On the other hand, the difference has its roots in the engine version. Both aircraft are powered by a CFM56 engine, but Lufthansa operates the older 5A5, whereas Easy Jet uses the newer 5B5 variant. The new generation of this engine brought many improvements, which are responsible for the environmental friendlier performance of EasyJet's engine.

4.5   Turboprop vs. Turbofan – ATR 72 vs. Embraer ERJ-145

Iberia operates the turboprop ATR 72 with a total number of 64 seats and a business class, whereas American Airlines operates the turbofan Embraer ERJ-145 with 50 seats only including a premium economy class next to the economy class. Table 4.6 shows the comparison of the Ecolabels between Iberia (Figure 4.8) and American Airlines (Figure 4.9).
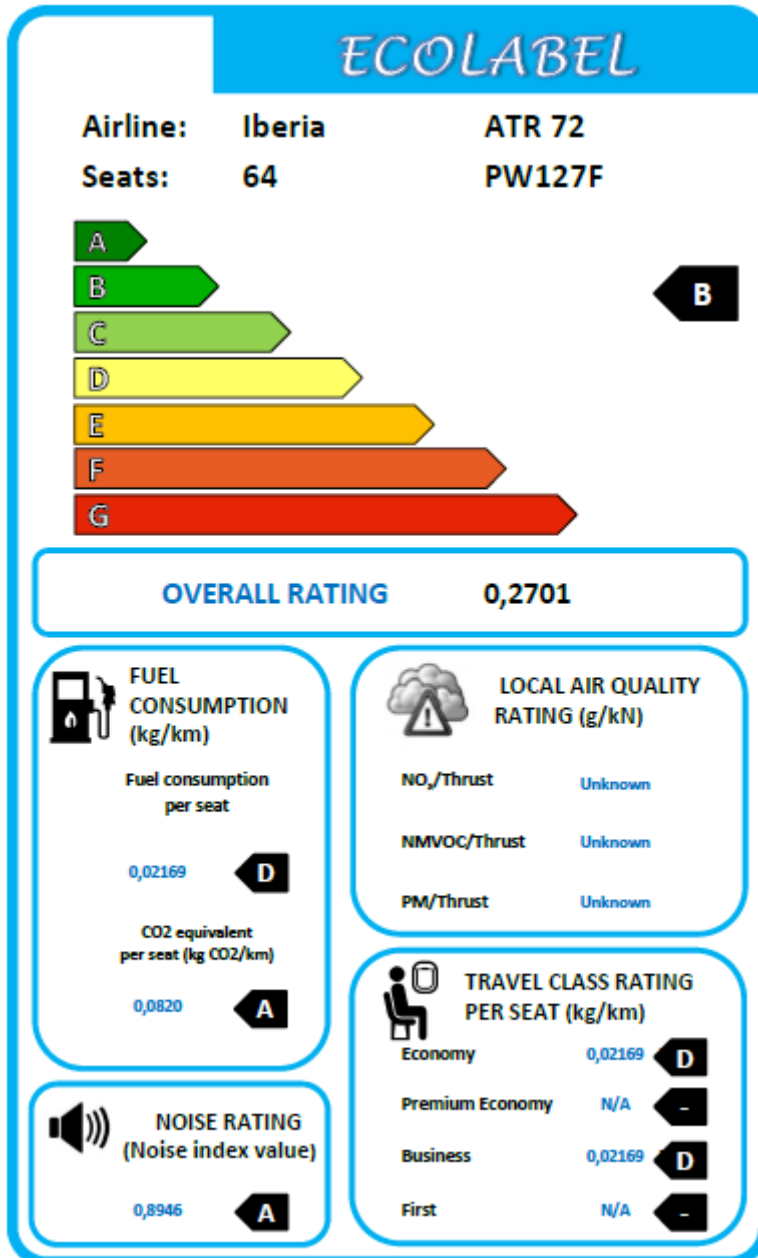
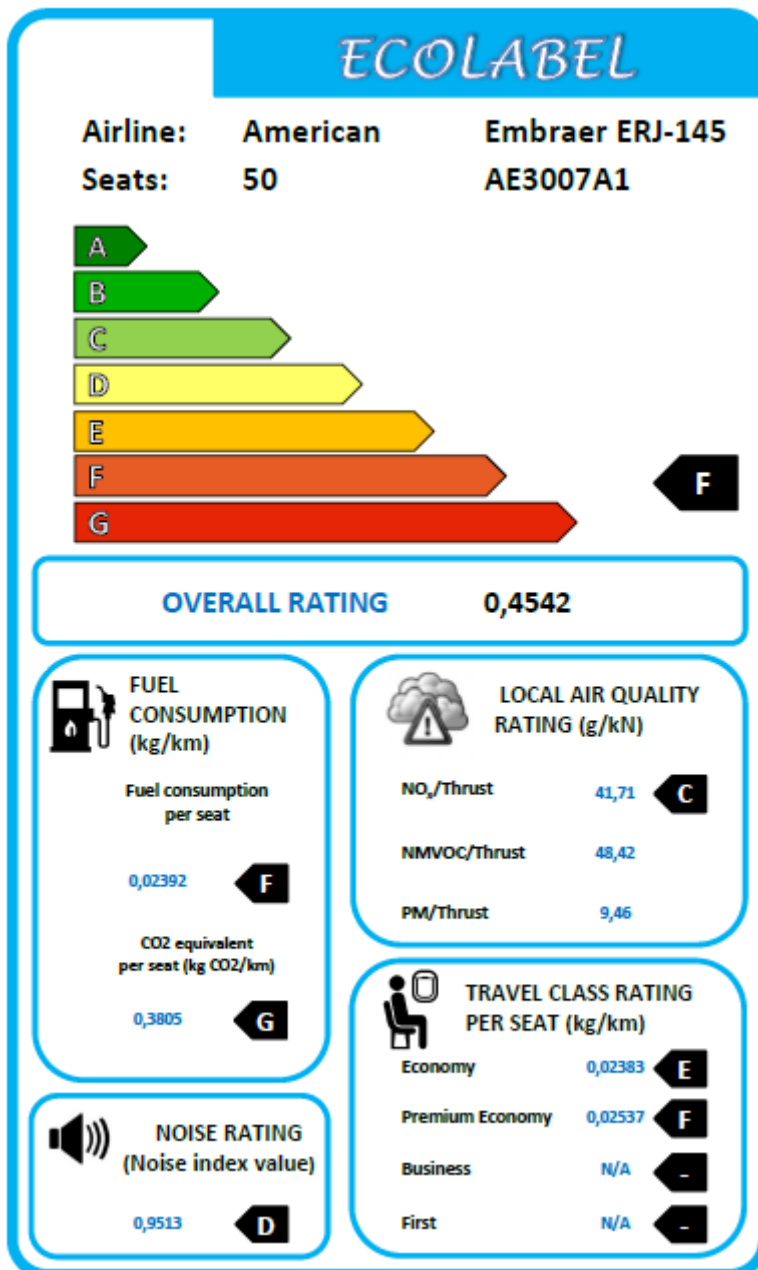**Figure 4.8** Ecolabel for Iberia ATR 72

