Project

Social Evaluation of Aircraft

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Abstract

Purpose – This project investigates social impacts of aircraft with a life-cycle approach using the example of the Airbus A380 program.
Methodology – Social impacts are analyzed by conducting a Social Life Cycle Assessment (S-LCA) based on the "Guidelines for Social Life Cycle Assessment for Products" from the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC). Stakeholder and subcategories are chosen, and data is collected by conducting qualitative interviews and web searches. An impact assessment is performed using the Subcategory Assessment Method (SAM). The results are interpreted and generalized.
Findings – During its life span, an aircraft or aircraft program has an impact on different stakeholders. The life cycle stage "raw material extraction" could lead to human rights violations, but also local communities near main manufacturing sites face social implications, both positive and negative. The economic importance of the aeronautic sector influences society, political decision makers, local communities, and workers. All this was evident also in the A380 program.
Research Limitations – Data availability limited the investigation partially. The project does not cover all life cycle stages and stakeholder groups. Instead, emphasis is given to selected stages and groups.
Practical Implications – The study can help aviation decision makers to provide a product, which improves the well-being of its stakeholders.
Social Implications – Performing an S-LCA in aviation puts social implications of the aircraft program into focus and provides a foundation for a general discussion about its social sustainability.
Originality – This seems to be the first research on the topic of S-LCA of an aircraft or aircraft program.

DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

Social Evaluation of Aircraft

Task for a *Project*

Background

In recent years, sustainability has become of importance, but while economic and environmental aspects are in the focus of sustainability assessments, the third pillar of sustainability often is neglected. To analyze social impacts of products, a Social Life Cycle Assessment (S-LCA) was developed by a work group of the United Nations to fill the gap in sustainability assessment. A life cycle approach has the advantage to provide a holistic picture of all impacts the product can have along its life span, however, S-LCA still lacks a standardized methodology and further research is necessary in this field. A life cycle approach has been used already to assess aircraft regarding its environmental and economic impacts, but manufacturing and using an aircraft has also several social impacts on different stakeholders. Thus, this project addresses the social aspects of the aeronautic sector by employing a Social Life Cycle Assessment.

Task

Task of this Project is to apply the methodologies, proposed by the "Guidelines for Social Life Cycle Assessment of Products" published by the Life Cycle Initiative in the United Nations Environmental Programme (UNEP), for the product aircraft, specifically the Airbus A380 program. Before, a systematic literature review on this topic has to be performed. Following subtasks are:

- Review the state of the art of S-LCA related to an aircraft or an aircraft program.
- Take the A380 program as an example and make an S-LCA to the level of detail possible in the frame of this project by collecting and selecting stakeholders, impact categories, indicators and related data as basis of the S-LCA.
- Generalize the findings from the performed S-LCA of the A380 program. In which way may an S-LCA for another aircraft program vary from the A380 example? What are the standard elements that will be part of every aircraft S-LCA?

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

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List of Symbols

A	Aspect ratio
b	Wingspan
$C_{D,I}$	Induced drag coefficient
C_L	Lift coefficient
e	Efficiency factor
L_{Aeq}	Continuous noise level
S	Projected wing area

List of Abbreviations

ADCN	Avionics Data Communication Network
AFDX	Avionics Full Duplex Switched Ethernet
AFR	Air-Fuel-Ratio
APU	Auxiliary Power Unit
CFRP	Carbon Fiber Reinforced Plastic
CS	Certification Specification
CSR	Corporate Social Responsibility
DASA	Deutsche Aerospace AG
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DOC	Direct Operating Costs
EADS	European Aeronautic Defense and Space
EASA	European Aviation Safety Agency
ECS	Environmental Control System
E-LCA	Environmental Life Cycle Assessment
EPNdB	Effective Perceived Noise level in Decibel
FAA	Federal Aviation Administration
GFRP	Glass Fiber Reinforced Plastic
GRI	Global Reporting Initiative
HFB	Hamburger Flugzeugbau GmbH
ICAO	International Civil Aviation Organization
ILO	International Labour Organization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
LDA	Landing Distance Available
LTIFR	Lost-Time-Injury-Frequency-Rate
LTO	Landing-Take-Off
MBB	Messerschmidt-Bölkow-Blohm GmbH
MLW	Maximum Landing Weight
MTOW	Maximum Take Off Weight
MZFW	Maximum Zero Fuel Weight
NGO	Non-Governmental Organization
OECD	Organisation for Economic Cooperation and Development
OEM	Original Equipment Manufacturer
PM	Particulate Matter
RAT	Ram Air Turbine
SETAC	Society of Environmental Toxicology and Chemistry
SHDB	Social Hotspot Database
S-LCA	Social Life Cycle Assessment

S-LCIA	Social Life Cycle Impact Assessment
TCP	Tricresylphosphate
TORA	Take-Off Run Available
UFP	Ultrafine Particles
UNEP	United Nations Environmental Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
VOC	Volatile Organic Compounds
WHO	World Health Organization

List of Definitions

Fuel efficiency
"Fuel efficiency is a form of thermal efficiency, meaning the ratio of effort to result of a process that converts chemical potential energy contained in a carrier (fuel) into kinetic energy or work" (Wikipedia 2021a).

Hub-and-spoke
"Being or relating to a system of routing air traffic in which a major airport serves as a central point for coordinating flights to and from other airports" (Merriam-Webster n.d.).

Landing Distance Available (LDA)
"The length of the runway which is declared available by the appropriate Authority and is suitable for the ground run of an aeroplane landing" (Skybrary 2021a).

Life cycle approach
"A life cycle approach identifies both opportunities and risks of a product or technology, all the way from raw materials to disposal" (UNEP 2004).

Point-to-point
"Point-to-point transit is a transportation system in which a plane, bus, or train travels directly to a destination, rather than going through a central hub" (Wikipedia 2019).

Stakeholders
"A stakeholder is a party that has an interest in a company and can either affect or be affected by the business" (Fernando 2021).

Sustainable development
"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987).

1 Introduction

1.1 Motivation

In recent years social aspects of products have become continuously more important for customers. Disclosed social grievances, such as child labor or unsafe working conditions in different industries, have sensitized buyers and led to a rethinking towards a more **sustainable** consume. This is reflected in a revenue increase of fair-trade certified products. While the revenue of fair products in Germany in 2010 did not exceed 500 million euros, in 2019, it was more than 1.8 billion euros (FFH 2021).

Not only for customers but also for companies social themes have become of significance. Many companies voluntarily implement **Corporate Social Responsibility** (CSR) policies. CSR refers to the social responsibility companies have towards their stakeholders (Anderson 2019). Airbus, for example, has formalized the “Responsibility & Sustainability Charter”, which should promote responsible business, and which is in line with the UN Sustainable Development Goals, a framework to establish a more just and sustainable world (Airbus 2021a).

Sustainability has three dimensions: the economic, environmental and the social dimension. A practical tool to analyze a product’s impact on these dimensions is a **Life Cycle Assessment** (LCA). While an Environmental Life Cycle Assessment (E-LCA) and Life Cycle Costing (LCC) are already well established and used, the Social Life Cycle Assessment (S-LCA) is still in its infancies (Pollok 2021). This is also true for an S-LCA of an aircraft, even though the aviation industry has a major social impact by employing over 65 million people globally and securing mobility (IATA 2018).

On the occasion of delivering the last **Airbus A380** in December 2021 to Airbus customer Emirates, the social impacts of an aircraft during its life span are being conducted and exemplified by the A380 (Emirates 2021).

1.2 Title Terminology

Social
The term *social* comes from the Latin word *socius* with the meaning companion, ally, or associate (Dolwick 2009). It refers to humans living in societies and their interaction with each other. This **interaction due to the co-existence** of members of a population is referred to as social whether this interaction is voluntary or unvoluntary (Wikipedia 2021b).

Evaluation
Evaluation describes the systematic process in which something is being **assessed** by its quality, importance, or value of something by using predefined criteria. An evaluation gives insights into existing campaigns and can help in the decision-making process for future projects (Wikipedia 2021c).

Aircraft
An aircraft is a **vehicle capable of flying** by using lift to counteract gravity (Wikipedia 2021d). This work only covers commercial airplanes, who are used to transport passengers by air.

1.3 Objectives

As mentioned above, a Social Life Cycle Assessment is not yet well established under researchers. For this reason, the main objective is to investigate the **possibilities and challenges** of conducting an S-LCA of an aircraft and therefore analyze the applicability of an S-LCA in the aeronautic industry. This work can be used as a guide where more research is needed.

Another objective of this study is to promote the inclusion of social aspects in sustainability research.

1.4 Previous Research

The Social Life Cycle Assessment of an Airbus A380 is being conducted, based on the framework "Guidelines for Social Life Cycle Assessment of Products", developed by the United Nations Environmental Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) (2009). Four years later, UNEP 2013 also published the "Methodological Sheets for Subcategories in Social Life Cycle Assessment", which provides information about the inventory indicators and the data needed to collect.

Barke 2020 provides another framework conducting an S-LCA combined with an LCC specifically for electric propulsion of future aircraft systems. The paper helps to apply the S-LCA methodology on aircraft systems.

Another helpful literature has been the dissertation of Weiss 2020. In his work, he develops a concept to aggregate all social, economic, and environmental indicators to one key performance number, which helps to evaluate a product. Besides, he provides social impacts of an airport, from which some can be used for an S-LCA of an aircraft as well.

Nimtz-Köster (2005) investigates the confrontation between Airbus, political-decision makers, and local communities as well as NGOs about the Airbus Finkenwerder plant extension for the A380.

1.5 Structure of the Work

The project consists of 7 chapters. The structure of this work is as follows:

Chapter 2 In this chapter the definition, historical development and the methodology of a Social Life Cycle Assessment is provided. Furthermore, the S-LCA is compared to E-LCA, and benefits and challenges of this tool are pointed out.

Chapter 3 In this chapter a systematic literature review on S-LCA related to aircraft or aviation is described. State of the art research is being summarized.

Chapter 4 Background information about the development of the Airbus A380 is given.

Chapter 5 An S-LCA of an Airbus A380 is conducted. The goal and scope of the study is being defined and the inventory analysis conducted. A social impact assessment is described.

Chapter 6 The insights acquired in the previous chapter is applied to generate a general framework for S-LCA for all types of aircraft.

Chapter 7 This chapter provides the summary and conclusion of the project.

Chapter 8 In this chapter, recommendations for future work on the topic are given.

2 Social Life Cycle Assessment (S-LCA)

In the following section, the Social Life Cycle Assessment will be depicted in detail as well as differences to the Environmental Life Cycle Assessment will be outlined. Which benefits and challenges an S-LCA brings, is described in the last section.

2.1 Definition of S-LCA

A Social Life Cycle Assessment can be described as a methodology to assess positive and negative **social impacts** of products and services during their complete life cycle. The life cycle of a product starts with the extraction of raw materials and ends when the product is disposed, including manufacturing, use, re-use, and recycling as seen in Figure 2.1 (UNEP 2009).

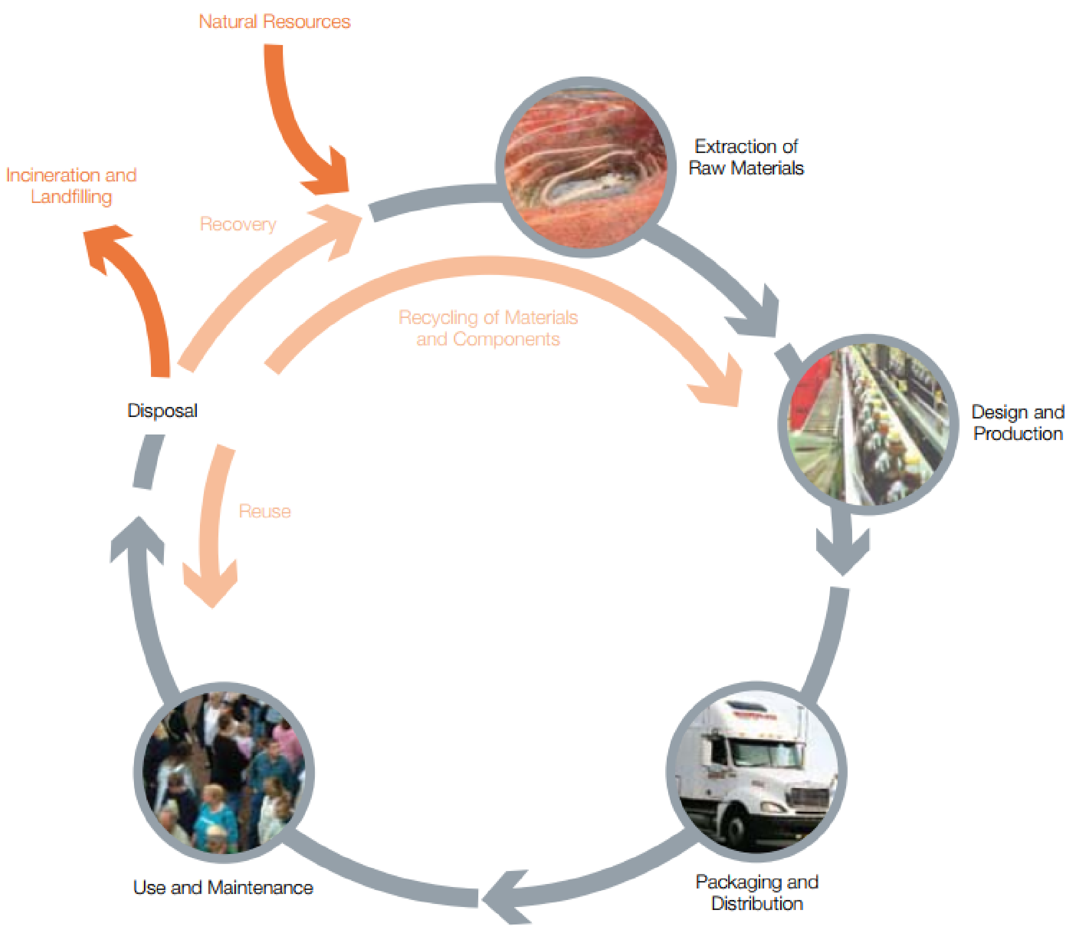

Figure 2.1 Life Cycle of a Product (UNEP 2009)

While focusing on social impacts, the S-LCA integrates the conventional life cycle assessment methodological steps (Sala 2015). The goal of an S-LCA is to identify all impacts a product can have on the direct **stakeholders** and ultimately help to improve **human well-being** by giving decision-makers information on possible social hotspots along the supply chain. Human well-being is the so-called area of protection – an issue of importance for society. To assess products and services, generic as well as site-specific data are being used (UNEP 2009). Though it does not provide information to whether a product should be produced, it is "used for increasing knowledge, informing choices, and promoting improvement of social conditions in product life cycles." (Benoît 2010).

2.2 Historical Development of S-LCA

The Social Life Cycle Assessment is a relative novel approach for integrating social aspects into decision making processes. In 1987 the report "Our common Future" by the World Commission on Environment and Development started an international discourse about sustainability (WCED 1987). Till then, Life Cycle Assessments were without a standardized framework. This changed when the Society for Environmental Toxicology and Chemistry (SETAC) produced a harmonized methodology called the "Guidelines for Life Cycle Assessment: A 'code of practice'" in 1993. The question how to deal with social aspects arose already in this time, and it was suggested to create a "social welfare impact category" (Benoît 2010). O'Brien 1996 published an article called "Social Environmental Life Cycle Assessment" (SELCA), in which he suggested for the first time to create an Environmental Life Cycle Assessment where social impacts are also included.

While empirical case studies were very rare in the early 2000s, there were numerous theoretical approaches to advance S-LCA (Huertas-Valdivia 2020). Scholars developed different methodologies how to assess social aspects in a life cycle of a product, in which different **impact categories** and **inventory data** were suggested. Among them is Weidema 2006, who recommends using Quality Adjusting Life Years as quantifiable indicator for the impact an organization or product can have on human well-being.

Dreyer 2006 points out the importance of **site-specific data** and the social responsibility of companies. In contrast to the E-LCA, where the impacts are gathered on process level, so that a physical link can be drawn between process and product, the social impacts in S-LCA, according to Dreyer, are related to the company's behavior.

Hunkeler 2006 proposes to connect social impacts and working hours to a **functional unit**. For every process along the supply chain the required working time is calculated with geographical specific factors to an index for well-being.

In 2003, UNEP/SETAC formed a taskforce to find a harmonized methodology to include social aspects in LCA, and over the course of the next years they developed the "Guidelines for Social Life Cycle Assessment of Products”, which was published in 2009, after it was reviewed by experts and stakeholders (Benoît 2010). Four years later, the “Methodological Sheets for Subcategories in Social Life Cycle Assessment” was published by the same research group (UNEP 2013).

After the Publication of the *Guidelines* and *Methodological Sheets*, case studies applying S-LCA increased significantly. A literature review by Huertas-Valdivia 2020 verified that 66 % of all case studies on the topic were published in the last four years prior to the study (2015-2018).

Although the publications by UNEP/SETAC have helped to provide a framework, there is still no standard homogeneous methodology.

2.3 UNEP – Guidelines for Social Life Cycle Assessment of Products

In 2009 the Life Cycle Initiative – a cooperation between the United Nations Environmental Programme and the Society of Environmental Toxicology and Chemistry - published the “Guidelines for Social Life Cycle Assessment of Products”. Although just considered guidelines, it has been an important milestone in the field of S-LCA, since it was the first extensive and uniformed **framework** developed by international scholars. The document helps to assess possible positive and negative social and socio-economic impacts of a product along their life cycle. Human well-being is considered the area of protection in S-LCA, and the primary objective of the proposed guidelines is the advancement of the stakeholders’ well-being along the product’s life cycle.

During the different stages of a product’s life cycle, along the **supply chain** in different geographical locations, it impacts positively or negatively on the direct stakeholders in each location. The UNEP/SETAC taskforce identifies five groups of stakeholders, each group sharing similar interests. The stakeholder categories, which can be extended, if necessary, in the *Guidelines* are the following:

- Workers/employees
- Local community
- Society (national/global)
- Consumers
- Value chain actors

Each stakeholder is linked to **subcategories**, which are the basis of an S-LCA. They are considered as socially relevant aspects – such as child labor, fair salary, safe and healthy living conditions. In total, 31 subcategories are proposed by the *Guidelines* and linked to the different stakeholders, as seen in Table 2.1.

Table 2.1 Stakeholder categories and subcategories (UNEP 2009)

Stakeholders	Subcategories
Workers	Freedom of association and collective bargaining Child Labor Fair salary Work hours Equal opportunities / discrimination Health and safety Social benefits / social security
Consumers	Health and safety Feedback mechanism Consumer privacy Transparency End of life responsibility
Local community	Access to material resources Access to immaterial resources Delocalization and migration Cultural heritage Safe and healthy living conditions Respect of indigenous rights Community engagement Local employment Secure living conditions
Society	Public commitments to sustainability issues Contribution to economic development Prevention and mitigation of armed conflicts Technology development Corruption
Value chain actors (not including consumers)	Fair competition Promoting social responsibility Supplier relationships

In 2013, UNEP published the "Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA)", which provides detailed information about subcategories, and suggest inventory indicators and data sources.

Subcategories can be grouped again under one or more **impact categories**. These are also social topics of importance, but broader than the more specific subcategories. According to the *Guidelines*, social issues of interests include for example human rights, working conditions, health and safety, cultural heritage, governance, and socioeconomic repercussions. The relation between impact categories, subcategories, and inventory indicators can be seen in Figure 2.2.

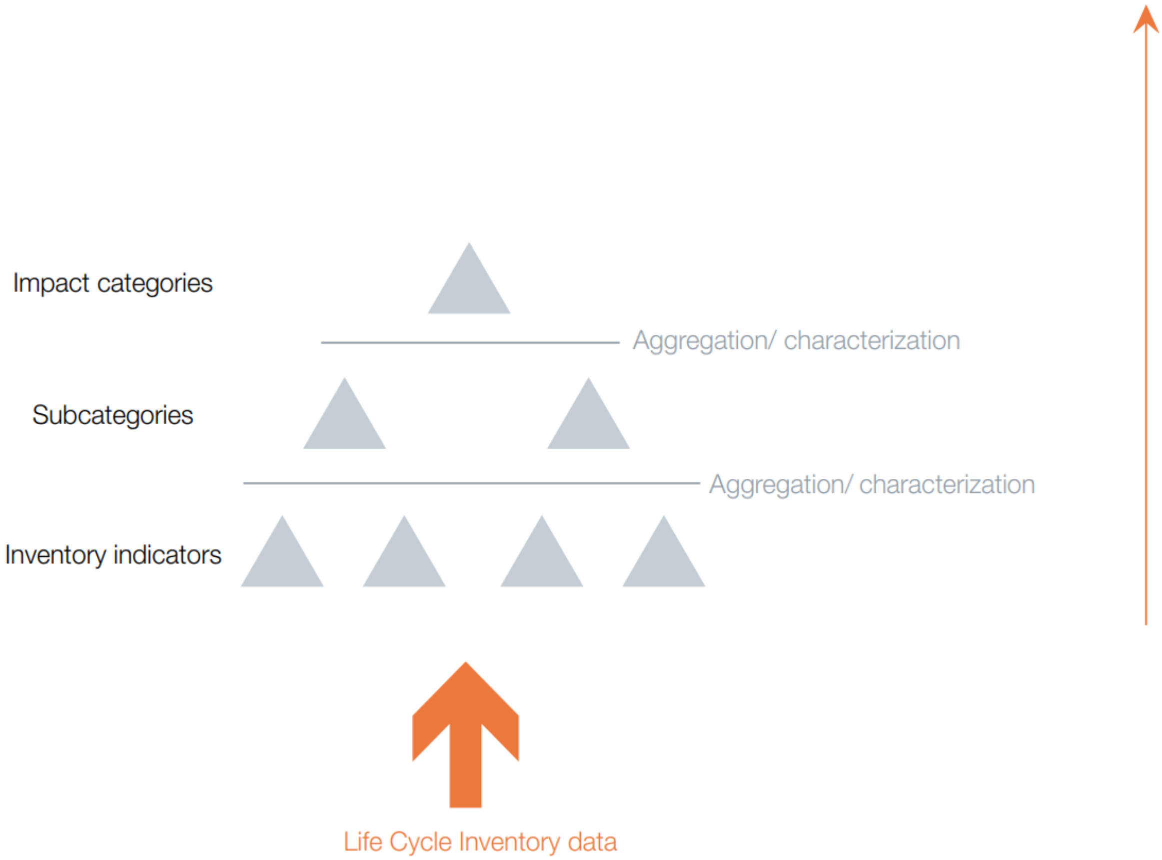

Figure 2.2 The concept of inventory indicators, subcategories, and impact categories (UNEP 2009)

2.4 Phases of a Life Cycle Assessment (LCA)

Since the S-LCA is based on the E-LCA, the framework follows the same norms of **ISO 14040** and **ISO 14044.** In these standards, four major phases of a Life Cycle Assessment are described:

- goal and scope of the study
- inventory analysis
- impact assessment
- life cycle interpretation

2.4.1 Goal and Scope

The first phase of an S-LCA is to define the goal and scope of the study and is very important as it determines the **time** and **resources** needed for the entire assessment. By describing the goal, the reasons, purpose, and target audience of the study are laid out.