Figure 4.9   Ecolabel for American Embraer ERJ-145

Table 4.6   Turboprop vs. Turbofan - Ecolabel comparison

Aircraft type	ATR 72		Embraer ERJ-145	
Airline	**Iberia**		**American**	
Engine type	PW127F		AE3007A1	
Overall rating	0.2701	(B)	0.4542	(F)
Fuel consumption				
Fuel consumption per seat	0.02169	(D)	0.02392	(F)
CO_2 equivalent per seat (kg CO_2 / km)	0.0820	(A)	0.3805	(G)
Local air quality				
NO_X / thrust (g / kN)	-		41.71	(C)
NMVOC / thrust (g / kN)	-		48.42	
PM / thrust (g / kN)	-		9.46	
Noise rating				
Noise index value	0.8946	(A)	0.9513	(D)
Travel class rating				
Economy (kg / km)	0.02169	(D)	0.02383	(E)
Premium economy (kg / km)	-		0.02537	(F)
Business (kg / km)	0.02169	(D)	-	

Local air quality data is not available for turboprops because turboprop engine power output is measured in units of Watt (shaft power), whereas turbofan engine power output is measured in Newton (thrust). Because air quality data is specific per thrust, it would not deliver an adequate value for comparison. To enable a comparison anyway, the overall rating of the ATR 72 has been upscaled.

The ATR 72 has an overall rating of B, whereas the Embraer ERJ-145 has an overall rating of F. The fuel consumption of the ATR 72 is rated two categories higher with a D than the Embraer ERJ-145 with a F. Looking at the CO_2 equivalent per seat the spread is at the limits of the rating categories. The ATR 72 is rated with A and the Embraer ERJ-145 can only receive a G. The local air quality for the Embraer ERJ-145 is rated with C. For the noise rating the ATR 72 has the best rating with an A, whereas the Embraer ERJ-145 is rated with D. The travel class rating shows different results for both aircraft. The ATR 72 is rated with D for economy and business class. In comparison the Embraer ERJ-145 is rated with E in the economy class and rated with F in the premium economy class.

All in all, the ATR 72 has a better rating in all categories. This result can be the consequence of the higher number of seats on the ATR 72. The more seats an aircraft has, the better the overall rating will be. However, another technical aspect is the reduced fuel consumption in comparison with the turbofan engine. This results from a better propulsive efficiency of the turboprop engine. It is caused by a greater movement of the air-mass flow of the propeller, which does not need to leave as fast as in the engine of the turbofan. The turboprop's by far better rating of the CO_2 equivalent per seat is caused by a lower cruise altitude than the turbofan even though the fuel consumption results are not spread this widely (**Scholz 2013**).

Also, smaller jet engines work more inefficient than bigger ones, and the very good efficiency of the turboprop in contrast creates the big gap between the ratings of those two aircraft.

5 Discussion

5.1 Influences for Good Rating Results

Out of all comparisons, some trends can be evaluated. First, as the number of seats is directly linked to 60% of the overall rating, the seating density has a big influence. Aircraft with a high-density cabin layout will receive better ratings than those with a spacious business and first class. Consequently, in terms of those calculations low cost carriers are environmentally friendlier than legacy carriers.

Next, it is obvious that recently introduced aircraft like Airbus A350, Boeing 787 Dreamliner or Airbus A321 neo have excellent ratings concerning fuel consumption. However, associated with an efficient fuel burning, the amount of emitted NO_x rises. This dampens the excellent rating of highly efficient engines.

Last, the result shows that turboprop engines are outstanding concerning fuel consumption. An ATR 72 (which had its entry into service in the year 1989) has a similar per head consumption as a high-tech turbofan-powered aircraft like an Airbus A350. Of course, this can be related to the cabin layout, but competitiveness to aircraft which are up to 25 years younger shows that turboprops have a high potential to reduce the emissions in future.

5.2 Source Reliability

For calculation of noise and emissions, data tables from **EASA 2018a, EASA 2018b** and **ICAO 2017** are used. Considering EASA and ICAO as international authorities, published data can be seen as reliable and trustworthy. However, to identify the exact data for one specific individual aircraft, the variant and the MTOW must be known. Different variants differ in values, e.g. MTOW and noise data. Airlines use a paper derate to limit the MTOW of an aircraft. Paper deration means, that an operator agrees to reduce the MTOW virtually. The aircraft itself is theoretically capable of being operated with MTOW according to type certificate. Because costs like landing fees depend on the MTOW, it is cheaper for an airline to license an aircraft at lower MTOW when it is known that the aircraft will be operated only on short distance missions. Differences in MTOWs and variants could not be respected because no information is available from public sources. Thus, as simplification, the first entry of the respective engine type has been used for calculation.