To limit the study in a reasonable way, the scope needs to be considered. To do so, some aspects are to be defined. Firsthand, the **product system** itself and the functional unit, which is defined by ISO 14040 as "quantified performance of a product system for use as a reference unit" needs to be determined. It is necessary to know that, when conducting a social life cycle assessment, finding quantitative data can be difficult and thus cannot always directly be linked to a functional unit.

The **system boundaries** – temporal as well as special – determine, which part of the life cycle will be assessed. It could be the case that some life-cycle stages can be neglected due to probable low social impacts of the product for stakeholders.

Stakeholder, subcategories, and impact categories are chosen as well in the scope of the study.

There are two different types of studies – a **generic** or a **site-specific** study. The latter one focuses on one specific location in one specific enterprise and therefore the data collection also needs to be site-specific, for example by performing interviews or questionnaires. In a generic study generic data are being used, such as available international or national data. It is preferred to use both generic as well as site-specific data.

2.4.2 Inventory Analysis

The second phase of the S-LCA is the inventory phase. Since here the data collection and evaluation is carried out, it can be considered as the most time-consuming phase. Even with unlimited time and resources, it would be difficult to conduct an S-LCA only with primary data at every step of the life cycle of the product. For this reason, a prioritization of unit processes where it is most likely that human well-being is endangered, is necessary. A **Social Hotspot Database** (SHDB) can help locating regions or sectors that have high probability of impacting the society in a negative or positive way. By using an SHDB, a researcher can collect generic data and then decides where site-specific data might be appropriate. Such a database has been developed and published online in 2010 by an NGO called *New Earth* (Benoît-Norris 2014).

For each subcategory defined in phase one, there are inventory indicators organized by the stakeholder categories. The *Methodological Sheets* by UNEP 2013 help researchers with the collection of data – be it **qualitative, semi-quantitative or quantitative** – for each inventory indicator.

2.4.3 Impact Assessment

The third phase of the Social Life Cycle Assessment consist of the social impact assessment, but the *Guidelines* do not recommend any specific approach of the different impact assessments. Generally, there are two different approaches of Social Life Cycle Impact Assessments (SLCIA) that are called **type I and II** (Sanchez 2014a).

A general framework for a type I S-LCIA is presented in the *Guidelines*, in which a two-stage assessment is proposed. In the first step the collected data are linked to the 31 suggested subcategories. The collected data may then be related to **performance reference points** to capture its significance. Performance reference points can be internationally accepted levels of minimum performance (Du 2014).

Type II S-LCIA is the approach used in E-LCA, in which impact pathways are being used. The inventory indicators are aggregated to **midpoint** and then **endpoint indicators**, which are, according to the *Guidelines*, human capital, cultural heritage, and human well-being. It requires the use of quantitative data (UNEP 2013).

2.4.4 Life Cycle Interpretation

In the interpretation of the conducted S-LCA, the **issues of magnitude** need to be identified. These could be social hotspots in a process unit discovered during the assessment, where human rights might be infringed.

Furthermore, the study needs to be evaluated regarding **completeness** and **consistency**. Where occurred possible data gaps? Were the methodological choices in line with the defined goal and scope? Lastly, conclusions and recommendations should be named as well as the involvement of stakeholders.

2.5 Comparison of S-LCA with E-LCA

While there are similarities between both life cycle assessments, there are also many differences, which are pointed out in the following.

Both E-LCA and S-LCA apply the life-cycle approach and use the same **ISO framework 14040** and **ISO 14044**. While both LCAs provide useful information for decision-makers, neither of them provides information whether a product should be made or not. Furthermore, E-LCA as well as S-LCA need a huge quantity of data.

The most obvious opposite between the two LCAs is the focus. While the E-LCA analyses the environmental impacts along a product's life span, the S-LCA focuses on social aspects. In S-LCA, quantitative data as well as semi-quantitative and **qualitative data** can be used, in contrast to E-LCA, which depends only on quantitative data. Another difference is that not only negative but also **positive impacts** can be found in S-LCA, while in E-LCA only negative impacts are described (UNEP 2009).

2.6 Benefits and Challenges of S-LCA

An S-LCA of a product can help to systematically identify social impacts and possible hotspot along the product's life span. The benefit of an LCA is the **holistic approach** by analyzing every phase along the life cycle. With the development of an S-LCA as well as the E-LCA and LCC all **three pillars of sustainability** can be investigated.

But while E-LCA and LCC are already standardized and well established, S-LCA still lack of methodological consistency (Huertas 2020). Although the *Guidelines* provide a framework, in the already existing case studies numerous different approaches were taken due to barriers and heterogenous methodologies.

One critical aspect is the use of qualitative data, which can be **biased**. In addition, it depicts a problem regarding the functional unit, which is - according to the *Guidelines* – necessary to define the study. A functional unit requires quantitative data, but for the social impacts qualitative data are being used as well (Pollok 2021). Furthermore, a **comparison** between similar studies can be misleading and even impossible if there was used different kind of data (site-specific vs generic).

Lastly, the question of interpreting the results can be highly **subjective**. Which social topics are more important than others? Which company can be evaluated higher: the one who has a higher amount of disabled worker but little turnover or the one with higher turnover but less diversity? The importance of certain social topics highly depends on geographical and cultural circumstances. While labor unions in European countries play a significant role, in the United States workers rather oppose to be members (Karlewski 2016). All these challenges have prevented the S-LCA to be applied in many sectors.

3 Systematic Literature Review on S-LCA of Aircraft

In this chapter, a systematic literature review is being conducted to give an overview of existing research. Furthermore, the content of the existing research is being summarized.

3.1 Overview

A **systematic literature review** is a scientific method to identify and evaluate all existing literature relating to one topic. By doing a systematic literature review, the **state of the art** relating a specific topic can be shown, and by following a methodological approach, biased literature selection is prevented. Before starting the bibliographic search, research goals are being defined. The actual search is mostly conducted in **electronic databases** (Klatt 2019).

3.2 Bibliometric Analysis

In the following subchapter, a systematic literature review is being conducted to identify the existing literature concerning S-LCA related to aircraft.

Before every research, it is important to get an overview of already existing literature on the topic to be investigated. It helps to not only find data sources, which were used by other researchers, but also to know where more research needs to be done. For this reason, in this project, a systematic literature review in the field of S-LCA related to aircraft is conducted.

To find existing literature about social evaluation of aircraft design Elsevier's Scopus is being used, complemented by Google Scholar. Only literature in English language is included.

The main research question to guide the review is the following:
What is the current state of scientific literature that links S-LCA to aircraft or aviation?

In Elsevier's Scopus, the **keywords** of Table 3.1 are determined and combined by the help of **boolean search**, which uses operators as AND, OR, (), or NOT to specify one's literature research. In the advanced search, it is possible to search these words in the title, abstract or author-specified keywords. In this way, the search results can be reduced to literature, in which at least one of the keywords from the left and the right side appear in the article's title, abstract or specified keywords.

Table 3.1 Keywords for systematic literature review

Keyword 1	Operator	Keyword 2
(“Social Life Cycle Assessment”) OR (SLCA) OR (“Social-LCA”))	AND	((Aircraft) OR (Aviation) OR (Airplane) OR (“Air Transport Industry”))

The total dataset involved only two publications. The first one is a conference paper from the 27th Conference on Life Cycle Engineering with the title” Socio-economic life cycle assessment of future aircraft systems” (Barke 2020). The second publication is a conference paper as well, with the title “Enhanced Assessment of the Air Transportation System” by Weiss 2011. It can be noted that the literature relating S-LCA with aircraft or aviation is **scarce**.

To find more publications, broader terms for SLCA were used instead of the keywords used in the left column in Table 3.1 (see Table 3.2). It needs to be noted, that these terms do not include a life cycle approach.

Table 3.2 Alternative keywords for systematic literature review

Keyword 1	Operator	Keyword 2
(("social assessment") OR ("social dimension") OR ("Social Impact") OR ("socio-economic")	AND	((Aircraft) OR (Aviation) OR (Airplane) OR (“Air Transport Industry”))

In this way, the dataset increased to 310 search results. To exclude documents unfit for the research topic, the search results were examined regarding their title and abstract. 266 documents could be excluded due to **unfit subjects**, so that 44 results were left from the search in Elsevier’s Scopus.

Google Scholar was only being used as a supplementary search system, since it does not support many of the features required for a systematic literature review, such as advanced search options (Gusenbauer 2020).

By searching the keywords of Table 3.1, the found dataset includes 547 documents because the keywords could be anywhere in the text. A quick screening showed that most of the documents were irrelevant. It is not possible to search in title, abstract, and keywords in Google Scholar. For this reason, the input “allintitle:” was put in front of the keywords to limit the search. In this way, only documents with the keywords in the title were shown. No data could be found which fulfilled the criteria. To expand the search, the keywords from Table 3.2 were used and adapted to the search in Google Scholar in the following way:

allintitle: (social OR socio) AND (assessment OR dimension OR Impact OR economic) AND (aircraft OR aviation OR airplane OR "air transport industry")

Now the total dataset involved 68 documents, from which only 22 remained, after excluding "only citation". To limit the result further, a **screening** of the documents was being conducted, from which 16 were being eliminated due to irrelevancy or already appearing in the Elsevier's Scopus search results. The remaining six documents could be classified as one book, one dissertation, one congress paper, one review, one article and one journal article.

In total, 50 documents have remained from the search in Elsevier's Scopus and Google Scholar, including both findings from searches with keywords from Table 3.1 and Table 3.2.

Figure 3.1 shows the **chronological development** of the publications. It is shown that most of the documents were published after 2000, whereas in the previous years, only few publications investigated social aspects of aircraft or aviation. Most publications have been released in the last ten years.

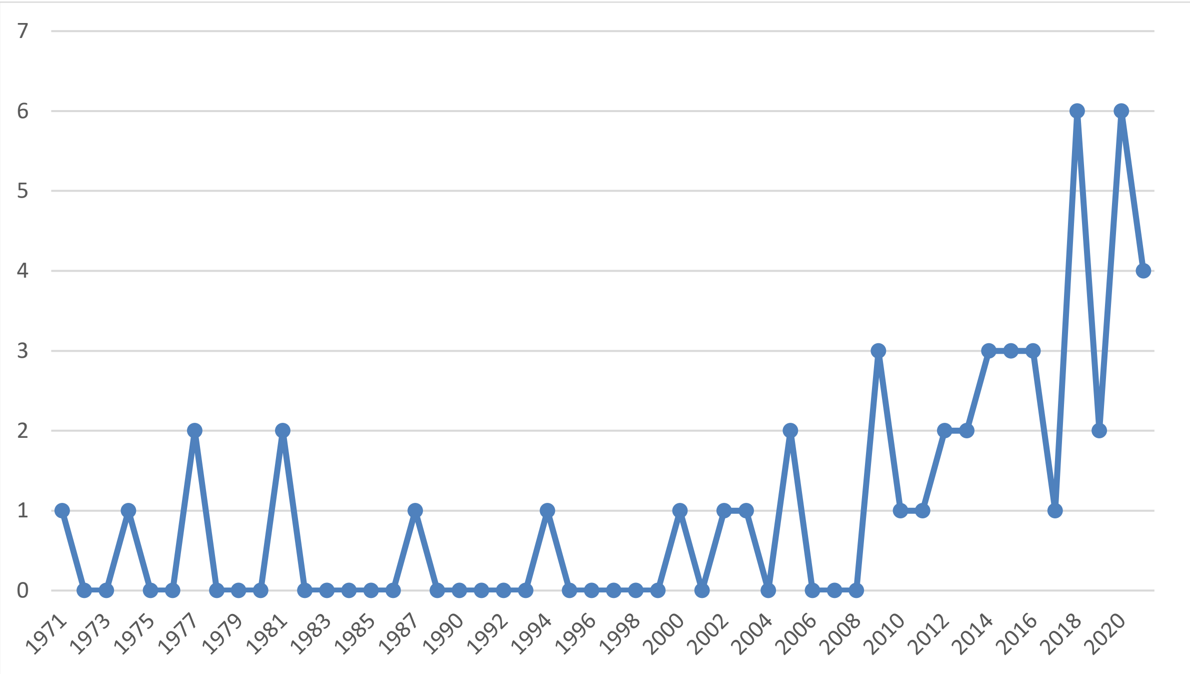

Figure 3.1 Documents on social aspects relating to aircraft published per year

Most of the documents were published in the **European Union**. Scholars from Germany and United Kingdom in particular, but also from the Netherlands and France have significantly contributed to the research, as it is seen in **Figure 3.2** Documents on social aspects relating to aircraft by countryFigure 3.2. Barke, Cerdas, Hermann, Pinheiro Melo, Spengler and Thies were the authors with the most documents in the search results together with Möhler and Spilski, with three publications each.

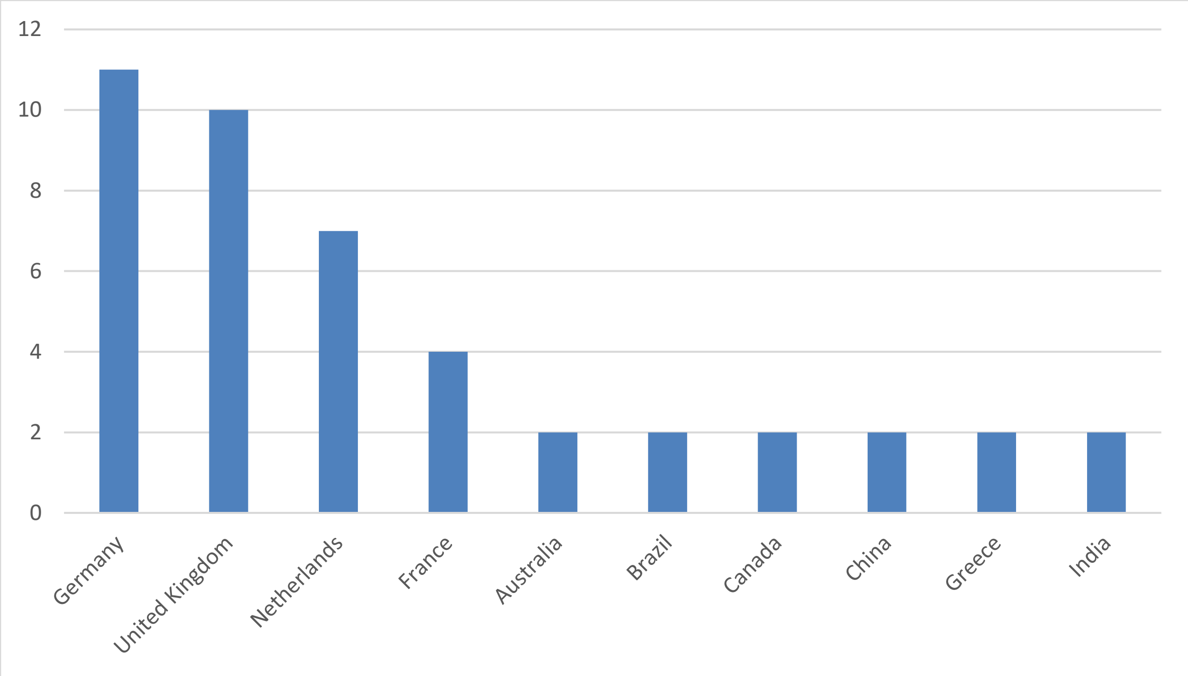

Figure 3.2 Documents on social aspects relating to aircraft by country

The 50 documents consist of conference proceeding, conference papers published in journals, conference papers, journal articles and reviews published in journals, one dissertation and one book chapter. Predominantly the documents constitute 46 % (23 in total) of **journal articles** and 36 % (18 in total) of **conference proceedings**, as seen in Figure 3.3.

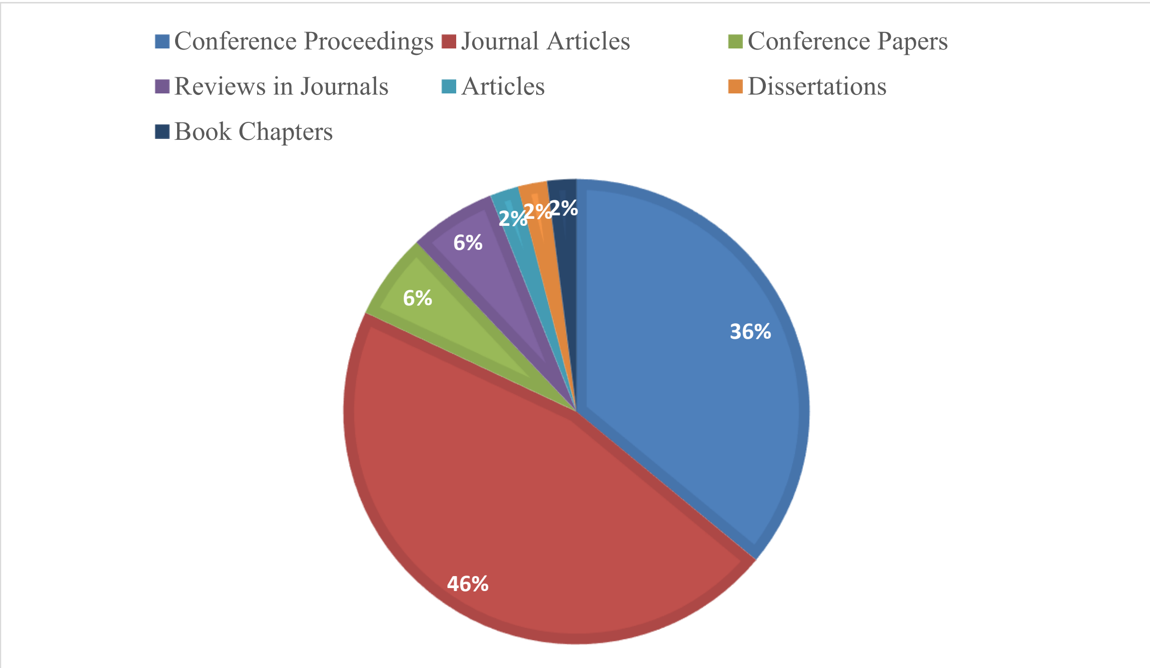

Figure 3.3 Document type of systematic literature review results (in %)

There are four publications, in which a life cycle approach is being used. Apart from the two publications found by using the keywords of Table 3.1, there are two more publications found, using keywords from Table 3.2. All four publications use a Life Cycle Sustainability Assessment (LCSA), which is a combination of E-LCA, LCC, and S-LCA, and thus include not only social but also environmental and economic aspects of a product during its life span. There is not one publication, in which an S-LCA is applied exclusively.

Although addressing social issues related to aircraft or aviation, the remaining documents contain no life cycle approach.

In Table 3.3, the search results for both keywords from Table 3.1 and Table 3.2 are being displayed.