Payload Range diagrams are taken out of the documents for airport planning, published by the respective aircraft manufacturer. The sources are reliable, whereas the method to extract the relevant data for SAR calculation seems to lead to inaccuracies, because the values have to be

read visually and manually (see Chapter 2.1.1). In fact, it is absolutely possible to read the values with an accuracy of 100 kg (example for payload from **Airbus 2017**). With a maximum payload of 50,000 kg, this means a potential error of 0.2%, which is neglectable.

Another aspect to be explained is the SAR data and its meaning and the use for this project. The SAR by itself is known for stating the reachable range with one kg of fuel. For the calculations in this project, the reciprocal value was used to state the fuel consumption per km. At a first glance, those values seem to be lower than expected, compared with average values provided by manufacturers and operators. The reason is located within the different flight phases. Assuming a similar taxi, take-off and landing procedure, the big difference in calculating required fuel results from the length of the cruise segment. Thus, the SAR gradient describes the estimated fuel consumption during the cruise. The cruise segment is the one with the lowest fuel consumption.

5.3   General Result Validity

Taking a closer look to the per-seat-consumption, it quickly becomes apparent that the calculated values do not reflect reality. Lufthansa claims to have a total fleet consumption of 3.84 l per seat per 100 km. This average value implicates that some aircraft have a better fuel consumption, and some are worse. According to calculations defined by **Van Endert 2017**, based on SAR values, an Airbus A340-600 operated by Lufthansa has a per seat consumption of 3.28 kg per seat per 100 km, which equals (with a maximum density of kerosene of 0.85 kg per l) 3.86 l per seat per 100 km. According to the present available data in the database, this is the worst fuel consumption of all calculated data and rated with category G. A fuel-efficient aircraft like the Airbus A320neo (fuel consumption rating A) is calculated with a per seat consumption of 1.47 kg per 100 km (or 1.72 l per 100 km), official reports state a reduced consumption compared to the CEO variants up to 20%. According to **Lufthansa 2017**, the average consumption for medium range missions (which are mostly executed by A320ceo-family aircraft) was 3.9 l per 100 km. However, the system behind calculating the values is the same. Whereas the absolute values of fuel consumption are not within the range what passengers expect, the normalization of all values deliver a correct result.

6 Conclusions and Recommendations

6.1 Conclusions

This project aimed to calculate, compare and discuss Ecolabels for many different passenger aircraft. With prerequisites from **Van Endert 2017**, it quickly turned out to be very time-consuming to fill the Excel tool manually to calculate a label. Furthermore, the information could only be saved as a separate Excel sheet and it was not possible to save several Ecolabels within the Excel file. Consequently, the decision was made to ease the process of the Ecolabel creation.

Considering the requirements to concentrate all data in one file and to store data that has been searched in an accessible database to reuse it in further calculations, a database has been created inside the tool. Automatic search functions have been implemented to minimize the effort of picking the correct data from several sheets. The time to gather all information for one Ecolabel has been reduced from roughly two hours to five minutes. The only information that must be searched and entered manually is the cabin layout of the evaluated aircraft. All other data is inserted automatically. Furthermore, the final result can be extracted as a PDF-file for further use.

Calculated Ecolabels give a good opportunity to compare different aspects of environmental impact. As shown in this project, comparisons can be drawn on different levels. It is easily possible to compare aircraft of the same size from different manufacturers, same aircraft with different cabin layouts or engines or even whole fleets. The key message according to calculations with the algorithm of **Van Endert 2017** is, that generally spoken aircraft with a high seating density will have a better environmental performance. The absolute number of seats is directly related to 60% of the overall rating, resulting in a strong dependence of this parameter. That means, an aircraft with relatively poor fuel consumption can get a better overall rating if the number of passengers is significantly higher than of an efficient aircraft with a spacious seating. With this background, it must be mentioned that this type of Ecolabel cannot precisely judge the efficiency of the technical aircraft product but is better used to decide which flight on a given route is the one with the least environmental impact. Remembering the objective to help customers to overview the market and to choose a flight respecting the environment, the revised and consumer-friendly Excel tool and the use of the calculated Ecolabels can assist passengers with choosing a flight in terms of the environmental impact of an aircraft.

6.2   Recommendations

As stated by **Van Endert 2017**, new standards about aircraft emission calculations are under development. If a new method turns out to be more precise and reliable than current methods, it is recommended to adapt the calculations and base the new results on new rating scales.

The Ecolabel was determined to ease the access to complex information. The idea was to simplify sophisticated calculations by using a well-known graphic display. However, the Ecolabel by itself is not as easy to understand as a label from e.g. a dishwasher. For the future, a small brochure can be created to explain the idea behind Ecolabels, their origin and benefit, and as well to give a small user guide for people who are not familiar with this complex topic.

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Appendix A

Engine Allocation and Cabin Layout Sources

The references for engine allocation and cabin layout are a vast amount of links; in favour of clearness, the listing is done tabulary. For cabin layout data, the website **www.SeatGuru.com**, which features seat maps for all major airlines and aircraft on the market, was used. The database on **www.planespotters.net** provided information on the installed engine type.

All sources have been archived. To shorten the long hyperlinks, the URL shortener Bitly was applied.

Aircraft Type	Airline	Engine	Reference: Cabin Layout (SeatGuru)	Reference: Engine (Planespotters)
Airbus A319	Easy Jet	CFM56-5B5	http://bit.ly/2HEY0vC	http://bit.ly/2IbWlNG
Airbus A319	Eurowings	V2524-A5	http://bit.ly/2FsV7Io	http://bit.ly/2KzzKcv
Airbus A319	Lufthansa	CFM56-5A5	http://bit.ly/2rarS98	http://bit.ly/2KtYylT
Airbus A320	Lufthansa	CFM56-5B4	http://bit.ly/2JCHOaP	http://bit.ly/2HRIbhx
Airbus A320	Aeroflot	CFM56-5B4	http://bit.ly/2rccHvd	http://bit.ly/2HRa8Ge
Airbus A320neo	Lufthansa	PW1127G-JM	http://bit.ly/2JCHOaP	http://bit.ly/2JQwdVE
Airbus A321	Lufthansa	V2533-A5	http://bit.ly/2KnDhKR	http://bit.ly/2rhwNEg
Airbus A321	American	V2533-A5	http://bit.ly/2vWjhMb	http://bit.ly/2JM04P2
Airbus A330-200	TAP Air Portugal	Trent 772	http://bit.ly/2HCx3ch	http://bit.ly/2HO0LLi
Airbus A330-200	TAP Air Portugal	CF6-80E1A4	http://bit.ly/2HCx3ch	http://bit.ly/2HSR9Ln
Airbus A330-200	TAP Air Portugal	PW4168A	http://bit.ly/2HCx3ch	http://bit.ly/2Kwdfoy
Airbus A330-200	KLM	CF6-80E1A3	http://bit.ly/2HDsXk3	http://bit.ly/2IaUVTH
Airbus A330-300	Lufthansa	Trent 772	http://bit.ly/2r7PqeW	http://bit.ly/2HNJ4Yo
Airbus A330-300	Air Transat	Trent 772	http://bit.ly/2I3IgSm	http://bit.ly/2w8BK86
Airbus A330-300	KLM	CF6-80E1A3	http://bit.ly/2HFVa9N	http://bit.ly/2ri8JSx
Airbus A340-300	Lufthansa	CFM56-5C4	http://bit.ly/2ra68dk	http://bit.ly/2HQePzT
Airbus A340-600	Lufthansa	Trent 556-61	http://bit.ly/2HCUiP9	http://bit.ly/2rieyzC
Airbus A340-600	South African	Trent 556-61	http://bit.ly/2HBFpkd	http://bit.ly/2KAueGq
Airbus A350-900	Lufthansa	Trent XWB-84	http://bit.ly/2HDwrmI	http://bit.ly/2HNYYlr
Airbus A350-900	Cathay Pacific	Trent XWB-84	http://bit.ly/2KrXUFo	http://bit.ly/2weeHJi
Airbus A380-800	Lufthansa	Trent 970	http://bit.ly/2HIPKHi	http://bit.ly/2IagELn
Airbus A380-800	Emirates	Trent 972	http://bit.ly/2jh1tlv	http://bit.ly/2IagELn
ATR 72	Czech Airlines	PW127F	http://bit.ly/2K0C9vn	http://bit.ly/2FRWpwU
Boeing 737-700	KLM	CFM56-7B22	http://bit.ly/2HB7s3a	http://bit.ly/2wa8TjV