Table 3.3 Systematic literature review results

Author	Title	Year	Journal
Aden, N.O.	Air transportation and socioeconomic development: The case of Djibouti	2020	Pervasive Health: Pervasive Computing Technologies for Healthcare
Aguirre, J.; Mateu, P.; Pantoja, C.	Granting airport concessions for regional development: Evidence from Peru	2019	Transport Policy
Barke, A.; Thies, C.; Popien, J.L.; Pinheiro Melo, S.; Cerdas, F.; Hermann, C.; Spengler, T.S.	Socio-economic life cycle assessment of future aircraft systems	2020	Procedia CIRP
Barke, A.; Thies, C.; Popien, J.L.; Pinheiro Melo, S.; Cerdas, F.; Hermann, C.; Spengler, T.S.	Life cycle sustainability assessment of potential battery systems for electric aircraft	2021	Procedia CIRP
Baudin, C.; Lefèvre, M.; Babisch, W.; Cadum E.; Champelovier, P.; Dimakopoulou, K.; Houthuijs, D.; Lambert, J.; Laumon; B.; Pershagen, G.; Stansfeld S.; Velonaki, V.; Hansell, A.L.; Evrard, A.-S.	The role of aircraft noise annoyance and noise sensitivity in the association between aircraft noise levels and medication use: results of a pooled-analysis from seven European countries	2021	BMC Public Health
Bergström, K.; Spilski, J.; Mayerl, J.; Möhler, U.; Lachmann, T.; Klatte, M.	Effects of aircraft noise on annoyance and quality of life in German children near Frankfurt/Main airport: Results of the NORAH (noise-related annoyance, cognition, and health) study	2015	Euronoise 2015
Bernier, X.	Regional airports and the accessibility of mountain areas: Networks, importance and contribution to development	2010	International Journal of Sustainable Development and Planning
Berry, B.; Sanchez, D.	The economic and social value of aircraft noise effects: A critical review of the state of the art	2014	11th International Congress on Noise as a Public Health Problem (ICBEN) 2014
Bezruchonak, A.	Geographic structure and regional socio-economic impact of low-cost airlines in selected cities of Central and Eastern	2018	MATEC Web of Conferences

	Europe: The role model for Belarus.		
Brandão, A.	The aircraft noise on major urban areas in Brazil - Institutional issues	2005	International Congress on Noise Control Engineering 2005
Bristow, A.L.; Batley, R.; Wardman, M.; Hullah, P.; Plachinski, E.	Modelling annoyance from aircraft noise using a range of indices: Lyon and Manchester airports	2005	International Congress on Noise Control Engineering 2005
Caves, R.	The Social and Economic Benefits of Aviation		Towards Sustainable Aviation
Clerry, B. B.	The Political and Social Impact of Aircraft Noise on Four Urban Communities	1974	University of Southern California
Cremonez, P.A.; Feroldi, M.; de Oliveira, C.J.; Teleken, J.G.; Alves, H.J.; Sampaio, S.C.	Environmental, economic and social impact of aviation biofuel production in Brazil	2015	New Biotechnology
Deeppa, K.; Ganapathi, R.	Role of price in low cost carrier	2017	International Journal of Applied Business and Economic Research
Dekkers, J.E.C.; van der Straaten, J.W.	Monetary valuation of aircraft noise: A hedonic analysis around Amsterdam airport	2009	Ecological Economics
Dimitriou, D.; Mourmouris, C.J.; Sartzetaki, M.	Quantification of the air transport industry socio-economic impact on regions heavily depended on tourism,	2017	Transportation Research Procedia
Dimitriou, D.; Sartzetaki, M.	Assessing air transport socio-economic footprint	2018	International Journal of Transportation Science and Techn
Efue, O.O.	Annoyance due to aircraft noise among residents near a small domestic airport in nigeria	1987	International Journal of Environmental Studies
El-Fadel, M.; Chahine, M.	Case history: An assessment of the economic impact of airport noise emissions near Beirut International Airport	2002	Noise Control Engineering Journal
Elhmoud, E.R.; Kutty, A.A.	Sustainability assessment in aviation industry: A mini-review on the tools, models and methods of assessment	2020	Proceedings of the International Conference on Industrial Engineering

			and Operations Management
Foraster, M.; Eze, I.C.; Vienneau, D.; Brink, M.; Cajochen, C.; Caviezel, S.; Héritiel, H.; Schaffner, E.; Schindler, C.; Wanner, M.; Wunderli, J.M.; Röösli, M.; Probst-Hensch, N.	Long-term transportation noise annoyance is associated with subsequent lower levels of physical activity	2016	Environment International
Franz, K.; Hörnschemeyer, R.; Ewert, A.; Fromhold-Eisebith, M.; Böckmann, M.G.; Schmitt, R.; Petzoldt, K.; Schneider, C.; Heller, J.E.; Feldhusen, J.; Büker, K.; Reichmuth, J.	Life cycle engineering in preliminary aircraft design	2012	Leveraging Technology for a Sustainable World - Proceedings of the 19th CIRP Conference on Life Cycle Engineering
Gillen, D.W.	A socio-economic assessment of complaints about airport noise	1994	Transportation Planning and Technology
Greiser, E.; Glaeske, G.	Social and economic consequences of night-time aircraft noise in the vicinity of Frankfurt/Main airport	2013	Gesundheitswesen
Hoffenson, S.; Forslund, A.; Söderberg, R.	Sustainability-driven tolerancing and design optimization of an aircraft engine component	2013	ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE)
Holsman, A.J.; Aleksandric, V.	Aircraft Noise and the Residential Land Market in Sydney	1977	Australian Geographer
Houthuijs, D.; Van Kamp, I.; Breugelmans, O.; Armeling, C.; Marra, M.; Van Poll, R.	Community response to aircraft noise: Recent examples from the Netherlands	2012	41st International Congress and Exposition on Noise Control Engineering 2012
Jenkins, L.; Tarnopolsky, A.; Hand, D.	Psychiatric Admissions and Aircraft Noise From London Airport: Four-Year, Three-Hospitals' Study	1981	Psychological Medicine
Keivanpour, S.; Mascle, C.; Ait Kadi, D.	A conceptual framework for value chain analysis of end of life aircraft treatment in the context of sustainable development	2014	SAE Technical Papers 2014-September

Klatte, M.; Spilski, J.; Mayerl, J.; Möhler, U.; Lachmann, T.; Bergström, K.	Effects of aircraft noise on reading and oral language abilities in German children near Frankfurt/Main airport: Results of the NORAH (noise-related annoyance, cognition, and health) study	2015	Euronoise 2015
Knipschild, P.	V. Medical effects of aircraft noise: Community cardiovascular survey	1977	International Archives of Occupational and Environmental Health
Knipschild, P.; Meijer, H.; Sallé, H.	Aircraft noise and birth weight	1981	International Archives of Occupational and Environmental Health
Mayo, Louis H.	SOCIAL IMPACTS OF CIVIL AVIATION AND IMPLICATIONS FOR R & D POLICY.	1971	NASA Contractor Reports
Pereira, S.R.; Fontes, T.; Coelho, M.C.	Can hydrogen or natural gas be alternatives for aviation? - A life cycle assessment	2014	International Journal of Hydrogen Energy
Pinheiro Melo, S.; Barke, A.; Cerdas, F.; Thies, C.; Mennenga, M.; Spengler, T.S.; Herrmann, C.	Sustainability assessment and engineering of emerging aircraft technologies-challenges, methods and tools	2020	Sustainability (Switzerland)
Porter, N.; Norman, R.; Oh, X.	Research roadmap for aircraft noise	2018	INTER-NOISE 2018 - 47th International Congress and Exposition on Noise Control Engineering: Impact of Noise Control Engineering
Seidler, A.; Schubert, M.; Wagner, M.; Dröge, P.; Römer, K.; Pons-Kühnemann, J.; Swart, E.; Zeeb, H., Hegewald, J.	Disease risks of traffic noise - A large case-control study based on secondary data	2016	Proceedings of the INTER-NOISE 2016 - 45th International Congress and Exposition on Noise Control Engineering: Towards a Quieter Future
Sreenath, S.; Sudhakar, K.; Yusop, AF.	Sustainability at airports: Technologies and best practices from ASEAN countries	2021	Journal of Environmental Management
Stansfeld, S.; Clark, C.; Cameron, R.M.; Alfred, T.; Head, J.; Haines, M.M.; van Kamp, I.; Kempen, E.; Lopez-Barrio, I.	Aircraft and road traffic noise exposure and children's mental health	2009	Journal of Environmental Psychology
Stevenson, I; Marintseva, M.	A review of Corporate Social Responsibility assessment and	2019	Transportation Research Procedia

	reporting techniques in the aviation industry		
Vilk, M.F.; Kaptsov, V.A.; Pankova, V.B.; Glukhovsky, V.D.	The problem of occupational hearing loss in aircrews of civil aviation	2018	Gigiena i Sanitariya
Walker, S.; Cook, M.	The contested concept of sustainable aviation	2009	Sustainable Development
Wang, Z.; Osseweijer, P.; Duque, J.P.	Assessing social sustainability for biofuel supply chains: The case of aviation biofuel in Brazil	2018	Wang, Z., Osseweijer, P., Duque, J.P.
Weiss, M.; Gmelin, T.; Sun, X.; Dzikus, N.	Enhanced assessment of the air transportation system	2011	11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, including the AIAA Balloon Systems Conference and 19th AIAA Lighter-Than-Air Technology Conference 2011
Whitelegg, J.	AVIATION: the social, economic and environmental impact of flying	2000	-
Wright, D.M.; Newell, K.; Maguire, A.; O'Reilly, D.	Aircraft noise and self-assessed mental health around a regional urban airport: A population based record linkage study	2018	Environmental Health: A Global Access Science Source
Yang, L.; Ngai, C.S.B.; Lu, W.	Changing trends of corporate social responsibility reporting in the world-leading airlines	2020	PLoS ONE
Zhang, X.	Communicating social responsibilities through CSR reports: Comparative study of top European and Asia-Pacific airlines	2021	PLoS ONE
Zur Nieden, A.; Ziedorn, D.; Römer, K.; Spilski, J.; Möhler, U.; Harpel, S.; Schreckenberg, D., Eikmann, T.	NORAH - Field study: The Effects of chronic exposure to traffic noise (aircraft, railway and road) on the self-measured blood pressure	2016	Proceedings of the INTER-NOISE 2016 - 45th International Congress and Exposition on Noise Control Engineering: Towards a Quieter Future

3.3 Content Analysis

The publications by Barke 2020 and Barke 2021 as well as Pinheiro Melo 2020 focus on novel aircraft technologies such as electric propulsion systems. In all three documents the E-LCA is complemented by LCC and S-LCA. Both Barke 2020 and Pinheiro Melo 2020 provide a framework to assess either potential battery or aircraft systems. As it focuses on a whole aircraft and is thus the most relevant document found during the systematic literature, a quick summary is given of the “Socio-economic life cycle assessment of future aircraft systems”.

The publication provides a conceptional framework by developing a guideline to create an evaluation for socio-economic sustainability in **future aircraft** with novel propulsion systems. The authors follow the ISO 14040/14044 standards and suggest defining goal and scope in the first place. The goal is to assess socio-economic aspects of aircraft with focus on **new propulsion systems** such as electric propulsion or usage of renewable fuels. The paper suggests defining the functional unit “as 100 kilometers traveled by a 70 kg passenger with 30 kg luggage and an aircraft load factor of 80% on a generic flight profile.” (Barke 2020). All life-cycle stages need to be included and by focusing on novel propulsion systems, also process chains of fuel production, hydrogen production, and electricity generation must be assessed. For the inventory analysis, data should be collected from manufacturers or airlines and the Social Hotspot Database. In case data are still missing, the authors of this paper suggest estimation based on available cost models. For the impact assessment, the stakeholders and indicators are to be defined. The authors identify aircraft manufacturers, airlines, passengers, airport operators, political decision-makers, and the local community/population near production sites or airports as stakeholders, each with different objectives. To include the economic aspects in the impact assessment, the conventional, environmental, or societal Life Cycle Costing, which can be used, depending on the focused stakeholders, are being used. For the interpretation, the different and often conflicting objectives of the different stakeholders need to be resolved by using “Multi Criteria Decision-Making” models.

In Barke 2021, a case study is being conducted, using an LCSA method. Eight potential **battery systems** for use in electric propulsion concepts are being evaluated in terms of environmental, economic, and social aspects in the stages of raw material extraction and production.

The paper by Weiss 2011, which was found by using the keywords of Table 3.1, focuses on an establishment of a **socio-eco efficiency index**, which indicates the overall performance of an aircraft. This number is the final output of environmental, economic, and social impacts by applying a multi-step procedure, in which all results are aggregated. In the paper, a simple example of a low noise aircraft is shown.

The other papers found do not include a life cycle approach in their research, but rather focus on specific social or socio-economic issues of air transport or aircraft.

Almost half of all findings of the systematic literature review addresses the psychological and physical **health effects** of (aircraft) **noise** on humans. Different effect of exposure to noise, such as impacts on birth weights, cardiovascular diseases, mental health, or cognitive abilities of children, have been investigated. In his article, Whitelegg 2000 does not only investigate aircraft noise but also the pollution of the air in the vicinity of airports and their effects on human health.

In some papers, the social impact of air transport on regions is being analyzed. Dimitriou 2017 and 2018 focus on the socio-economic impacts air connectivity has on regional and national level. If a region is internationally well connected by airports, it can improve its trade, **tourism**, investments, and productivity. Aside from direct **job creation** by the air transportation industry, a lot of regions benefit from growing tourism due to air connectivity. In regions like Greece, tourism is often the main source of national income. Furthermore, it is claimed that aviation market provides access to education, health, and basic services. It is shown how Greece’s economy is strongly dependent on a strong and resilient aviation sector for its main national income is the tourism industry and over 70% of the tourists arrive by air.

Which effects the **biofuel** supply chain for aviation has on Brazilian society, is being investigated by Cremonez 2015. The focus lies on the issues of employment, working condition, labor right, gender equity and social development.

Another document, which was not found during the systematic literature review, but instead was recommended by Professor Dr. Scholz, is a dissertation by Weiss 2020 from the Deutsches Zentrum für Luft- und Raumfahrt (DLR). He analyses the socio-eco-efficiency of the air transport system with the focus on **airports**. By assessing all three pillars of sustainability – economy, environment, and society – Weiss creates a holistic investigation of air transport sustainability. Regarding social impacts of airports, both negative and positive effects are identified. On the one hand, airports create direct and indirect employment as well as higher **mobility**. On the other hand, the local community could face negative consequences due to emission and noise. As already proposed in Weiss 2011, an aggregated number, which includes the results of environmental, economic, and social assessment, is being used to help decision-makers find optimal solutions while considering all three pillars of sustainability.

4 Background Information of the Airbus A380

In the following chapter, the development of the Airbus A380 is briefly depicted to provide background information necessary to understand arousing social conflicts, which will later be addressed in the S-LCA of an A380.

4.1 Airbus A380 – General Description

The Airbus A380-800, manufactured by Airbus, is the **largest commercial long-range airplane** in the world with a maximum capacity of 853 passengers in an all-economy class configuration (Figure 4.1).

Figure 4.1 Flyover of an Airbus A380 (Green 2010)

The wide-body **double deck** aircraft is powered by four engines, either operated by Rolls-Royce (Trent 900 series) or Engine Alliance (GP7200). The A380 has a range of 8,000 nm with maximum passenger payload, as can be seen in Figure 4.2 and has been flying to over 70 destinations worldwide. It has a length of 72.7 m and a wingspan of 79.8 m (Airbus 2005).

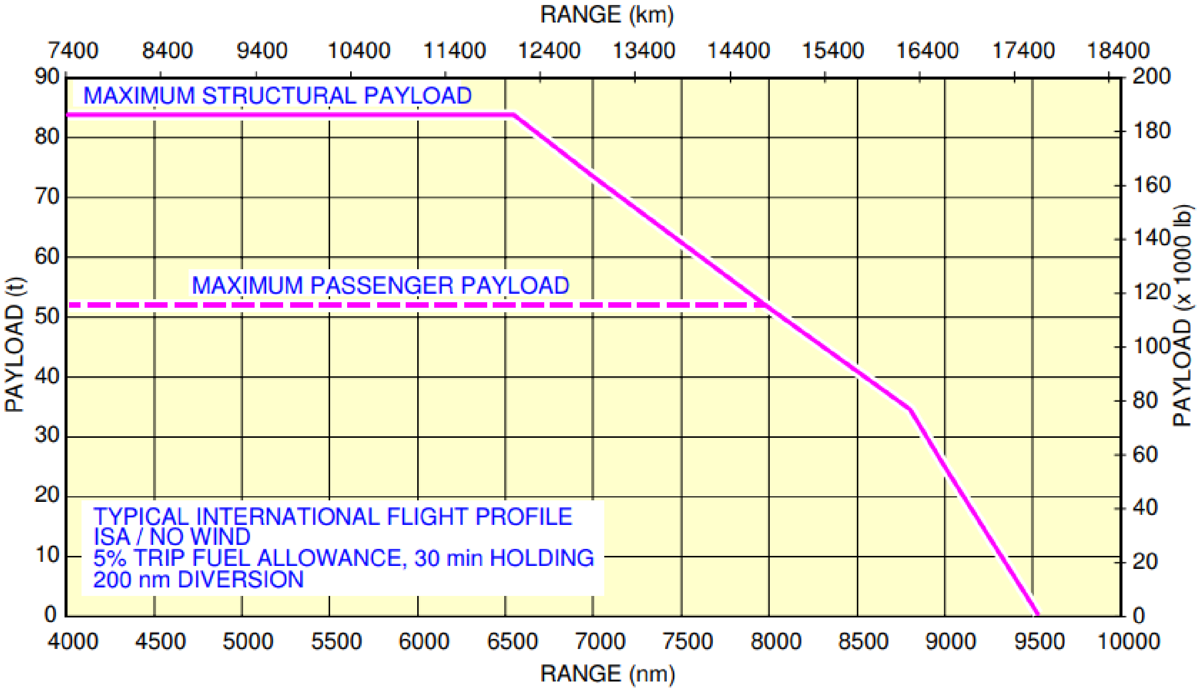

Figure 4.2 A380 payload-range diagram (Airbus 2005)

For the WV000 weight variant of the A380-800, following characteristics are provided in Airbus 2005:

- Maximum Take Off Weight (MTOW): 560 t
- Maximum Landing Weight (MLW): 386 t
- Maximum Zero Fuel Weight (MZFW): 361 t
- Standard seating capacity: 555 (see standard configuration for upper deck and main deck in Figure 4.3 and Figure 4.4)
- Passenger compartment volume (main deck): 775 m^3
- Passenger compartment volume (upper deck): 530 m^3
- Maximum payload: 83 t

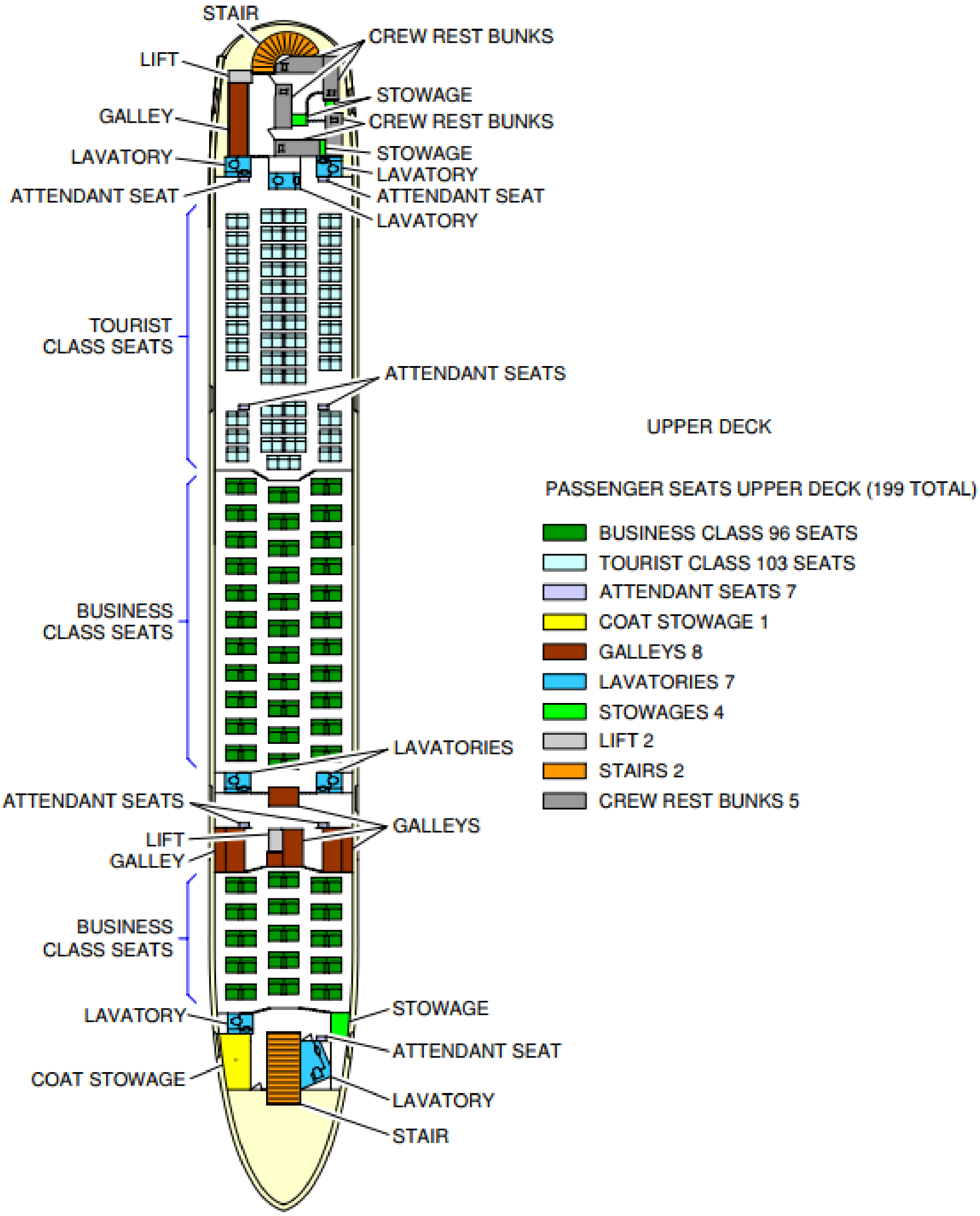

Figure 4.3 A380 standard configuration upper deck (Airbus 2005)

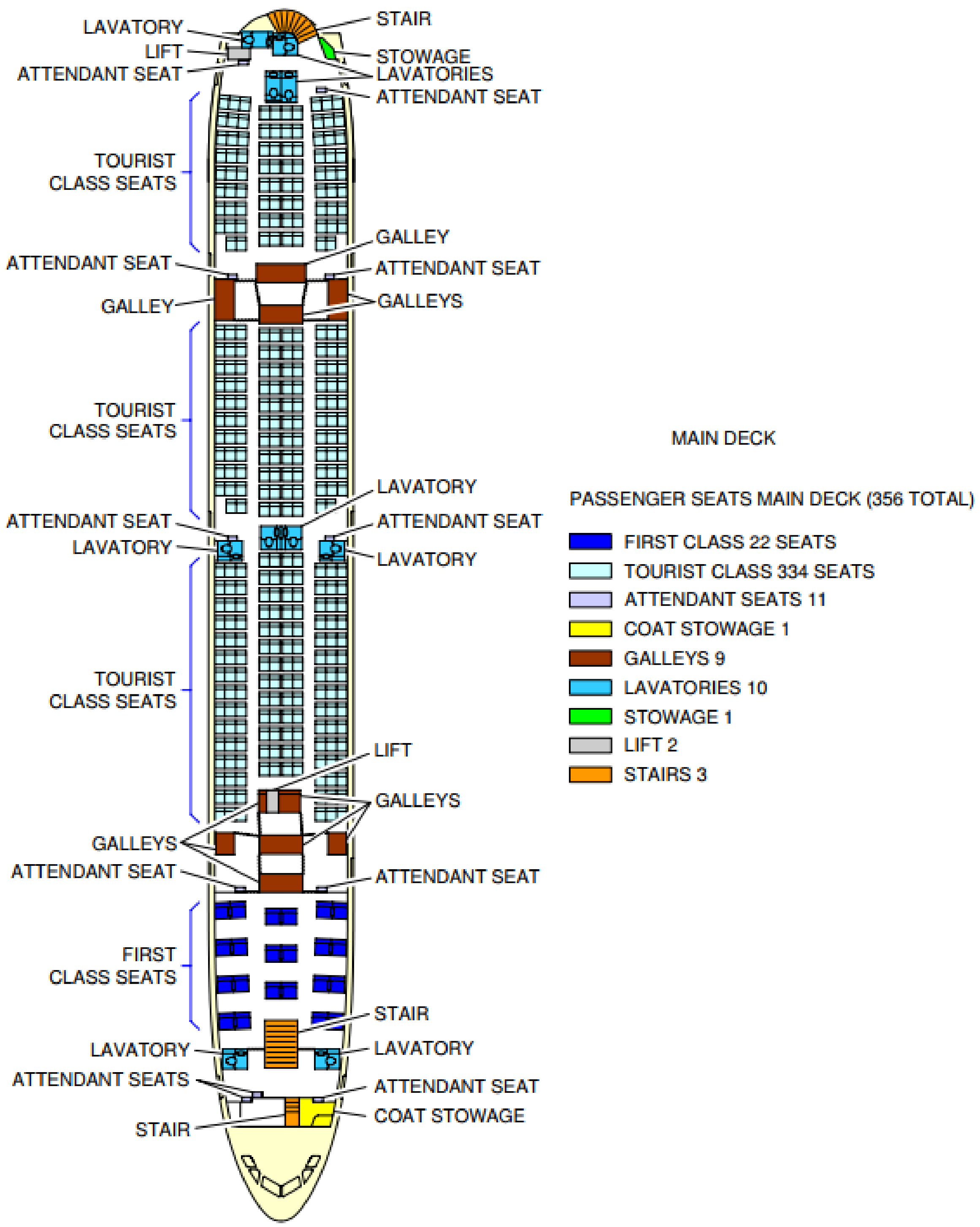

Figure 4.4 A380 standard configuration main deck (Airbus 2005)

4.2 History of the Development of the A380

In the late 1980s European aerospace manufacturers started planning an **ultra-high-capacity airliner** to compete with Boeing's 747 series, which was already introduced in 1969 and highly successful. To end the dominance of Boeing and to be part of the growing high-capacity airliner market, European companies felt the need to build its own superjumbo (Loeffler 2019).