Boeing 737-800	KLM	CFM56-7B24E	http://bit.ly/2FsyJPi	http://bit.ly/2HP8WqD
Boeing 737-800	American	CFM56-7B24	http://bit.ly/2I5o5nm	http://bit.ly/2FJmoGS
Boeing 737-900	KLM	CFM56-7B26	http://bit.ly/2HZdx98	http://bit.ly/2HPe9Px
Boeing 737-900	Alaska Airlines	CFM56-7B26	http://bit.ly/2HZdx98	http://bit.ly/2wh6gwQ
Boeing 737 MAX-8	Southwest Airlines	LEAP-1B28	http://bit.ly/2r9ZAe6	http://bit.ly/2JTOSA6
Boeing 747-400	KLM	CF6-80C2B1F	http://bit.ly/2vVNfzP	http://bit.ly/2HQXfvH
Boeing 747-400	Lufthansa	CF6-80C2B1F	http://bit.ly/2jgApTu	http://bit.ly/2jw8m2u
Boeing 747-400	Virgin Atlantic	CF6-80C2B1F	http://bit.ly/2rffu79	http://bit.ly/2rkPbNt
Boeing 747-8	Lufthansa	GeNx-2B67	http://bit.ly/2r9vRlr	http://bit.ly/2HRKGA9
Boeing 757-200	Delta	PW2037	http://bit.ly/2JDscnv	http://bit.ly/2FJ4qnG
Boeing 757-300	Condor	RB211-535E4B	http://bit.ly/2rc96x4	http://bit.ly/2IbWUXN
Boeing 767-300ER	Air Canada	CF6-80C2B6	http://bit.ly/2JEivp2	http://bit.ly/2JTOqSy
Boeing 777-200ER	KLM	GE90-94B	http://bit.ly/2FqWFCU	http://bit.ly/2HQclFR
Boeing 777-200ER	British Airways	GE90-85B	http://bit.ly/2vVOe2Z	http://bit.ly/2HQd2yX
Boeing 777-200	Pakistan International	GE90-110B1	http://bit.ly/2KlqtEx	http://bit.ly/2Kz8tqi
Boeing 777-300ER	KLM	GE90-115B	http://bit.ly/2HCYOx5	http://bit.ly/2Iis541
Boeing 777-300ER	Air France	GE90-115B	http://bit.ly/2HEaj7n	http://bit.ly/2Ifd42M
Boeing 787-8	Norwegian	Trent 1000-A	http://bit.ly/2raskDD	http://bit.ly/2wfNohE
Boeing 787-9	Air New Zealand	Trent 1000-H	http://bit.ly/2KkKqvb	http://bit.ly/2IisbIV
Boeing 787-9	KLM	GeNx-1B	http://bit.ly/2KprHP6	http://bit.ly/2HUkKE8
Boeing MD-90	Delta Airlines	V2525-D5	http://bit.ly/2KoiKpi	http://bit.ly/2FK4Pq0
Bombardier CRJ100/200	Air Canada	CF34-3B	http://bit.ly/2r9aPDz	http://bit.ly/2HQxbRu
Bombardier CRJ700	Air France/HOP!	CF34-8C1	http://bit.ly/2HDoZUA	http://bit.ly/2rjitvY
Bombardier CRJ900	Lufthansa	CF34-8C5	http://bit.ly/2jgBDhy	http://bit.ly/2FJSVMV
Embraer ERJ-145	American	AE3007A1	http://bit.ly/2vWCBZD	http://bit.ly/2IfcXnC
Embraer E170	Egyptair	CF34-8E5	http://bit.ly/2jj0W2J	http://bit.ly/2FJF8WC
Embraer E175	LOT	CF34-8E5	http://bit.ly/2ra39Sr	http://bit.ly/2HQ9HQw
Embraer E190	JetBlue	CF34-10E6	http://bit.ly/2vYNz0O	http://bit.ly/2HTwzdN
Embraer E195	Lufthansa	CF34-10E5	http://bit.ly/2FuiYHJ	http://bit.ly/2wah1B6