Airbus officially launched the project in 1994 under the project name A3XX. The design team considered numerous design configurations, including a single deck aircraft or a horizontal double-bubble fuselage. But to provide more passenger seats, reduce the weight of the structure, and to avoid problems with evacuating the aircraft, a decision in favor of a **double deck** layout with an elliptical fuselage was made (Späth 2021a).

With the objective to form a partnership for the limited market of ultra-high-capacity airliners, Boeing and Airbus conducted a joint study how future air transport would look like (Späth 2021a). Boeing abandoned the project because it predicted a decrease of the **hub-and-spoke** system, in which large number of passengers are transported to hubs and from there to their final destination, and thus the need for larger aircraft. Instead, Boeing counted on the expansion of **point-to-point** system and the need for smaller aircraft flying with higher frequency (Woo 2021). While Airbus predicted a need for around 1,100 ultra-high-capacity airliners, Boeing forecast demand for only 334 (Johnsen 2009).

With an approved 8.8 billion euros to build the then renamed Airbus A380, Airbus started the project in the end of 2000 (Loeffler 2019). Over the next years the development costs rose to over 25 billion euros (Späth 2021b).

It was decided that the production of the Airbus A380 should take place in different sites in Europe. The final assembly should take place in Toulouse, France, although there were four other cities applying for it as well: Sevilla, Hamburg, Rostock-Laage and Saint-Nazaire (Jörn 2015).

The different parts were built all over Europe with major construction sites for A380 sections in Hamburg Finkenwerder for the front and rear fuselage, Stade for the vertical tail fin, Saint Nazaire for the center fuselage, Cádiz for the horizontal tailplane, and Broughton for the wing sets (Slutsken 2018). The sections were transported via a **surface transportation** network by special roll-on-roll-off ships to Bordeaux, from where all sections were transported by barge via Garonne River to Toulouse. Few components were sent in the Airbus Beluga. In Toulouse the final assembly took place. The assembled A380 were then flown to Hamburg Finkenwerder, where the furnishing and painting took place. From there, deliveries to customers from Europe and the Middle East were executed (Jörn 2015).

In April 2005, the A380 had its first **maiden flight**, six months later the first A380 arrived in Finkenwerder (Figure 4.5). It received certification in the end of 2006. Due to several delays, the first delivery to a customer – Singapore Airlines – took place in October 2007, one year later than planned (Hayward 2020).

Figure 4.5 First arrival of an A380 in Finkenwerder (picture provided by Professor Scholz)

But the demand for the A380 fell short of expectations and when orders were cancelled by major customers in the beginning of 2019, Airbus announced the **termination of production** of the Airbus A380 for 2021. To this date, only 251 A380 have been sold (Späth 2021).

4.3 Reasons for the End of Production

There are several reasons which could have let to the **early demise** of the A380. Firstly, Boeing's prediction of an increasing demand for direct flights proved to be right. In the last 20 years, the number of direct connections between two cities have doubled and the number of flights at regional airports have grown twice as fast as top-tier European airports (EPRS 2021).

Furthermore, **fuel efficiency** is not optimal due to several reasons being pointed out in the following. One major problem is the **increased weight** of the A380. While designing the A380-800, developers had planned a whole A380 aircraft family, in which the A380-800 should just have been the **basic version**. A 6.7 m longer version, the A380-900 was firmly planned by Airbus and thus airfoils and landing gear, which can be seen in Figure 4.6, were designed optimal for this version instead of the A380-800, for which they are oversized (Späth 2021c). Also, the elliptical fuselage is heavier than the typically round fuselage of an aircraft.

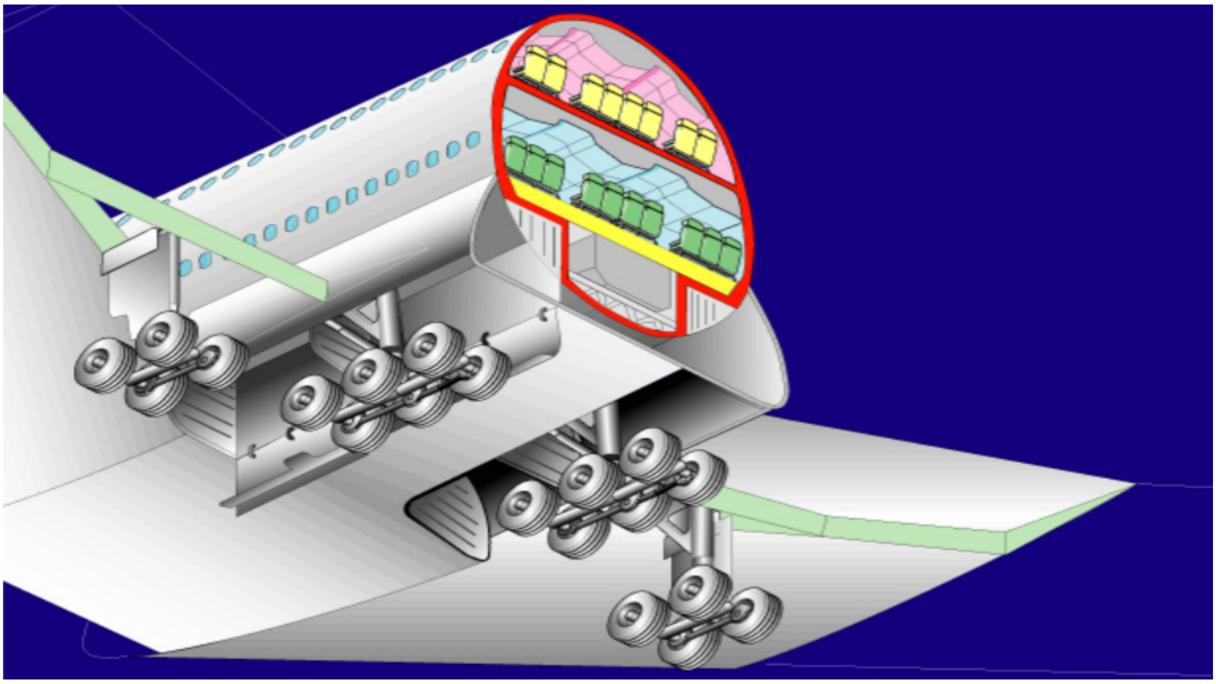

Figure 4.6 A380 landing gear (Scholz 2015)

The **tailplane** of the A380 is relatively large as well, as can be seen in Figure 4.7. The function of a tailplane is to provide control and stability around the vertical and horizontal axis of the aircraft, and it depends on its volume. The tail volume is the result of a multiplication of the area of its surface and the distance that area has from the aircraft's center of gravity. Either an aircraft has a smaller tailplane and a longer fuselage (lever arm), or a larger tailplane and a shorter fuselage. While an undersized tailplane reduces the stability and control of an aircraft and thus should not be done normally, a large tailplane is more stable but produces more **drag** and is heavier (Engelbrecht 2010). Since the A380 is designed as a double decker, the fuselage is relatively short. For that reason, the tailplane is relatively large and heavy and, as said before, produces more drag.

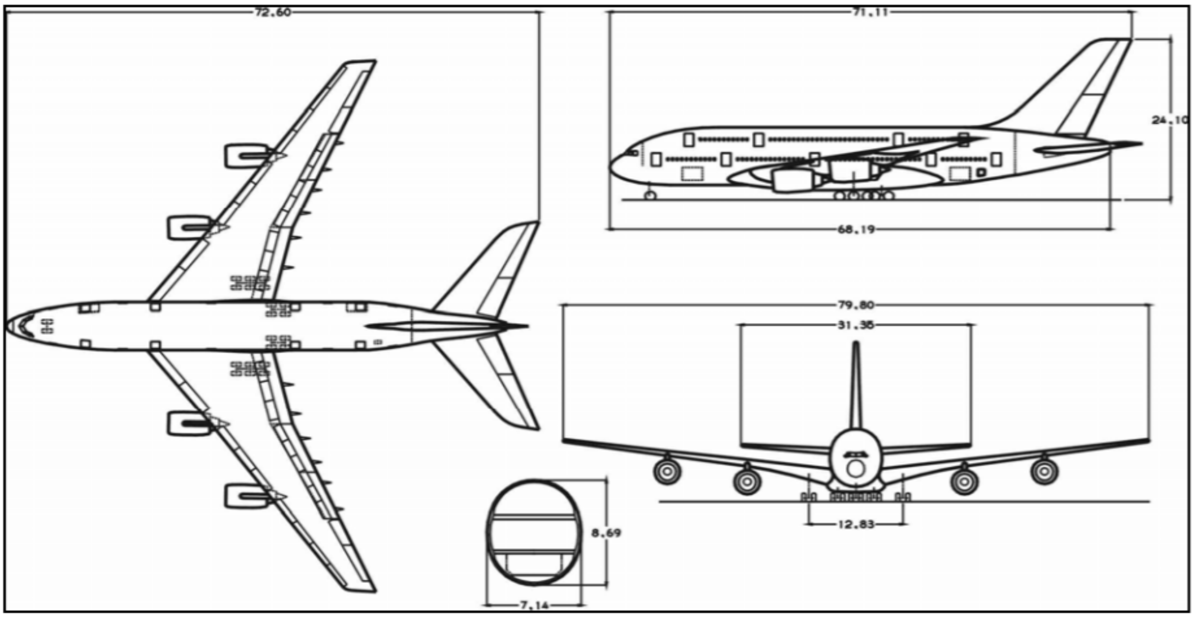

Figure 4.7 Three-view drawing of an A380 (Scholz 2015)

Another point is the increased induced drag due to a relatively **low aspect ratio**. This is due to the fact that the designers of the A380 were restricted by the maximum dimension of 80 m by 80 m mandated by airports. Because of that, the wingspan is not optimal for the dimensions of an A380, which would have needed optimally longer wings, and thus, the aspect ratio is unusually low. The aspect ratio is defined as:

$$A = \frac{b^2}{S} \tag{4.1}$$

A high aspect ratio is corresponding with a **low induced drag**, which is calculated as the following:

$$C_{D,i} = \frac{C_L^2}{(\pi \cdot A \cdot e)} \tag{4.2}$$

Furthermore, a low induced drag also increases the lift-to-drag-ratio, which determines the aerodynamic efficiency of an aircraft. On the other hand, a low aspect ratio means more induced drag and a lower lift-to-drag ratio, which lead to less fuel efficiency and higher **Direct Operating Costs** (DOC). The A380 with a wingspan of 79.8 m and a wing area of 843 m^2 has an aspect ratio of 7.53. In comparison to other common present-day aircraft, such as the B787 or the A350 with an aspect ratio of 9.5, it is relatively low (Hamilton 2014).

By delaying the introduction of the A380 to the market for over a year, competing aircraft with more fuel-efficient jet engines, such as the B787 or the A350, were soon released and became competitors on the long-range aircraft market. Specific fuel consumption has been improved to the A380 engines by around 6 % to 7 % (Loth 2021). New engine option could have improved fuel efficiency, but the engine manufacturer Rolls Royce did not develop a **neo-version** for the A380 (Späth 2021c).

Another point is the **relative payload** of the A380, which is lower than other present-day aircraft. The relative payload is defined as the maximum payload divided by the maximum take of weight (MTOW), both values can be found in Airbus 2005. The A380-800 with a maximum payload of 84 t and a typical MTOW of 560 t has a relative payload of 0.15, whereas the A340-600 has 0.17.

These facts summed up led to a less efficient aircraft design and thus relatively high operating costs for the airlines to operate the A380, especially, when a flight is not fully booked. Combined with the increased demand for point-to-point flights, lowered the demand for the A380 significantly.

Nonetheless, it must be noted that the argument, two engines would be cheaper for airlines than four, is only true for aircraft types, who could theoretically fly with only two engines. The bigger an engine, the lower is the **specific fuel consumption**, thus aircraft with two engines twice as large as the same aircraft with four engines would consume significantly less. In the case of an A380, the engines are already big and there would be no option to operate an aircraft of that size with only two engines.

Another disadvantage of the A380 is the larger time intervals following airplanes are obliged to keep due to more dangerous wake turbulences of the A380. The idea of Airbus was to increase the **capacity of hubs** by transporting larger numbers of passengers in larger airplanes. Since there can only be a certain number of airplanes landing at an airport, larger planes like the A380 are the only option to expand the limited capacity of airports. However, it is necessary that, by operating larger airplanes, the number of flights is not decreasing to have a positive effect on the airport's capacity. How long the time difference between one take-off and the next one is, is largely determined by the wake turbulences of an airplane. **Wake turbulences** are created by every aircraft, but their strength depends on the aircraft's weight, speed, wingspan and -shape. The heavier and slower the aircraft flies, the stronger the vortex. Especially during take-off and landing, the wake turbulences are enormous due to distinct wing configuration or flap extensions. The turbulences are triggered by the air pressure difference between the upper wing surface (lower pressure) and under the wing (higher pressure). The airflow at the rear of the wing rolls up which leads to a swirling of air masses. The resulting wake consists of two counter-rotating cylindrical vortices (FAA 2021). The energy in these air vortices, which depends on the mass of the wake turbulence producing airplane, can be dangerous for following airplanes, especially, when they are smaller. The wake vortices lose more power over distance; thus, it is important to know the length of wake vortices of different aircraft types to determine when the next aircraft can start without risking being drawn into the wake vortices of the previous aircraft. ICAO categorizes wake vortices of different aircraft types based on their MTOW.

Due to its mass, the Airbus A380-800 is momentarily the only aircraft categorized as ***super*** by the FAA, who uses a similar system as ICAO (see Table 4.1).

Table 4.1 FAA and ICAO aircraft weight class (Wikipedia 2021e)

FAA Aircraft Weight Class		
Code	**Class**	**MTOW**
J	Super	A380-800 and An 225
H	Heavy	≥ 300,000 lb (136,000 kg)
L	Large	< 300,000 lb (136,000 kg), > 41,000 lb (18,600 kg)
S	Small+	≤ 41,000 lb (18,600 kg), > 12,500 lb (5,670 kg)
	Small	< 12,500 lb (5,670 kg)

ICAO WTC		
Code	**WTC**	**MTOM**
H	Heavy	≥ 136,000 kg
M	Medium	< 136,000 kg, > 7,000 kg
L	Light	≤ 7,000 kg

Although Airbus did extensive research in the field of wake vortices to prevent an upgrading of the A380 in comparison to other heavy aircraft types, testing and measuring of the wake turbulences of the Airbus A380 showed that during take-off and landing the generated turbulences are more significant than the ones created by category *heavy* (Skybrary 2021b).

For the A380, the classification into the category *super* means that following airplanes, for example a B757 (categorized as *medium*), need to have a distance of 7 nm instead of 5 nm for leading airplanes categorized as *heavy* (see Table 4.2). Consequently, despite being able to transport more people, there is no general advantage in capacity for hubs by operating A380 aircraft.

Table 4.2 FAA wake separation standards (Mitsikas 2018)

Leader/Follower	Super	Heavy	B757	Large	Small
Super	MRS	6	7	7	8
Heavy	MRS	4	5	5	6
B757	MRS	4	4	4	5
Large	MRS	MRS	MRS	MRS	4
Small	MRS	MRS	MRS	MRS	MRS

4.4 Brief History of Airbus

European aerospace manufacturers formed Airbus Industrie as a *Groupement d'Intérêt Économique* (Economic Interest Group or GIE) as a response to the dominating aerospace industry of the United States in 1970. It was **initiated by the governments** of France, Germany, and the United Kingdom in 1967 and its shareholders consisted of French Aérospatiale, German Deutsche Airbus, British Hawker Siddeley, Dutch Fokker-VWF and the Spanish CASA (CH 2021).

The first aircraft manufactured by Airbus was the A300, but it was the **A320** launched in 1987, which established Airbus Industrie as one of the leading aerospace companies. It became clear that Airbus Industrie was not only a short-term collaboration and discussions about establishing a conventional company emerged.

In 2000, three of the four partner companies (DaimlerChrysler Aerospace, successor to Deutsche Airbus, Aérospatiale-Matra, and CASA) merged into one company – European Aeronautic Defense and Space (**EADS**), so that EADS owned 80 % of Airbus Industrie. The other 20 % remained with BAE Systems. In 2013 EADS was renamed into Airbus Group.

4.5 Airbus Plant Hamburg-Finkenwerder

One of the production sites of the Airbus A380 is in Hamburg Finkenwerder. The main headquarter of Airbus Commercial Germany is based in Hamburg. Nowadays Airbus produces in Finkenwerder more than half of all **Single Aisle** Jets of Airbus in Finkenwerder, which makes Hamburg to one of the biggest sites for aerospace globally. Around 14,000 workers are employed at Airbus Finkenwerder so that Airbus is one of the biggest employers in Hamburg. The structural assembly of the A320-family as well as the A330 and A350 takes part in Finkenwerder. The final assembly of the A320 is also carried out there. The plant has its own airport from were deliveries of assembled aircraft to customers around the world take place (Airbus 2021b).

Airbus Finkenwerder plant is located on the former site of the Hamburger Flugzeugbau GmbH (HFB), which was founded in 1933 by the owner of the shipyard company Blohm & Voss, Walther Blohm. In 1936, the development of **seaplanes** like the BV 138, as can be seen in Figure 4.8, and HA 136 B started, for which a harbor basin to take-off and land was needed (Wohlers n.d.).

Figure 4.8 Take-off of an BV 138 on the Mühlenberger Loch (Hansen 2008)

For this reason, the **Mühlenberger Loch**, a river area with numerous sandbanks between Cranz and Blankenese, was excavated. A shallow water bay was created in this way. The material dumped between the old Elbe islands Schweinesand, and Hanskalb-Sand created a new island called Neßsand (GOEP 2016).

After the Second World War, the plants in Finkenwerder were destroyed by the allies but Walther Blohm founded Flugzeugbau Nord GmbH in 1954 in cooperation with the HFB (see plant at that time in Figure 4.9).

A fusion with Messerschmitt AG and Bölkow GmbH into Messerschmitt-Bölkow-Blohm GmbH (MBB) took place, which later formed the **DASA** (Deutsche Aerospace AG) after the takeover by DaimlerChrysler AG. Since 2000 DASA has been part of EADS (Wohlers n.d.).