Appendix B

Basic Data for Noise Rating Calculation

According to **Van Endert 2017**, the noise rating calculation has been executed for all engines mentioned in both **EASA 2018a** and **EASA 2018b**. The new calculation is documented in Excel sheet "Noise Calculation". From the sheets "TCDSN_Props" and "TCDSN_Jets", both turboprop and jet engine ratings have been copied into the calculation sheet and sorted by ascending values. Within this list, the counting function delivers a total number of 18958 entries. Each category contains 2708 values, resulting from dividing the total number of entries by the number of seven categories (and rounding on integers). The limit for each category is therefore the value assigned to a multiple of 2708 in the sorted list. A small error is created by rounding. Seven categories at 2708 entries cover 18956 values. To include the two highest values, the maximum limit of category G has been set manually to the highest occurring value. Consequently, category G contains 2710 values, however this increases the range by 0,07% and is therefore neglectable. A normalization of all values from 0 to 1 has been added.

Figure B.1 shows the number of entries over all noise ratings. For the best and worst rating categories, the range is quite wide, whereas between a rating of 0,92 and 0,96, most aircraft are settled. Consequently, the range of categories covering this area are expected to be narrow.
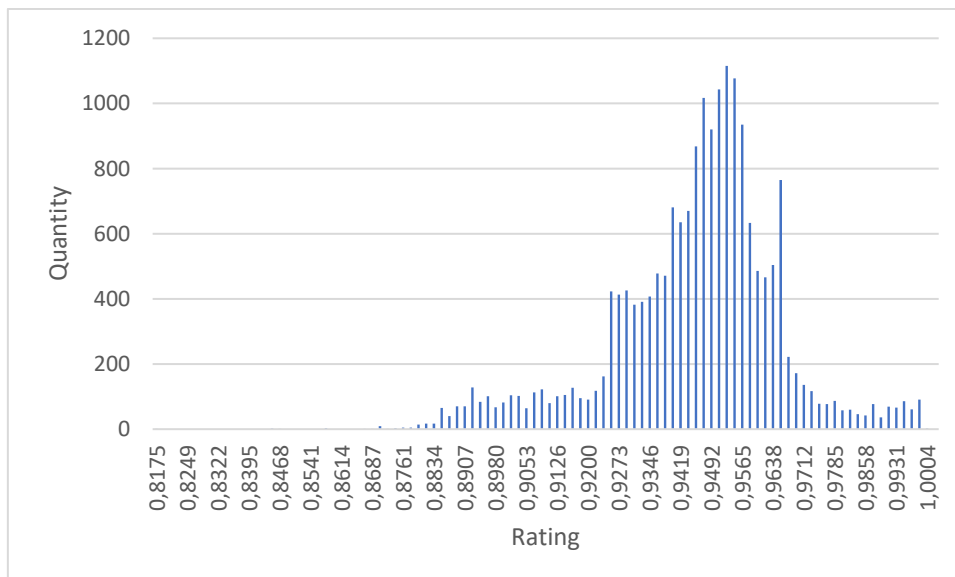

Figure B.1   Noise Rating Distribution