Figure 4.9 Airbus plant Finkenwerder in 1964 (Hansen 2008)

4.6 Protests and Lawsuits Against Extension of Airbus Finkenwerder Plant

For the city of Hamburg, it was very desirable to be a major assembly site for the biggest airplane in the world. It was not only a matter of **prestige** to be an important international site of aeronautical manufacturing but also of economy by possibly creating a significant number of jobs. For this reason, already in 1997 Hamburg politicians of SPD and Grüne agreed to construction measures for preparing area in case Hamburg-Finkenwerder was chosen to be the final assembly site. One year later, in 1998, Hamburg officially applied for becoming the final assembly site for the A3XX. In the catalogue of requirements presented by Airbus, the size of the required runway was specified. Back then, the factory Finkenwerder as well as the runway were not big enough for the A3XX. To compete with the other applying cities, a **plant extension** had to be approved to ensure an extension of the runway and place for the assembly halls. For that reason, Hamburg planned to fill up 170 ha out of the 675-ha area of the river basin Mühlenberger Loch (RPO 2001). It was not the first time, Hamburg planned to fill the Mühlenberger Loch. In 1979, a plan was announced by the senate to extend the MBB-plant into the river basin (Cords 1980). Due to public outrage, it was not realized (Nimtz-Köster 2005).

In the Mühlenberger Loch the largest **freshwater mud flats** in Europe are located which have important **ecological functions**. The shallow water is rich in nutrients and thus provides food for many different birds, such as the northern shoveler, cormorants, geese and many more. For many migratory birds - some of them endangered species' - the Mühlenberger Loch is a very important resting place in spring and fall. Also, many fishes use the shallow water as a nursery (GOEP 2016). For these reasons, the Mühlenberger Loch was and is protected nationally and internationally. The German government declared it as protected landscape, the European Union as bird reserve and the international treaty, the Ramsar Convention, as wetland of international importance (Nimtz-Köster 2005).

Environmental associations filed a complaint against the plans of the city to partly fill up the Mühlenberger Loch. The European Environment Commissioner at the time, Ritt Bjerregaard launched infringement procedures against Germany and also her successor, Margot Wallström denied a certificate of exemption, for which Hamburg applied. The requirement for an exemption is a complete and prompt **compensation** for the protected areas and Wallström deemed the proposed compensation areas in Lower Saxony and Schleswig-Holstein to be insufficient (Nimtz-Köster 2005).

After former German Bundeskanzler Gerhard Schröder had sent a letter to the President of the European Union, in which he campaigned for a certificate of exemption, Wallström did **approve the exemption** by reasoning that "the project is of outstanding importance for the region of Hamburg and for northern Germany as well as the European aerospace industry" (EC 2000).

One month after the Brussels decision, Airbus declared that the final assembly site would take place in Toulouse, while furnishing, painting and the delivery to customers from Europe and the Middle East would take place in Hamburg. The city of Hamburg then issued a planning approval decision for the plant extension, but after over 200 **lawsuits** were filed, the administrative court stopped the construction. Nonetheless, although the court ruled the decision of the European Commission as unlawful, it denied environmental associations the right to sue and nullified the construction stop and the work on the plant extension began (Figure 4.10 and Figure 4.11) (Westphal 2005).

Figure 4.10 Start of the plant extension (ReGe 2021)

Figure 4.11 Progression of the plant extension construction (Airbus 2002)

The costs for the land reclamation were around 693 million euros and around 11 million cubic meters of sand were used. In September 2002, the filling up of the Mühlenberger Loch was finished (Figure 4.12) (Petters 2007).

Figure 4.12 Finished plant extension in the Mühlenberger Loch (ReGe 2021)

One of the three **compensation areas** for the Mühlenberger Loch was created in Hahnöfersand by relocating the dyke and thus forming new freshwater mud lands. For the northern shoveler Hahnöfersand has not been an adequate compensation area, instead of the predicted 1000 animals, only 100 northern shovelers at the most have been using the area as resting place. Another compensation area in Haseldorfer Marsch could not be built after the administrative court of Schleswig had ruled that the already protected area could not be a compensation area (BUND 2012). The other compensation areas in Borghorster Elbwiesen and Hörner Au took over 12 and 18 years respectively (Veit 2018). In 2006, the European Commission declared to Hamburg that the exemption certificate should have not been approved in 2000 (BUND 2012). Since a compensation area must be created promptly, the measures to compensate for the Mühlenberger Loch can be ruled as **insufficient**.

Not only the extension by filling up the Mühlenberger Loch provoked protests and lawsuits but also the runway extension to the south. After proposing a runway extension by 363 m in May 2000, Airbus applied for another extension by 598 m in February 2003 to ensure that the planned **cargo version** of the Airbus A380 could start and land in Finkenwerder (NDR 2015). The southern end of the runway would inflict with private houses and orchards area in Rosengarten in the village Neuenfelde (see Figure 4.14). Neuenfelde is a western district of Hamburg and lies on the left side of the river Elbe. It is the eastern part of the cultural landscape Altes Land, which is the largest fruit-producing region in Northern Europe. Mostly apples but also cherries pears and plums are grown in this region and during blossoming time attracts many visitors (Busch 2019).

In June 2002, the Hamburg parliament approved the so called “Lex Airbus”, which classified the plant extension as **charitable** to strengthen the position of the city. Nevertheless, the administrative court later ruled that this law did not justify any infringements of property, since the Airbus aerodrome was private (NDR 2015).

In the meantime, the city of Hamburg started to buy properties in Neuenfelde, a total of 67 houses were bought to extend the runway and prevent possible future lawsuits against noise pollution (George 2019). But many residents did not want to sell their property.

After a change of the Federal Aviation Act by the federal council, which now allowed to classify private aerodromes as charitable, Hamburg parliament enacted a law on **expropriation** in February 2004 (Nimtz-Köster 2005).

In April 2004, a new **planning permission resolution** was enacted to extend the runway by 598 m. One month later, the city and Airbus started with the destruction of the main dyke of Neuenfelde, which was stopped by the supreme administrative court to protect the interests of the Neuenfelde residents. Over 200 lawsuits were filed against the new planning permission resolution and in August 2004 supreme administrative court Hamburg ruled it **unlawfully** due to substantial legal shortcomings (Nimtz-Köster 2005).

After the construction stopped, the first **official meetings** between residents and the mayor of Hamburg, Ole von Beust, took place to find a solution. Airbus offered a fund over 3 million euros for the community and declared there would be no further extensions of the plant while the city of Hamburg guaranteed for the continued existence of Neuenfelde as a village (NDR 2015).

One of the properties in discussion belonged to the **church** Neuenfelde. In November 2004, negotiations between the church and the city came to a halt which was criticized by mayor Ole von Beust but also the Bishop Maria Jepsen. Furthermore, protests of 10,000 Airbus worker took place (NDR 2015).

In the beginning of December of 2004, only the church and two more landowners would not sell their property to the city. In Figure 4.13 the remaining private properties are depicted in white, while all the green areas were already in possession of the city.

Figure 4.13 Private and public properties in the area of the future runway (Manager Magazin 2004)

After long discussions, one farmer with four properties sold them, but only after the city had guaranteed to fulfill 19 **demands** of the former pool of plaintiffs. Among other things, it was demanded that the noise pollution would not exceed a certain level, the "Lex Airbus" would be repealed, no more runway extension or industrial settlements east and south of the runway would be planned and the empty houses in the Hasselwerder Straße would be re-rented (HA 2004). By buying these properties, the city of Hamburg freed the way for the extension of the runway. The remaining two properties in Neuenfelde did not need to be bought by changing the course of the runway (Sucher 2004). Although there were still pending lawsuits by other residents and the church, the building of the runway started in April 2006 (Figure 4.15).

Figure 4.14 Airbus runway and Rosengarten before 2. plant extension (Spiegel 2004)

Figure 4.15 Airbus runway and Rosengarten while 2. plant extension (ReGe 2006)

In March 2007 Airbus announced that it would currently only focus on the commercial passenger jet and all activities for the freight version of the A380 were stopped. Environmental associations consequently demanded the stop of the extension of the runway, but the federal administrative court rejected a notice of appeal (NDR 2015).

Finally in June 2007 the city of Hamburg officially handed over the runway to Airbus (see final runway in Figure 4.16). **Pending lawsuits** have not been settled over a decade (HA 2018).

Figure 4.16 Finished plant extension into Mühlenberger Loch and Neuenfelde (Picture from Google Maps)

4.7 Extension of the Runway

According to Airbus, the reason for the required second runway extension was that the existing runway was too short for the **cargo version** of the A380. At that time, the length of the runway was around 2,630 m long, from which 2,530 m (Take-Off Run Available (TORA)) were useable. Data for the runway length before the second plant extension for the A380 varies from reference to reference. The shortest determined length can be found in a map from the company Jeppesen (see Figure 4.17) (Loth 2021).

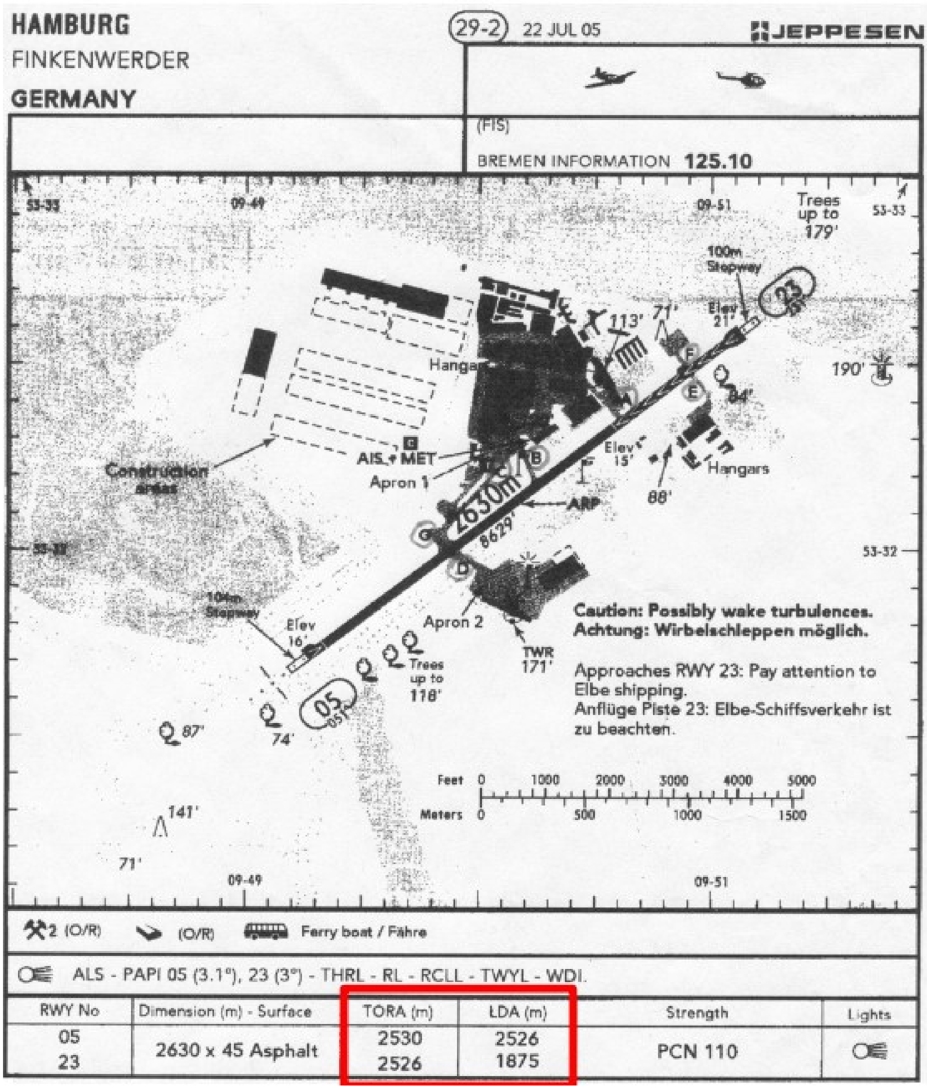

Figure 4.17 Runway length before the plant extension of 598 m (Loth 2021)

According to Airbus, for the ferry flights of the planned A380-800F, a weight of 410 t needed to be considered. The weight of 410 t resulted from the Airbus requirement that a **customer acceptance flight** must have 66 % of the MTOW and in the planning permission resolution a MTOW of 620 t was specified (OVGH 2006). However, according to all other publications by Airbus concerning the masses of the cargo version, the A380-800F was supposed to have a MTOW of only 590 t, an empty weight of 249 t, a maximum payload of 153 t, a maximum fuel mass of 248 t, and a maximum landing mass of 427 t. Why Airbus changed the MTOW of the cargo version for the planning resolution is not known (Loth 2021).

Since the A380F was never built, there is no data available about the take-off- or landing-weight as a function of the length of the runway. Nonetheless, the geometry of the A380-800 and the A380-800F is the same and the difference in weight can be accounted for in given charts for various take-off- and landing-weights of the A380-800. As such the necessary runway length for the A380-800F can be found. Corresponding diagrams are given in Airbus 2005.

According to Figure 4.18, the take-off weight for the A380 still be operable on the Finkenwerder runway before the second extension (2630 m) is around **550 t** under ISA-conditions and with GP7200 engines. For the cargo version of the A380 the runway situation would have been much the same.

According to one interviewee, who was a former Airbus employee and worked on the A380, a major concern of Airbus was also that, in case of a sudden abort of a take-off with full thrust setting, there would be enough runway length left to let the airplane come to a standstill. However, this concern is not justified, as the case is included in Figure 4.18.

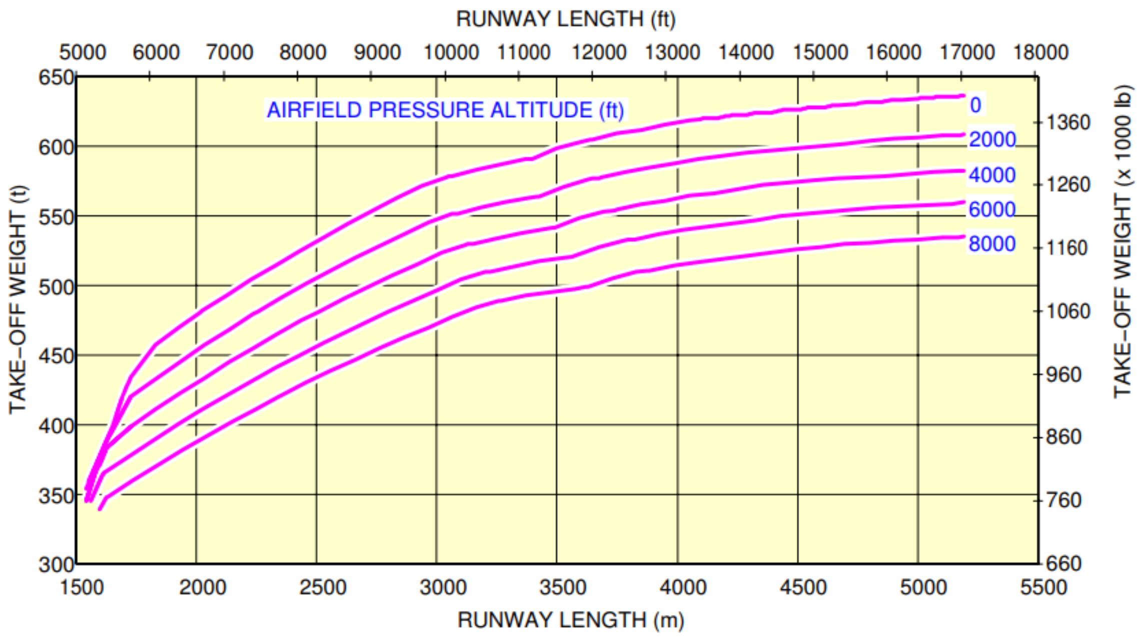

Figure 4.18 Take-off-weight as a function of runway length for A380 (ISA-conditions and Engine Alliance GP7200 engines) (Airbus 2005)

For landing in south-west direction (230°), it needs to be considered that the available landing distance (LDA) is not the same as the surface length. This is due to the high terrain on the north bank of the Elbe together with an angle of approach of 3°. As such the landing threshold is displace by around 750 m (Nimtz-Köster 2005). The diagram is valid for all temperatures and dry runway. A wet runway, requires more runway length. But it is normal that not all conditions (air temperture, pressure, wet runway, system failure like flap failure) can be met at the same time. For a landing distance available of 1,800 m (rounded down), a landing weight of 360 t is possible, which means 111 t could be distributed between payload and fuel weight. It is never possible to have both maximum fuel weight and maximum payload at the same time. But 111 t could be distributed between payload and fuel weight. In case of 10 t remaining fuel in the tanks while landing, it would still be possible to transport 66 % of the maximum payload. Other combinations of payload and fuel weight would be possible as well. Hence, the old runway would still be long enough to transport cargo and have enough fuel to land, so that no further extension was imperative (Loth 2021).

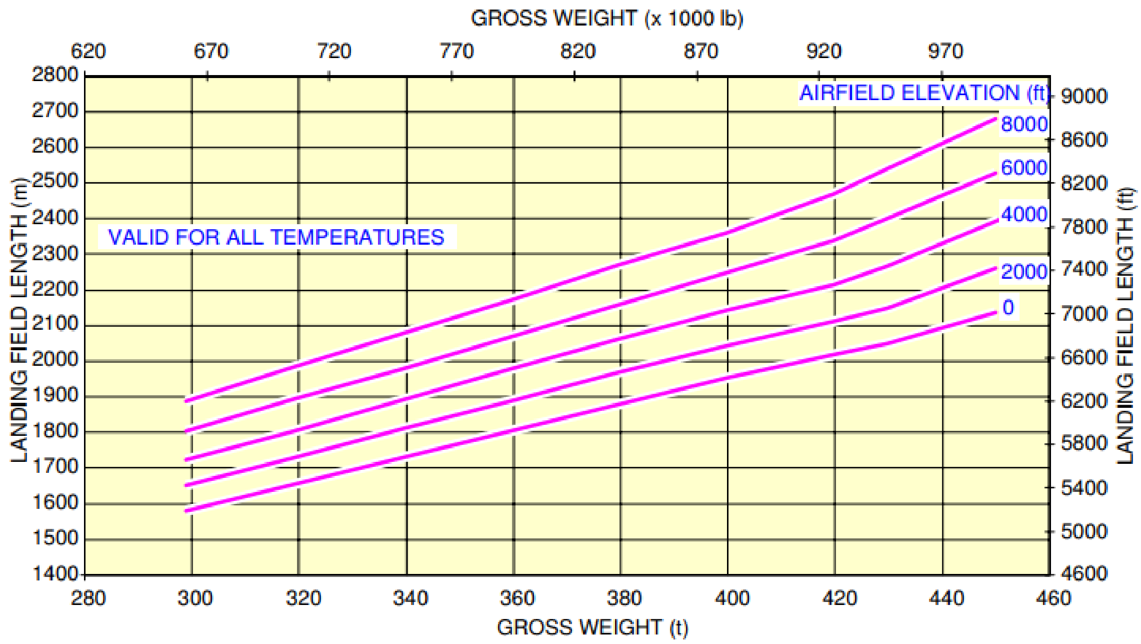

Figure 4.19 Landing field length as a function of landing weight (ISA-conditions, Engine Alliance GP7200 engines, dry runway) (Airbus 2005)

For operations at Airbus Hamburg-Finkenwerder airport it is incomprehensible why it was a requirement to land with 96% of the MLW and to have the same mass requirement for take-off and landing. According to Airbus, this requirement is for a worst-case scenario, which means that right after take-off, the aircraft has an emergency and needs to land right away. However, in the rare case of an emergency, other airports such as Hamburg Airport could be used for **an emergency landing**. Furthermore, it is common practice to dump all fuel in case of an emergency landing, which would reduce the weight significantly (Carstens 2018).

A380 aircraft were delivered from Hamburg Finkenwerder plant only to customer from Europe and the Middle East. The highest fuel capacity to achieve the **maximum range** would not be necessary. Furthermore, it would also be possible to refuel the tanks on the delivery way.

It also needs to be pointed out that it is common practice that not all requirements can be fulfilled. Requirements such as long enough runway for wet surfaces or high temperatures, as well as maximum masses need to be balanced out and **compromises** usually must be made.

It can be noted that there would be other possibilities to deliver the planned cargo version of the A380 without a runway extension. However, it can be assumed that it was highly desirable for Airbus Germany to have a facility similar to the one in Toulouse. The final runway now has a length of 3183 m (Figure 4.20).

Figure 4.20 Runway Hamburg Finkenwerder (OpenAIP 2012)

5 S-LCA of an Airbus A380

After giving background information about the product to be assessed, in the following chapter a Social Life Cycle Assessment is performed on the Airbus A380. For this purpose, *the Guidelines* for Social Life Cycle Assessment are being used as methodology.

5.1 Goal and Scope of the Study

5.1.1 Goal Definition

As described briefly in Chapter 2.4.1, the objective of the study needs to be pointed out. Following the *Guidelines* methodology, these questions will be addressed: why the S-LCA is conducted; what the assessed object is and who will use the study.

Public awareness of social issues of products and along their supply chains has come more into focus. Not only by implementing laws and guidelines like the United Nations Sustainable Development Goals or the Anti-Slavery laws applied in many countries, but also because many companies are conscious about their social responsibility. The number of members of amfori Business Social Compliance Initiative, who's goal it is to improve worldwide social standards in the supply chain, has been increasing from 644 in 2010 (BSCI 2013) to 2,414 members in 2019 (BSCI 2019).

The aviation sector has a great potential to improve social impacts, because it is one of the most important industrial sectors in the European Union. The aeronautics industry employs 405,000 workers and generates 130 billion euros revenues (EC 2021a). Furthermore, it has a complex network of **suppliers** worldwide since 65 % to 80 % of the final costs of an aircraft product consists of parts, components, materials, and services provided by suppliers (Horng 2007). By assessing the social impacts along the supply chain, it could help decision-makers to improve negative social issues and thus the life of people world-wide affected by the aeronautics industry.

But while there have been some E-LCAs conducted for aircraft, the social aspects have been neglected so far. An LCA methodology has the advantage to analyze the impact of a product during its whole life span and thus is also the best option to apply for social impacts. Unfortunately, S-LCA is not yet internationally standardized, although the UNEP *Guidelines* provide a general framework. At this point, the published S-LCAs vary strongly from each other and are still in an experimental stage. But while there are already S-LCA studies for a lot of products, social aspects of aviation and aircraft design have not yet been addressed in a holistic way from cradle to grave (see Chapter 3.2). The goal of this study is to evaluate the

social impact of an aircraft during its lifetime and thus to lay a foundation for S-LCA of aircraft for future assessments. The study should also help to emphasize strengths and weaknesses of S-LCA applied for this specific product.

For this study, the development of an Airbus A380, a commercial long-range aircraft with large capacity, is being analyzed. A more detailed description of the product to be assessed was given in Chapter 4.1.

The function of the Airbus A380 is the **safe and comfortable transportation** of passengers by air.

This study is for academical purpose and was written as a project at the Hamburg University of Applied Science. It will be published on various websites, databases and with various libraries (see page 2). As such, it will be open to the public.

5.1.2 Scope of the Study

In the following subchapters, important aspects concerning the scope of the study will be defined, namely the functional unit, the system boundaries, data sources, stakeholder categories, included subcategories, impact categories, inventory indicators and study limitations.

5.1.2.1 Functional Unit

Barke 2020 proposes in his paper a functional unit defined as “100 kilometers traveled by a 70 kg passenger with 30 kg luggage and an aircraft load factor of 80% on a generic flight profile.”. Defining the functional unit in this way goes in line with the functional unit **passenger kilometers** being commonly used in E-LCA for transportation systems (Chalaka 2020). But as already mentioned in the *Guidelines*, social impacts are not always expressible in quantitative data, more common are **qualitative or semi-quantitative data**. In E-LCA and LCC the environmental and economic impacts can be expressed per functional unit due to the reliance on quantitative data. As S-LCA follows the same ISO framework as E-LCA, the *Guidelines* recommend the use of a functional unit as well, but the type of data collected can make it very difficult. The question arises how social impacts such as *equal opportunities for workers* or *cultural heritage* can be expressed per above mentioned functional unit (Pollok 2021).

Therefore, in this study, the functional unit is being neglected entirely due to the high amount of qualitative data being used and consequently the difficulty to express most indicators per functional unit.

5.1.2.2 System Boundaries

In this study the aircraft's social impacts are being assessed from **cradle to grave** but with the focus on the manufacturing and use phase. While there are already some Airbus A380 taken out of service, social impacts of the end-of-life phase have not yet been fully apparent. Thus, this life-cycle phase is only briefly discussed. Another emphasis of this study are the social impacts of aircraft on the **local community** stakeholder group.

5.1.2.3 Data Sources

While conducting the research, mostly **site-specific data** were collected. The following sources are used during the S-LCA:

- Interviews with local community members
- Interview with former Airbus employees
- Web search

5.1.2.4 Stakeholder Categories

The S-LCA method defined by UNEP/SETAC recommends the involvement of **five stakeholder categories**: *worker*, *local community*, *society*, *consumers*, and *value chain actors*. The included stakeholder groups in the following S-LCA of an Airbus A380 are oriented towards these recommendations. The stakeholder groups *workers*, *local community* and *society* are assessed but additionally other stakeholder groups are included as well, while *value chain actors* are left out.

The stakeholder group *consumers* can be divided into two different stakeholders, when assessing an aircraft. The customers are the airlines - who buy from the aeronautics manufacturers, for that, the **airlines** can be considered as consumers. On the other hand, consumers can also be regarded as the group of people who will use the aircraft as means of transportation - which are the **passengers**, who buy flight tickets. Therefore, it is reasonable to divide the stakeholder group of *consumers* into *airlines* and *passengers*. Both groups have different, sometimes opposite interests such as profit increase through expensive tickets or maximum number of passengers (airlines) against affordable tickets and comfort (passengers). However, due to the time and data limitations, the stakeholder group *airlines* is not included into this study.

In this particular study, it is reasonable to consider **political decision-makers** or the state as stakeholder, since the GZBV, a holding company for the German government, holds a share of 11% of the Airbus Group (Airbus, 2021c).

Furthermore, the manufacturing organization of the investigated product is included into the stakeholder groups, since the A380 is the first product being manufactured after the restructuring of Airbus Industrie into EADS, a **multinational company**.

Depending how detailed a stakeholder group is defined and how broad the perspective is, several stakeholder groups could be added. There are groups affected by aviation industry in a **direct**, **indirect, induced, and catalytic way**. Regions in the vicinity of airports, especially in touristic regions, have numerous different groups affected by air transportation and thus by aircraft (Dimitriou 2017). Site businesses in airport vicinity such as hotels or restaurants, catering services or air traffic control could be counted as stakeholders, but a study with such broadly formulated terms is not feasible. For this reason, only directly affected groups are analyzed, indirectly affected or induced stakeholder groups are neglected.

Due to time and data limitations, further possible stakeholder groups are excluded from this study - such as airports, as locations where flight operations take place, future generations, whose livelihood, and health will be significantly affected by environmental impacts and global warming, or Non-Governmental Organizations (NGOs).

Summarized, for this study the following stakeholders have been chosen with a strong emphasis on the local community near Finkenwerder manufacturing site:

- Local community
- Workers
- Passengers
- State
- Organization (Airbus)

5.1.2.5 Included Subcategories

The UNEP/SETAC *Guidelines* define 31 subcategories, following **international agreements**, CSR Initiatives, and **legal frameworks** which are listed in Table 2.1 (UNEP 2009).

Due to the focus and limitations of the study, some subcategories are excluded. While there could be grave social issues concerning **human rights violation** such as child labor along the supply chain, the focus on the workers is site-specific for the manufacturing site Airbus Finkenwerder. Since it is highly likely that European aircraft manufacturer Airbus is following European legislation and does not gravely violate human rights, the subcategory *child labor* was excluded. Due to no available data about the supply chain from raw material extraction to aircraft system manufacturers there is only little general information where possible violations of human rights such as child or forced labor could occur. The same can be applied for the subcategory *respect of indigenous rights*, which is not applicable for the site-specific study for Finkenwerder. Since the stakeholder consumer has been changed into passenger, different subcategories are assessed, and others left out.

On the other hand, the additional added stakeholders mentioned in 5.1.2.4, provoke new subcategories. In total, the study includes 17 subcategories. In the following Table 5.1, the subcategories according to the stakeholders used for this study are listed.

Table 5.1 Stakeholder categories and related subcategories for S-LCA of an A380

Stakeholder categories	**Subcategories**
Local community	Delocalization and migration Community engagement Cultural heritage Safe & healthy living conditions Local employment
Workers	Freedom of association and collective bargaining Fair salary Equal opportunities/discrimination Health and safety Social benefits/social security
Passengers	Health and safety Comfort
Society	Public commitment to sustainability issues
State	Political power and prestige Economic growth
Organization	Profit International teamwork Technology development

5.1.2.6 Impact Categories

While the *Guidelines* point out that momentarily subcategories and stakeholders form the basis on which an S-LCA is developed, they also propose the following impact categories basing on internationally recognized standards:

- Human rights
- Working conditions
- Health and safety
- Cultural heritage
- Governance
- Socio-economic repercussions

These impact categories can be used for the present study as well since almost all subcategories and stakeholders can be connected to these proposed categories. Only the subcategory *comfort* cannot be associated with one impact category.

5.1.2.7 Inventory Indicator and Related Data

The *Methodological Sheets* for subcategories provide examples of inventory indicators and possible **sources for data collection** as well as units of measurements. Furthermore, it gives a detailed description of the subcategories to avoid any misinterpretation (UNEP 2013).

According to these methodological sheets, the following inventory indicators, unit of measurements and data methodologies in Table 5.2 were chosen for this study. Inventory indicators for new subcategories are listed additionally.

Table 5.2 Indicators, units of measurements and data sources for inventory analysis

Subcategory	**Inventory indicator**	**Unit of measurement**	**Data methodology**
Delocalization and migration	Number of individuals who resettle (voluntarily and involuntarily) that can be attributed to organization	quantitative	Site visit or site-specific audit Interviews with community members
	Compensation policies	qualitative	Interviews with community members
Community engagement	Freedom of Peaceful Assembly and Association	qualitative	Interviews with community members U.S. Dept. of State Human Rights Country Reports
	Trust of Politicians	qualitative / semi-quantitative	Interview with community members World Economic Forum rankings, by country
	Number and quality of meetings with community stakeholders	qualitative / semi-quantitative / quantitative	Interviews with community members Newspaper reports
	Organizational support	qualitative	Interviews with community members
Cultural heritage	Strength of Policies in Place to Protect Cultural Heritage	qualitative / semi-quantitative / quantitative	Interviews with community members, management, and NGOs Review of organization-specific reports, such as GRI reports and Social Impact Assessments
Local employment	Presence of local supply network	semi-quantitative	World Economic Forum rankings of supplier quantity, by country
	Percentage of workforce hired locally	quantitative	Site visit or site-specific audit Review of organization-specific reports, such as GRI report
Safe and healthy living conditions	Pollution levels	quantitative	Measured pollution levels
	Strategies for prevention	qualitative	Interviews with community members
Material assets	Value of property	qualitative / semi-quantitative / quantitative	Interviews with community members Site-specific reports
Freedom of association and collective bargaining	Presence of unions within the organization is adequately supported	qualitative / semi-quantitative	Interview with workers and trade union representatives

	Workers are free to join unions of their choosing	semi-quantitative	Interview with workers and trade union representatives
Fair salary	Lowest paid worker, compared to the minimum wage	semi-quantitative / quantitative	Wage reports Interview with workers
Hours of work	Number of hours effectively worked by employees (at each level of employment)	quantitative	Interview with workers
	Number of holidays effectively used by employees (at each level of employment)	quantitative	Interview with workers
Health and safety - workers	Number/ percentage of injuries or fatal accidents in the organization by job qualification inside the company	quantitative	Review of enterprise-specific reports
Equal opportunity / discrimination	Presence of formal policies on equal opportunities	qualitative	Review of enterprise-specific reports
	Ratio of basic salary of men to women by employee category	semi-quantitative / quantitative	GRI Sustainability report
Social benefits	List and provide short description of social benefits provided to the workers	qualitative	Review of enterprise-specific reports Interview with workers
Health and safety - passengers	Quality of labels of health and safety requirements	qualitative	Certification by EASA
	Number of incidents	semi-quantitative / quantitative	Review of reports
Comfort	Levels of noise	qualitative / quantitative	Data provided from enterprise
Public commitment to sustainability issues	Presence of publicly available documents as promises or agreements on sustainability issue	qualitative	Review of enterprise-specific reports, such as GRI reports
Political power and prestige	-	qualitative	Review of newspaper
Contribution to economic growth	Number of national employments	quantitative	Review of enterprise-specific reports
Profit	Revenue	semi-quantitative / quantitative	Review of enterprise-specific reports
International teamwork	Challenges and benefits	qualitative	Interviews with worker Review of newspaper
Technology development	Innovations and patents developed during the project	Qualitative	Interview with worker

5.1.2.8 Study Limitations

Every Life Cycle Assessment study is limited by **time**, **data availability** or **resources**. This is even more true for a complex product such as an aircraft, which consists of million distinctive parts with hundreds of suppliers worldwide and a life span of several decades. Therefore, it is necessary to decide which processes will be considered and which are neglected and how detailed different aspects are being analyzed.

An enormous limiting factor is data availability. As mentioned in Chapter 2.3, a Social Hotspot Database created by New Earth is a very helpful tool to identify possible social hotspots in a supply chain. It provides country- and sector-specific data, which can be used for a **risk assessment**, or measuring positive impacts in a LCA software such as SimaPro or Open LCA (NEB 2019). While examining recently published S-LCA case studies, it becomes obvious that the database is commonly used and an essential part of collecting generic data. Unfortunately, the cost of purchasing an SHDB license is 1,500 $. There is no other free database available which is a very limiting factor for conducting an S-LCA, especially of an aircraft with a complex supply chain. For E-LCA, an assessment software with databases included can be used for free or as a demo version such as Open LCA or SimaPro to calculate impacts and provide results in an organized way. Since there is no SHDB available for free, it was not possible to simplify the assessment with a software tool.

Another problem with data availability concerns the material list, which can be found in the Structure Repair Manual for an Airbus A380. Due to **confidentiality** regarding almost all aspects of an aircraft, it was not possible to access a list of materials (Lopes 2010).

As mentioned above, the emphasis of the study lies on the local community of the manufacturing site of an Airbus A380. Other stakeholder and life cycle phases will be assessed as well, but in less detailed description.

5.2 Inventory Analysis

The inventory analysis is the phase in which all necessary data are collected and analyzed. In case that a functional unit has been defined, the collected data are being related to it. It is the most time-consuming phase of the study.

5.2.1 Data Collection

As mentioned already in Subchapter 5.1.2.7, the data collection poses a major challenge due to the complexity of an aircraft and its supply chain, as well as missing data from an SHDB and confidential material information of the assessed aircraft.

Data collection should include both generic data, to get an overview of the sector and the country it is produced in, as well as specific data at company and product level. In this study, the focus lies on site-specific data from the manufacturing site Airbus Finkenwerder.

The primary and site-specific data were gathered by performing **qualitative interviews** with stakeholder groups, namely local community members and workers. The interviews were carried out in a way that the inventory indicators of each subcategory, named in Subchapter 5.1.2.6 were addressed, but in a semi-structured way. Qualitative interviews allow the interviewees to answer in an open way and bring their own perspectives and interpretations into the narrative, whereas structured questions of the interviewer could limit and influence the responses by presuppositions. In this way, interviewees could add new information and concepts, on which the interviewer had not thought before (DeCarlo 2018). The questions on the questionnaire were used as a guide and to stimulate the narration. The questions and the summarized and translated answers can be found in the Appendices A, B, and C.

The first step of collecting data is a **desktop screening** to find general information about the product and its processes. This step has the purpose to find possible hotspots and to determine a focus of the on-site data collection. Since there was no social hotspot database available for this study, only information from the web was gathered. The collected data suggested that there had occurred problems with the local community as described in Chapter Protests and Lawsuits Against Extension of Airbus Finkenwerder Plant4.6. For this reason, the focus of this study lies on this stakeholder group.

The interviews were performed to check, if there had occurred problems between the company and the local community members who live or lived in the vicinity of the manufacturing site of the Airbus A380 in Finkenwerder. There were several **refusals** by community members to perform an interview due to the sensitive topic the questions addressed and bad experiences with press and media. Only 7 interviews in total could be performed. All interviewees have been affected by the presence of the company.

To complement the small number of interviewees, data were also collected from different **newspaper** in which interviews with local community members were performed as well. Additional information could be collected in the book “Das Mühlenberger Milliarden Loch” by Nimtz-Köster 2005.

Data for the stakeholder group *worker* were collected from an interview with an employee of Airbus who was part of the A380 program in Finkenwerder as an engineer. **Global Reporting Initiative** (GRI) performance data provided information about social standards and policies of the organization and the organization itself offers information in its **annual reports** (Airbus 2021d).

Another former employee was interviewed, after he gave remarks about a presentation of the present study, performed by the author of this project in the course of the Hamburg Aerospace Lecture Series in November 2021. The focus of this interview was on *international teamwork* and *technology development*.

The data for the stakeholder groups *passengers*, *state*, and *company* were collected in a web search.

Data for the supply chain and end-of-life stage were collected in a web search as well, but due to data limitations, these life cycle phases will only be briefly discussed.

5.2.2 Data Analysis

The collected data provide insights into the inventory indicators related to the subcategories. The findings are provided in the next subchapters. Furthermore, information about the supply chain and the end-of-life stage is given.

5.2.2.1 Local Community – Delocalization and Migration

To extend the runway for the Airbus A380 and to prevent lawsuits by owners or tenants against noise pollution, the city of Hamburg bought 67 houses in the Rosengarten und Hasselwerder Straße in Neuenfelde. Around 200 inhabitants had to leave their homes (George 2019). Two of the interviewees had to sell their houses, of whom one had to leave Neuenfelde completely due to the lack of new property areas in the village. All interviewees described the **pressure on the property owners** from politicians, media, and the public as enormous to sell their houses. As described in Chapter 4.6, many of the property owners sued against the plant, which caused long delays and uncertainties if the final assembly site of the Airbus A380 could be in Hamburg.

As explained in Chapter 4.6, Hamburg senate tried to **legislate expropriation** by reasoning the plant extension would serve common benefit but due to substantial legal shortcomings of the planning resolution, the supreme administrative court did not allow expropriation for the plant extension. Only one property was expropriated and ruled as legal by the administrative court in 2007 (Tagesspiegel 2007). It was a property a farmer gave away to 25 residents and was only used as farmland and for noise level measurements. No community member was forcefully resettled.

For selling their houses, the interviewees got a **fair price** from Hamburg with which it was possible for them to build a new house. The affected interviewees could negotiate with the city about the prize of their houses. The farmer Quast, who sold the last property to the city, received over two million euros (Vowinkel 2004). As mentioned in Chapter 4.6, Quast enforced 19 demands from politicians for Neuenfelde. One of the points were the reviving of the Hasselwerder Straße, but it took 15 years till some of the houses were re-rented while others were torn down (George 2019). As a reason for the decade long **vacancy**, the senate named the pending lawsuits in relation to the plant extension of Airbus Finkenwerder and the avoidance of further actions against noise emissions by tenants (Knödler 2009).

5.2.2.2 Local Community - Community Engagement

As described by all members of the local community, peaceful assemblies and protests were an integral part of the dispute between Airbus, the city of Hamburg and the local community. Different associations formed the *Schutzbündnis für Hamburgs Elbregion* (protection league for Elbe regions of Hamburg), the largest citizens' initiative in German history (Nimtz-Köster 2005). The protesters **right to assemble** was not restricted at any point.

According to some interviewees, meetings between community members and Airbus representatives took place in different settings. Airbus organized several **information events** open for all community members: Additionally, there were meetings between workers' council members and representatives of the community. None of the interviewed community members could comment on the quality or outcomes of these meetings. One community member claimed that communication between Airbus and the community had further improved over the course of and after the dispute.

The first time an official meeting between the senate and the mayor of Hamburg, Ole von Beust, and the community members took place, was in the end of 2004. Before, there were some informational meetings about the planning resolutions. All interviewees described these meetings as not constructive and claimed **misinformation** about the need for the runway extension was spread by the leading politicians. Generally, the communication between political decision-makers and the local community was evaluated as poorly by the interviewees. Criticized was the thread of expropriation, the juridical decisions made in **summary proceedings**, and the alleged incitement of the press by politicians. For this reason, the trust in politicians has been decreased.

In her bachelor thesis, Berkhahn 2015 analyzed the communication between local community and the city of Hamburg and Airbus and the city of Hamburg. She points out that on the one hand, the Hamburg **senate promised Airbus** any kind of construction measures, but on the other hand did not inform the local community. Only when the planning permission was submitted, it is prescribed by law to present it to the public and only had the purpose to influence the outcome in a positive way for Airbus without considering opinions of community members. Although lawsuits from community members stopped the construction at the plant, the senate still did not reach out to the communities to find a solution. Instead, an expropriation law was issued. Only when there were no other options, the mayor and other representatives of the city **initiated a meeting** with local community members. According to Berkhahn, by prioritizing economic interests, the city tried to decrease **public participation** in decision-making processes.

According to one member, support by the company for the local community was offered by **donating** a heating system in the culture center of the village, which is used to have concerts or meetings. Furthermore, another interviewee mentioned donations by Airbus for the local sports club, kindergarten, and school. In news reports, it was mentioned that Airbus would open a protection fund for the community of Neuenfelde over three million euros under the condition that all lawsuits were closed. Since there was no information, if the fund was established or not and the lawsuits continued over years, it can be assumed that the fund was not opened. The interviewees did not recollect to receive a fund. However, six out of seven interviewees emphasized that their criticism was focused on the behavior and the poor communication of the senate, not Airbus. For them, Airbus is a company with **business interests** and with a request for an extension, for which they asked for permission from the city. The measures the city took to achieve the promised extension, was the focus of the outrage.

5.2.2.3 Local Community - Cultural Heritage

The region **Altes Land** represents a unique cultural landscape, founded in the 12th century by Dutch settlers who started cultivating the marsh land by draining the areas and building dikes. The region inhabits cultural monuments such as traditional farmhouses and churches and a 700-year-old development of fruit farming. In 2021, the region applied for recognition as **World Heritage** by the UNESCO and is supported by federal funds (Hintz 2021). For the runway extension 20 ha fruit trees were felled (George 2019). The farmers received compensation areas by the city.

For the extension of the runway, the **main dike** needed to be mostly removed. The Rosengarten dyke was a medieval dike built by early Saxon settlers around their dwelling mounts in the Elbe marshlands (Waller 2009). Some of the houses, which were destroyed for the plant extension have been there since at least 10 generations, which is shown on an information board standing in the Rosengarten (see Figure 5.1). In Figure 5.2 the old ring dike is also visible, protecting the Rosengarten from flooding of the Old Süderelbe.

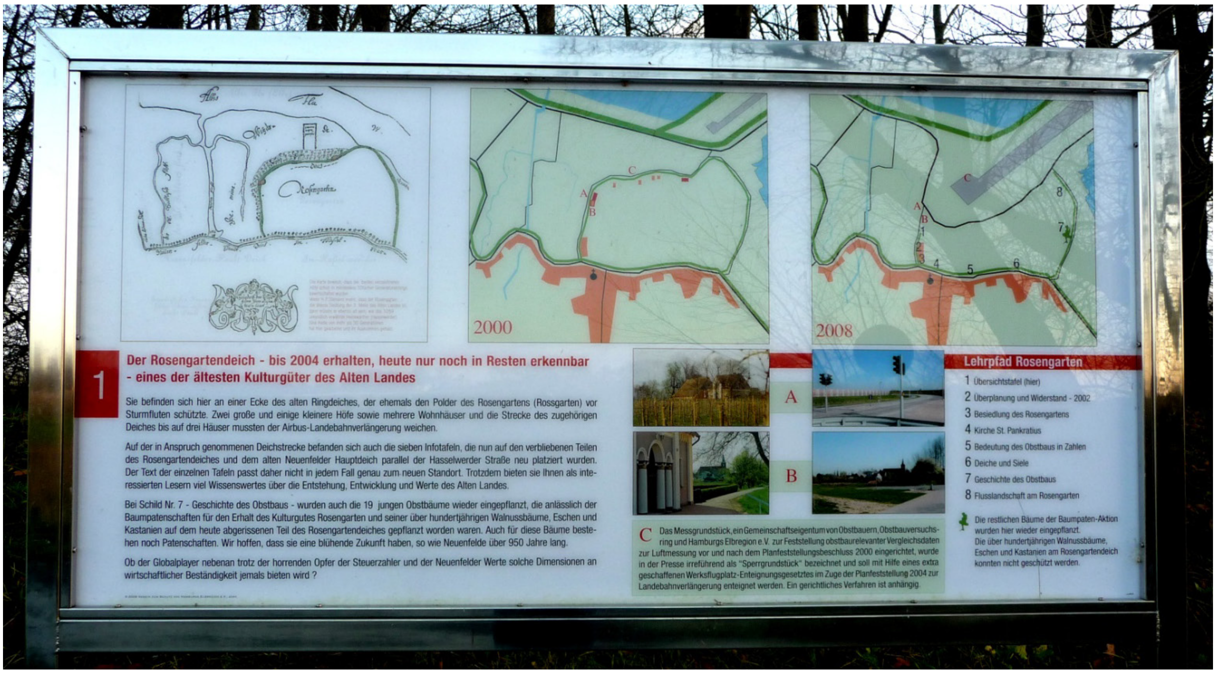

Figure 5.1 Information board in Rosengarten, Neuenfelde (own picture)

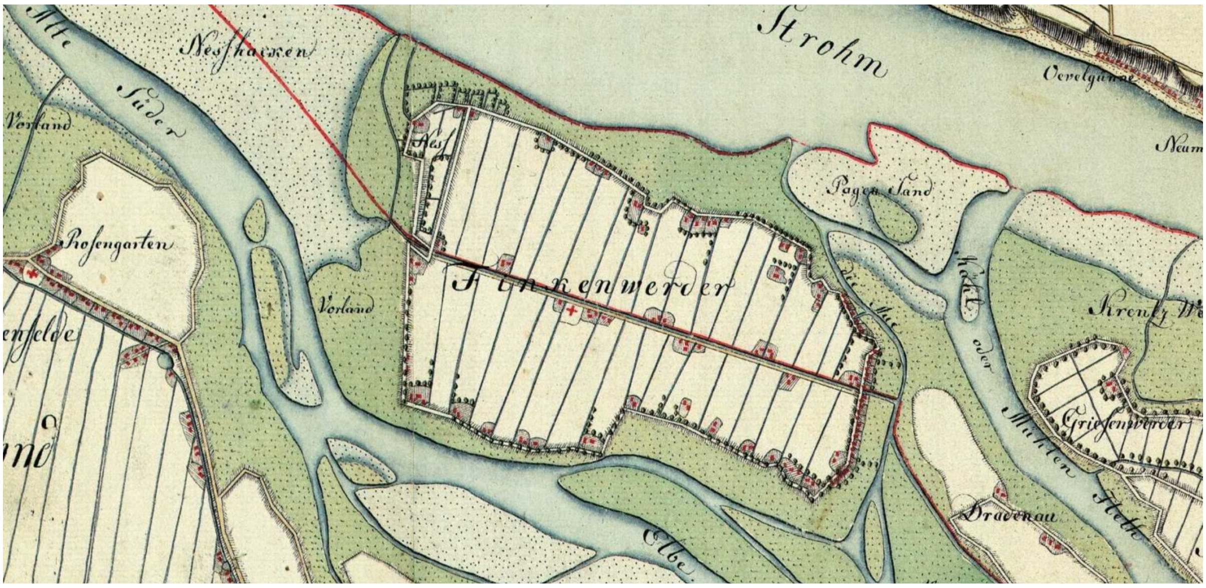

Figure 5.2 Old map of Finkenwerder and Rosengarten, 1762 (public domain)

Furthermore, the baroque Pankratius church, which was built between 1682 and 1687, is lying directly in the approach corridor (Busch, 2019). The Airbus A380 produces **wake vortices** which could have caused detached roof tiles of the historical church (Härig 2013). According to an interviewee, Airbus immediately fixated all roof tiles.

Another interviewee mentioned that the city planned the removal of the **church** to have a cleared approach corridor. But the church is under monumental protection and inhabits the largest still preserved organ from the famous **organ** builder Arp Schnitger (Figure 5.3). A removal of the church could not be enforced.

Figure 5.3 Arp Schnitger organ in St. Pankratius church in Neuenfelde (Gemeinholzer 2017)

5.2.2.4 Local Community - Local Employment

The metropolitan area of Hamburg is an important site for **the aerospace industry**. Apart from Airbus, Hamburg Airport and Lufthansa Technik around 300 **suppliers** are based in Hamburg (Kästner 2019). There is no information in the collected data, how the local supply network specifically for the Airbus A380 has been organized.

The interviewed worker claimed that the number of local suppliers increased by companies choosing Hamburg as location site during the production of the A380. As an example, he mentioned suppliers with a manufacturing site in Toulouse, who expanded their company to new locations such as Hamburg because of the different manufacturing sites for the A380. The exact quantity of additional local suppliers for the A380 he could not tell.

For the local community, Airbus is an important employer, even many protesters have family members working in Finkenwerder. The exact number of workers coming from the local communities is not known. Apart from local employment, it is also common that **guest workers** are coming from different sites of Germany or Europe. The interviewees reported that local house owners often rent rooms to guest workers who work either at Airbus or the Hamburg port.

The main argument for the Hamburg senate to apply for the final assembly site of the A380 was **job creation**. In the planning permission resolution form May 2000, which was shown to the author of this work by an interviewee, it is written that 4,700 new jobs would be created under consideration of permanent employment in Airbus, the suppliers and additional purchasing power of wages and salary. This prognosis was based on an estimate 46 A380 production rate per year.

Three years after the first Airbus A380 had been delivered to the first customer airline, 4,000 of the 12,000 employees in Finkenwerder were linked to the Airbus A380. Another 4,000 jobs were created in the supplier network (Maaß 2010). How many jobs were created by the Airbus A380 is difficult to analyze, since the aerospace companies do not strictly separate their workforces by aircraft model.

After Airbus had announced in February 2019 that the A380 production would be terminated in 2021, an audit in the Hamburg senate took place. In this audit, questions about the consequences for workers and the general evaluation of the A380 program in terms of job creation were asked. The senate confirmed a positive impact for Hamburg and Germany despite the termination of the program. By extending the Finkenwerder plant for the Airbus A380, necessary steps were taken to ensure the future of the Hamburg Aerospace industry by **extending competences** and researching on future-oriented technology. Hamburg aerospace industry is now leading in **cabin systems** for large airplanes. Since 2000 the number of employees has increased from 7,800 to 12,700 in the Finkenwerder plant of Airbus. The overall number of workers in the aerospace industry has increased from around 27,000 to 42,000 in the metropolitan area of Hamburg in the same years. According to Airbus Operations, around 800 workers were directly linked to the A380 program and assumably the same amount in the supplier network within Germany in 2019 (HH-Bürgerschaft 2019).

With the extension of the Airbus plant in Finkenwerder, it was ensured that Hamburg now has a similar infrastructure as Toulouse. For decisions where production sites for future work packages should be located, this is an advantage and could further increase local employment.

5.2.2.5 Local Community - Safe and Healthy Living Conditions

The permanently growing demand for mobility and transportation have consequently led to environmental impacts such as **air pollution** or **noise exposure** for residents in the vicinity of airports. But for the local community near one of the production sites for the A380 further impacts on health and safety did occur, which will be elaborated in this subchapter.

Studies have shown that aircraft noise causes the most annoyance among exposed communities in comparison to road or railway traffic (Griefahn 2006). Communities residing in the approach corridors of airports are especially exposed to aircraft noise. There are already several studies showing negative impacts on public health by long exposure to noise sources (Bradley 1979 and Lefèvre 2020)

The World Health Organization (WHO) estimates that only in Western Europe at least one million **lost healthy life years** are caused every year by health issues, such as sleep disturbance or cardio-vascular diseases, aroused by permanent noise exposure (WHO 2011).

There is evidence that both road and aircraft noise can cause high blood-pressure and heart rate, but also mental health issues or cognitive impairment of children can occur as well as an increased level of annoyance (WHO 2011).

Aircraft noise has different causes. A major cause of noise during take-off are the aircraft **engines**. It can be divided into fan noise and jet noise; the latter causes most of the aircraft noise. The high-speed jet leaving the nozzles at the rear of the engine has an inherent shear layer instability, which later breaks down into turbulences. Modern **bypass engines** suppress the jet noise dramatically (Papamoschou 2004).

Another source of noise is the **aircraft frame**, which causes friction and turbulences. Due to the use of landing gears and flaps during landing, resistance increases, and noise levels rise (Auckland Airport 2021).

Thus, an important issue in the aerospace industry is the reduction of aircraft noise for above mentioned reasons. In 1972, the Standards and Recommended Practices for Aircraft Noise were introduced by the International Civil Aviation Organization (**ICAO**) with the purpose to ensure that the latest available technology for **noise reduction** is applied in aircraft design. In the *Standards,* there are three different **measurement points** defined to classify the noise level the aircraft emits - which are the approach reference point, the sideline reference, and the flyover reference point (Figure 5.4).

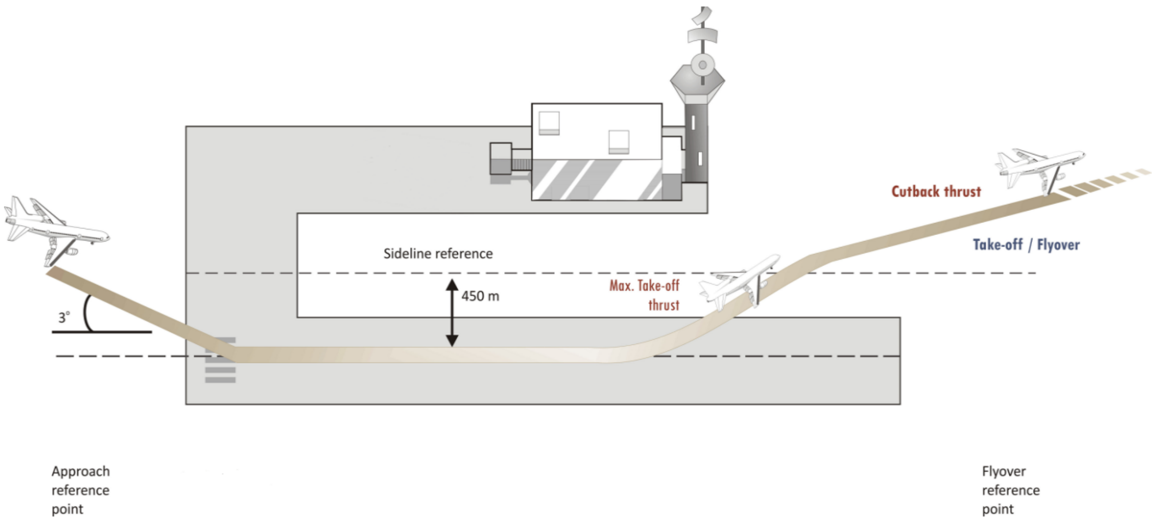

Figure 5.4 Aircraft noise certification reference measurement points (ICAO 2021)

The measured noise levels of all measurement points are accumulated, and the accumulated noise levels thus generate the overall noise level of the aircraft (ICAO 2021).

The aircraft are classified in **chapters**, of which chapter 1 is the loudest and includes all aircraft built before 1972 and thus didn't follow the *Standards*. By increasing the bypass ratio, jet engines have become significantly more quiet and new chapters were introduced with more stringent noise standards. In total, there are five different chapters, which can be seen in Figure 5.5. The most stringent standard is chapter 14, established in 2013. It requires a noise reduction by -17 EPNdB (Effective Perceived Noise level in decibels) in comparison to the baseline chapter 3. In Figure 5.5, it can be seen that the noise limit depends on the Maximum Take-Off Mass, since larger airplanes with more transportation capacity generally produce more noise (ICAO 2021).

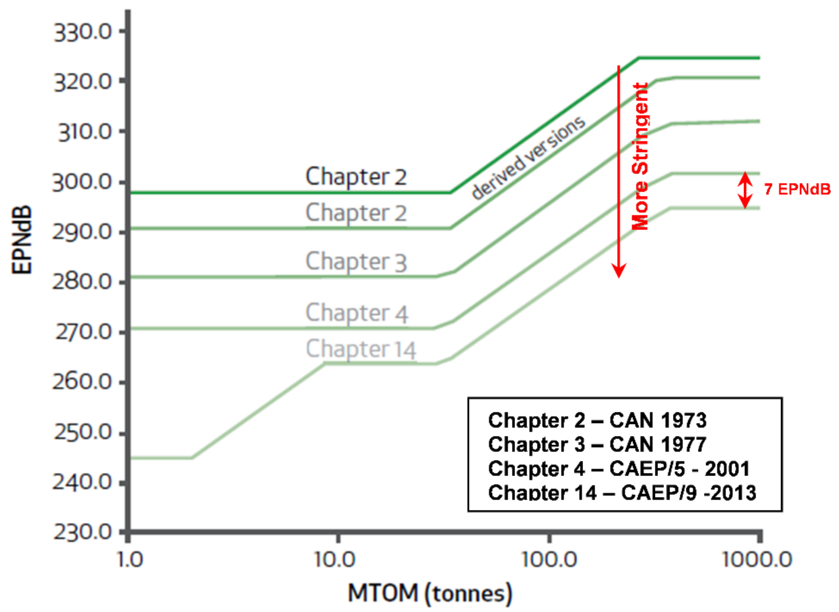

Figure 5.5 The progression of the ICAO Noise Standards for airplanes (ICAO 2021)

The Airbus A380 is classified as chapter 14 and has an accumulated noise level of 287.6 EPNdB, which means it is compliant with the **most stringent standards** at this time. It is considered one of the quietest wide-body aircraft currently flying, only the smaller Boeing 787 is less noisy.

To be able to operate at the London Heathrow Airport, which has stricter noise regulations (a so-called **Quota Count (QC) system** than ICAO's Chapter 4 standard regarding take-off and landing during the night (11 pm till 6 am), noise reduction during the design of the A380 was prioritized. During night, no aircraft is allowed to operate with a higher rating than QC/2. The Airbus A380 has achieved a QC/0.5 rating for arrival and a QC/2 rating for departure, so that it can operate without limitations. While the older Boeing 747-400 does not comply with these regulations, the newer Boeing 747-800 has also met the QC requirements (CAA 2014).

Figure 5.6 depicts the noise footprint of the Airbus A380 in comparison to Boeing 747-400 during arrival and departure.

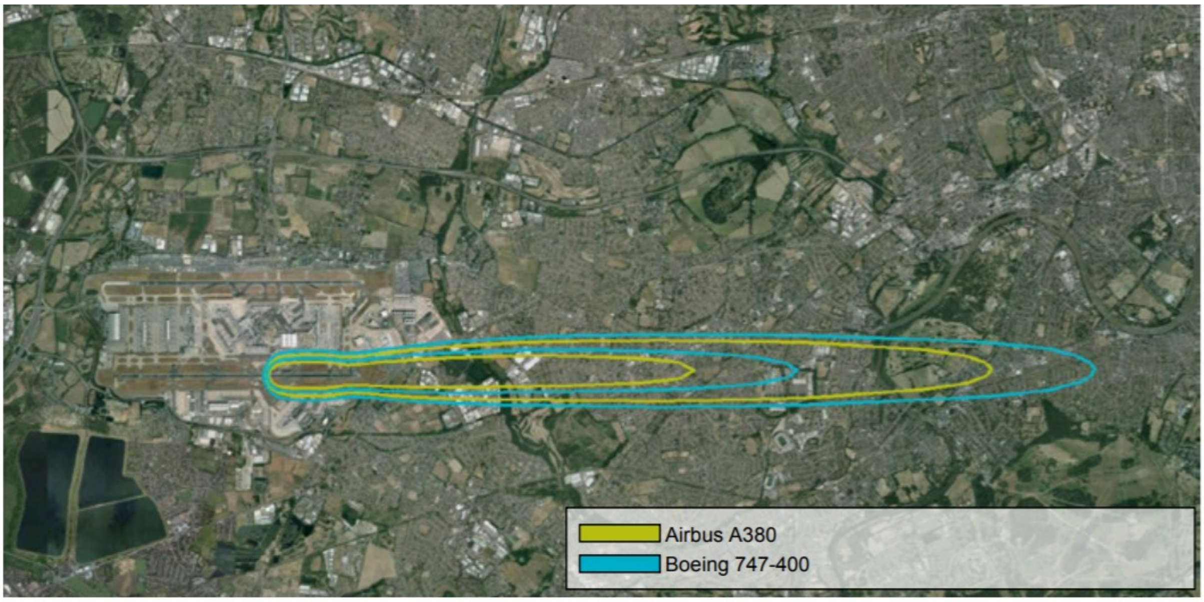

Figure 5.6 Airbus A380 noise contour during arrival (85 dB(A)) and departure (90 dB(A)) in comparison to Boeing noise contour (CAA 2014)

Noise reduction was achieved among others through **engine optimization**. One example are the noise absorbers – the so-called liners – which are usually split by longitudinal splices. In the A380 engines however, the liners were manufactured in one piece for the first time, which reduced radiation of motor-alone tones and improved acoustical performance (Leylekian 2014). Furthermore, nacelle improvements were implemented by installing new composite inlet to improve the airflow control and thus reduce engine noise (NetComposites 2005). Both engine optimization methods were **patented** by Airbus. To optimize the take-off regarding noise reduction, a software has implemented a Departure Analysis Software, which analyzes ambient conditions, airport constraints and aircraft parameters (Airbus 2015). Furthermore, during the design phase of the A380 computational tools to model aircraft aerodynamics could show areas of high airflow, which could cause noise increase – also inside the cabin. In this way the designs could be improved regarding noise performance (Moskvitch 2014).

According to Airbus 2021e, the **larger wing area** allows the A380 to descent with significantly less speed, which consequently causes a decrease of aircraft noise in comparison to older wide-body aircraft.

The **operating hours** for the airfield Finkenwerder are restricted to Monday to Saturday from 6 am to 10 pm. Sundays and on public holidays no regular operations are allowed and not more than 35 flight movements per day are authorized. From 2008 till 2013 in the last quarter of the year the numbers of take-offs and landings in direction 5 (via Neuenfelde) were the numbers as given in Table 5.1.

Table 5.3 Numbers of take-offs and landings in direction 5 in the last quarter of the years 2008-2009 (HH-Bürgerschaft 2014)

	2008	2009	2010	2011	2012	2013
Take-offs	450	434	359	538	588	583
Landings	112	166	202	132	112	124
Total	562	600	561	670	700	707

For every single aircraft the emergency systems and all other components need to be tested in the so called **First Flights**. One of the main emergency systems to be tested is the Ram Air Turbine (RAT), which is a small wind turbine connected to a hydraulic pump or electrical generator used as a power source in case of the loss of both primary and Auxiliary Power Units (APU). The power is generated by ram pressure in consequence of the speed of the aircraft from the airstream and can drive important systems such as flight controls. The largest RAT propeller is built in the Airbus A380 with 1.63 meters in diameter (Labidi 2019).

When folded out, the RAT creates higher noise emissions than normal flights. From 2011 till 2016 the number of First Flights of the A380 in comparison to single-aisle aircraft were the numbers as given in Table 5.4.

Table 5.4 Number of First Flights in Finkenwerder of A380 and Single Aisle aircraft from 2011-2016 (HH-Bürgerschaft 2017)

	2011	2012	2013	2014	2015	2016
A380	26	30	25	30	27	28
Single-Aisle	385	418	447	443	434	480

Also, in the previous years from 2008 till 2011, the mean number of First Flights of the Airbus A380 were 30. There is a **time restriction** for the landing approaches of the First Flights for the A380 from 3pm till sunset but latest till 10 pm (HH-Bürgerschaft 2013a).

The law for **aircraft noise protection** determines that in closed rooms with sufficient ventilation a continuous noise level of 40 dB(A) cannot be exceeded and only on maximum five working days per year a maximum noise level between 60 and 75 dB(A) is allowed (HH-Bürgerschaft 2014). In living areas, the continuous noise level $L_{Aeq,day}$ shall not exceed 60 dB(A) (Lärmkontor 2020).

During a development plan in Neuenfelde, noise studies were being executed in 2010, 2011, 2013 and 2017. The result of this study was that the aircraft movements from the Finkenwerder plant do not cause higher continuous noise levels than 55 dB(A) during the day and no flights are allowed during nighttime (Lärmkontor 2020).

Also, Airbus maintains two **measuring points** in Neuenfelde, one in Rosengarten and another one in the Gymnasium Hochrad. The measured data for the years 2009 till 2012 show no exceeding of the legal noise level limit (see Table 5.5). There is no data available which aircraft causes the highest noise levels.

Table 5.5 Noise level measuring in Neuenfelde from 2009 till 2012 (HH-Bürgerschaft 2013b)

	2009	2010	2011	2012
Measuring point “Rosengarten”	53.1dB(A)	53.2dB(A)	52.5dB(A)	52.6dB(A)
Measuring point “Gymnasium Hochrad”	50.9dB(A)	50.3dB(A)	50.6dB(A)	50.9dB(A)

To ensure that the continuous noise level in closed rooms do not exceed the above-mentioned limitations, sound **insulation measures** were performed by installing ventilation systems and insulating glass windows with a sound absorption value of at least 35 dB(A) (HH-Bürgerschaft 2014).

The interviewees commented that the noise levels due to the A380 flights did not cause higher noise levels. As seen in Table 5.4, most of the First Flights have been carried out by single-aisle aircraft and less than 10% by an A380.

Not only noise pollution but also **jet engine emissions** can cause health effects for humans living in the vicinity of an aircraft. Jet engines emit particulate matter (PM), volatile organic compounds such as CO_2, CO or **NOx**, polycyclic aromatic hydrocarbon, and black carbon (Bendtsen 2021). While idling, the jet engines combustor pressure and temperature is low, and the Air-Fuel-Ratio (AFR) is high. This leads to uncomplete oxidation processes which create unburnt hydrocarbons and CO. During take-off on the other hand, combustor temperature and pressure are high and the AFR low. Fuel-rich mixture and low oxygen create smoke by uncomplete fuel burning. This smoke is burnt off in a secondary combustion and creates NOx (Bräunling 2015).

There are few studies analyzing the impact of air pollution around airports on the local community. In one report on Amsterdam Airport Schiphol, it could be determined that ultrafine particles (UFP) from airports as well as from turbine engine can cause **cell damage** (He 2020).

Another study analyzed the relation of air pollution by ultrafine particles from jet engine emissions in the vicinity of Los Angeles airport and **pre-term births**. The researchers concluded that there probably exists a causality between long-term exposure to UFPs from aircraft engines and negative birth outcomes (Wing 2020).

Generally, the air pollution at an airport is high, mostly due to engine emissions, but can vary depending on the type of engine and its condition, as well as the fuel type and operation mode. Not many studies have been conducted yet, but the above-mentioned strongly suggest that aircraft jet engine emissions, like diesel exhaust, can have **severe health impacts** for humans living in the vicinity of airports (Bendtsen 2021).

These studies were made in the vicinity of large airports such as Amsterdam Airport Schiphol or Los Angeles International Airport. In 2019, the number of aircraft movements in Schiphol was 497,000 (Schiphol 2021) and in Los Angeles 691,257 (LAWA 2021). By comparing these aircraft movements to the maximum 35 allowed flights per workday (around 8,800) from the Airbus Finkenwerder airport, it becomes clear that aircraft movements are less than 2 % of the number of flights at large airports. Therefore, the air pollution studies may not be applicable for Airbus Finkenwerder airport and the residents in the vicinity of it.

Jet engines have been continuously improved over the last decades towards more **fuel efficiency**. Fuel efficiency depends on the pressure created by the compressor and the temperature of the combustion inside the engine. The higher temperature and pressure, the more fuel efficient the jet engine is, but also the more nitrogen oxides it emits. ICAO regulates NOx-emissions of engines by increasingly stringent limits and are referred to by corresponding **CAEP meeting numbers** (EASA 2021). The limits are defined as mass (Dp) of NOx-emissions divided by the thrust of the engine (Foo) and are measured during the Landing and Take-Off (LTO) cycle (EASA 2021).

Both jet engines used for the A380, the Rolls Royce Trent 900 series as well as the Engine Alliance GP7200, have been certified under the strictest CAEP meeting number 6 from 2008 as it can be seen in Figure 5.7 (black and red circles). While the Rolls Royce Trent series has NOx-emissions between 52.6 and 55.8 g/kN, the emission of the Engine Alliance GP7200 is higher with 61.8 g/kN.

- Rolls Royce Trent 970B-84:
    - Engine overall pressure-ratio: 39.4
    - Dp/Foo: 55.8 [g/kN]
- Rolls Royce Trent 972E-84
    - Engine overall pressure-ratio: 38.7
    - Dp/Foo: 54.2 [g/kN]
- Rolls Royce Trent 97
    - Engine overall pressure-ratio: 38
    - Dp/Foo: 52.6 [g/kN]
- Engine Alliance GP7270
    - Engine overall pressure-ratio: 36.6
    - Dp/Foo: 61.8 [g/kN]

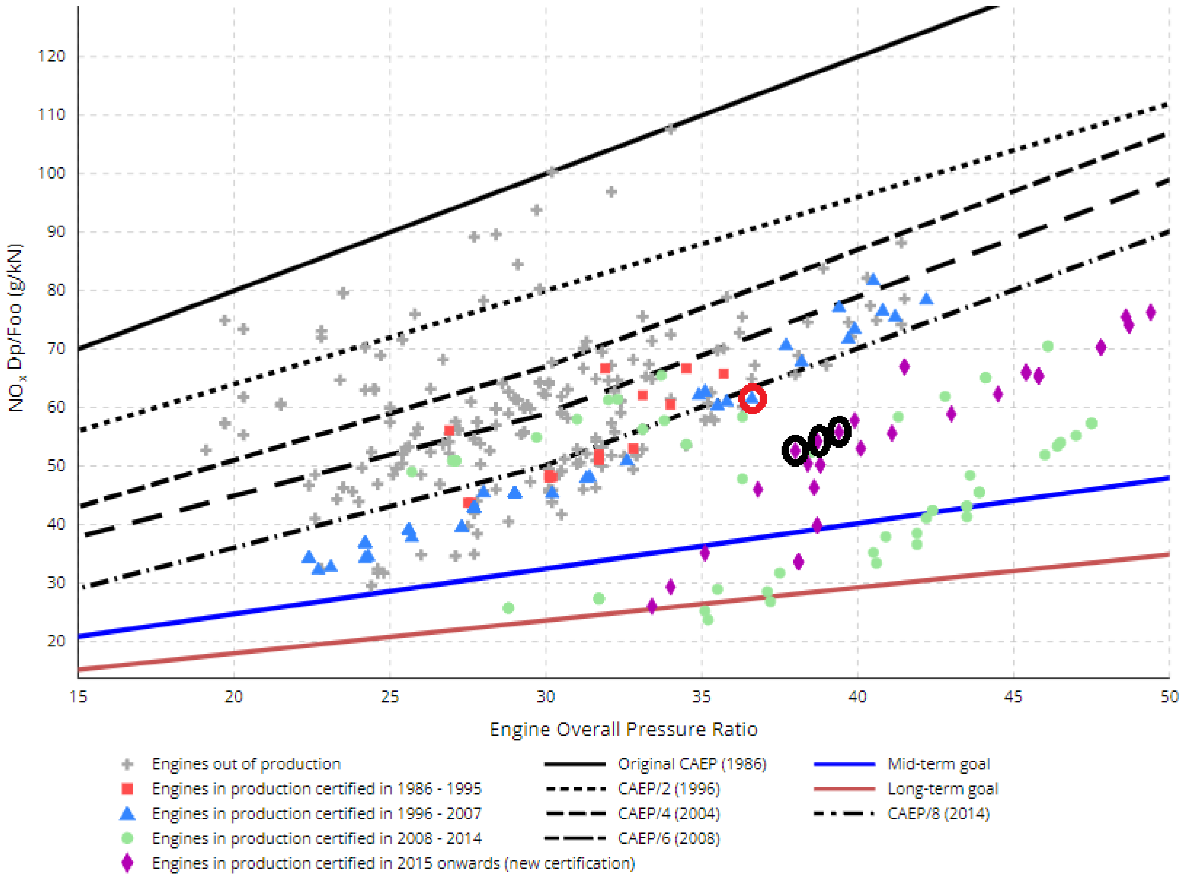

Figure 5.7 Progression of CAEP meeting numbers and NOx-emissions of different jet engines (adapted from EASA 2021)

There are **measure points** for air quality in Hamburg Finkenwerder West and Airbus Finkenwerder, where nitrogen dioxide and particulate matter (PM) with a smaller diameter than 10 µm concentration are measured. There are only 17 measure stations in Germany for UFP (Birmili 2018) and none in Hamburg. This is problematic since soot particles from gas turbine emissions are mostly ultrafine particles. It is presumed that UFP can enter more easily into respiratory tracts and are more toxic (Jonsdottir 2019). No data could be collected for UFP concentration in the vicinity of Finkenwerder.

The results of the data collection for 2019 in Finkenwerder West and Airbus Finkenwerder can be seen in Table 5.6 and Table 5.7 with comparison of measure stations at the Hamburg Airport, in residential areas and near highly used streets.

Table 5.6 and Table 5.7 show that regarding annual average of nitrogen oxide, nitrogen dioxide and PM10 concentration at the Airbus plant in Finkenwerder are slightly lower than at the Hamburg Airport and **significantly lower** than the highly frequented street Stresemannstraße. Measured data in residential areas vary from each other but are comparable to the data measured in Finkenwerder. For PM10, exceeding of threshold value of 50 occurred on six days in Finkenwerder West. These values were higher than at the airport or in residential areas. No data were available for Stresemannstraße. Maximum nitrogen dioxide values were similar high in Finkenwerder as in residential areas but significantly lower than at Hamburg Airport and Stresemannstraße. All values are in the **legally allowed limitations**.

Table 5.6 Mean values of nitrogen oxides and PM10 emissions at different measuring points in Hamburg in 2019 (HLM 2020)

	NO	**NO_2**	**PM10**
Threshold value (annual average)	-	40	40
Finkenwerder Airbus	5	16	-
Finkenwerder West	5	17	17
Hamburg Airport	8	21	20
Bramfeld	5	15	-
Wilhelmsburg	6	24	18
Stresemannstraße 1.5m	21	40	-

Table 5.7 Number of exceeding of nitrogen oxides and PM10 emission limits at different measuring points in Hamburg in 2019 (HLM 2020)

	NO_2 (1 h)	**PM10 (24 h)35**
Annually allowed exceedance	18	
Threshold value	200	50
	Exceeding / max.	Exceeding / max.
Finkenwerder Airbus	0 / 102	-
Finkenwerder West	0 / 91	6 /92
Hamburg Airport	0 / 154	6 / 70
Bramfeld	0 / 85	-
Wilhelmsburg	0 / 101	6 / 60
Stresemannstraße 1.5m	0 / 150	-

5 out of 7 interviewees commented on **smeary residues** from exhaust emissions around their houses. One interviewee remarked that by extending the Airbus plant a U-shaped protection wall was built, which gives a certain protection for the local community against noise pollution and emissions during ground tests. Apart from that, no further protection was done by the city due to low values of emissions and the small amount of aircraft movement (HH-Bürgerschaft 2014).

According to three interviewees, safety issues occurred due to **wake turbulences**. There were incidents occurring in Neuenfelde induced by the wake turbulences. Tiles from roofs fell or umbrellas flew away endangering people. It was reported that Airbus took immediate measures when such incidents occurred. All tiles of the church, which lies directly in the approach corridor, were attached securely (see Figure 5.8).

Figure 5.8 Overfly of A380 over St. Pankratius church (picture given by Quast)

Regarding healthy living conditions, all interviewees of the local community pointed out the **psychological pressure** by the local press and the senate on the opponents of the plant extension and the owners of properties laying in the way of the future runway. Furthermore, having to leave their homes and neighborhood, tight social fabrics broke up. The interviewees claimed, that as a result, **mental health** issues such as insomnia, depression, and anxiety occurred to some protesters and partly to themselves. Especially, the aggressive behavior of the press, by invading private space, reaching out to children of the protesters, and depicting the local community members in a negative light in the news, was mentioned by all community members. The newspaper *Bild*, for example, called a farmer who first did not want to sell his property a “Prozesshansel” (Process Hansel) who is boycotting the industry location Germany (Havekost 2004). Full names and yearly income of the protesters were published in newspapers. According to some interviewees, this led in some cases to trauma. Some community members moved out of Neuenfelde. Airbus workers initiated a protest against the stop of the plant extension in October 2004, and in some cases the property owners, who refused to sell their land, were blamed to destroy employment (see Figure 5.9). It shows the enormous pressure on the plant extension opponents also from parts of society.

Figure 5.9 Protests of Airbus workers against stop of plant extension (Langer 2004)

5.2.2.6 Local Community - Material Assets

The noise and air pollution in the vicinity of airports not only have negative impacts on human health, as discussed in the previous chapter, but also on the **housing prices**, even more for real estates who lie in the approach corridors for the aircraft. Especially noise pollution has an adverse impact on the willingness of the population to pay for property. Furthermore, noise protection laws enforce limitations in settlements and thus can also restrict development of infrastructure (Batóg 2019).

Several studies show the loss in value of real estate due to high levels of noise. An increase in noise level by one dB(A) causes a decrease in housing prices by 0.08-2.22 % (Batemann 2001). A change of willingness to pay can be detected from a continuous noise level above 50-55 dB(A) (Navrud 2002).

One effect of decreased housing prices and therefore lower income from renting is **internal migration**. Lower income households move to more affordable areas, whereas higher income household move to more quiet areas (Weiss 2020).

Two of the interviewees supported these studies by their experiences that the plant extension reduced their real estate values significantly (One interviewee claimed to have a loss in value by 30 %). Not only the elongated runway and increased noise pollution was mentioned for the value of loss as cause, but also the decreased attractiveness as residential location due to the vacant houses in the Hasselwerder Straße.

By looking into the rent index of Hamburg districts, Neuenfelde as well as Finkenwerder are under the five districts with the lowest rent index in Hamburg with 10.56 €/m^2 and 10.53 €/m^2 in 2021 (Wohnungsboerse 2021). How much the noise and air pollution cause the low rent index is not known. The relatively bad public transportation connectivity and the location on the other side of the Elbe could also influence the low rental index.

5.2.2.7 Workers - Freedom of Association and Collective Bargaining

The largest **labor union** in Germany for workers in the metal industry is IG Metall. According to the interviewed worker, the IG Metall union members have a strong position in the company and together with the work council **influence** the decision-making process of the company. An example is the agreement in the beginning of this year to not dismiss around 2,300 workers in German Airbus locations due to the ongoing pandemic, but to support voluntary retirements, short time work and reduction of working hours (Müssgens 2021). The worker confirmed that all employees are allowed to a labor union member and that the company supports labor unions by providing meeting rooms.

By committing to comply with **the International Labour Organization** (ILO) conventions and the Organisation for Economic Co-operation and Development (OECD) “Guidelines for Multinational Enterprises”, Airbus recognizes the rights of employees to form, join, and be active in trade unions and employee representative bodies in accordance with national laws, collective bargaining agreements, and local customs (Airbus 2019).

5.2.2.8 Workers - Fair Salaries

The **collective agreement**, negotiated by labor unions and employer, determine among others the salaries of the different worker groups. The employer is not allowed to disburse less. For workers in metal and electrical sector the remunerations are listed in tables (IGM 2021). In these tables payment for extra hours can be found as well.

In an online job-platform 81 % of 1,273 current or former Airbus employees evaluated the wages at Airbus as good or very good. Based on 771 responses regarding salaries the mean salary lies between 13,200 € as an apprentice and 129,700 € as a leading project manager. **Salary satisfaction** lies 27 % over the mean value in this sector (kununu 2021).

This is also reflected in the interviewees explanations who described the salary as very good. Furthermore, he mentioned gratifications such as Christmas bonuses.

5.2.2.9 Workers - Hours of Work

In the **tables** mentioned above the working hours per week are listed, depending on the different federal states. For Hamburg (Nordverbund) 37.5 working hours per week were negotiated (IGM 2021). In online evaluations of Airbus as employer several current and former workers mentioned that working hours per week at Airbus are 35 h (kununu 2021).

In the tables the **number of holidays** is determined as minimum 30 days per year which is 1.6 days more than the mean value of holidays for employees in Hamburg (DHZ 2020). Furthermore, the interviewed worker pointed out that, in case of extra hours due to deadline pressure for projects, the employee can negotiate whether these hours can be equalized later by time-off or paid out. Employees in office position can also **freely arrange** their working time. This might not be true for workers such as aircraft technicians where work in shifts is the norm.

The interviewee confirmed overall flexibility provided by the company since not only flexible work shifts but also home-office is offered.

5.2.2.10 Workers - Equal Opportunities / Discrimination

There are formal policies by Airbus to implement **gender equality** and **diversity**. In its annually "Universal Registration Document 2020" Airbus 2021f drafts its gender equality and diversity policies.

Airbus commits to zero tolerance to discrimination and harassments and in its "Code of Conduct" and "Supplier Code of Conduct" formulates its expectation towards its suppliers and workers to implement this policy. Incidents of discrimination can be reported via a confidential Open Line and are, according to Airbus, investigated.

The company engages in numerous programs and **initiatives**, such as "Women in Aviation and Aerospace Charter" or "Management Basics Leadership Foundation Programme", to support women and underprivileged people. Furthermore, Airbus commits to the UN Women's Empowerment Principles.

In **Figure 5.10** Ratio of men to women employed by Airbus in different positions in 2020 (in %) Figure 5.10 the number of women in the workforce in different positions are shown. The **quota of women** is still significantly lower in all areas than of men. Airbus 2021f announced to increase the percentage of woman of all new recruits in the following year to 33%. While in 2013 there were neither women represented in the Board of Directors, nor in the Company's Executive Committee, since 2017 there have been three or two women.

Figure 5.10 Ratio of men to women employed by Airbus in different positions in 2020 (in %) (Airbus 2021)

5.2.2.11 Workers - Health and Safety

According to Airbus 2021f, the main causes for **injuries** of workers in 2020 were tripping, falling, slipping or the use of tools and equipment.

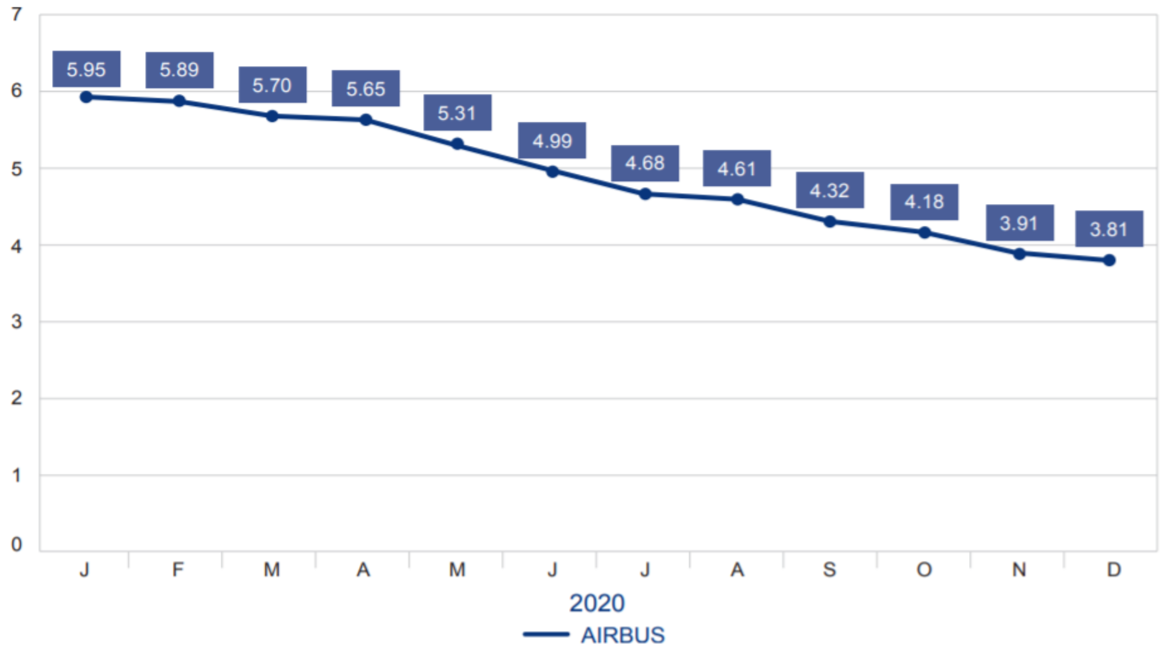

Figure 5.11 LTIFR of Airbus workers in 2020 (Airbus 2021)

In Figure 5.11 the Lost-Time-Injury-Frequency-Rate (**LTIFR**) is shown for Airbus workers in 2020. LTIFR refers to the number of lost time caused by an injury during work per one million hour work.

Airbus takes measurements to improve working condition regarding safety and health, such as investments in the identification and the prevention, elimination, or control of physical and psychological risks to workers. Furthermore, Airbus is following the International Standard, **ISO 45001**, for its occupational safety management system.

5.2.2.12 Workers - Social Benefits

The list of benefits and **social security** offered by Airbus to full-time employees include the following, which were confirmed by the interviewee (Airbus 2021g):

- Company Pension Scheme
- Employee Discounts (e.g., travels, children entertainment)
- Employee Stock Purchase Plan
- Health Insurance

- International Mobility
- Job Training Upskilling
- Parental Leave
- Paid and Unpaid Holidays

5.2.2.13 Passengers - Health and Safety

Safety is one of the key issues for manufacturers of aircraft. To get a certification by the aviation authorities, such as the European Union Aviation Safety Agency (EASA) or the Federal Aviation Administration (FAA), it must be demonstrated that all safety relevant systems comply with the requirements, specified in the **Certification Specifications** (CS). According to **CS 25.1309b**, a failure of an aircraft system, which would lead to catastrophic events, such as fatalities or the loss of the whole aircraft, must be extremely improbable (10^{-9}) and cannot be caused by a single failure. Furthermore, hazardous failure conditions must be extremely remote and major failure condition remote. For this reason, it can be assumed, that all certified aircraft are safe, including the Airbus A380.

As of November 2021, the Airbus A380 has not been involved in any incidents resulting in fatalities, grave injuries, or hull loss. However, two **uncontained engine failure** incidents occurred. An uncontained engine failure can pose a safety risk too when parts of the failed engine exit the engine case at high speed and impact on the pressurized fuselage or nearby engines (Skybrary 2020). The first accident occurred on the Qantas flight 32 on the way from Changi Airport in Singapore to Sydney on November 4th, 2010. An engine fire, caused by a nonconforming **defect oil supply pipe**, led to a separation of the intermediate pressure turbine disc from the drive shaft, which subsequently caused the uncontained engine rotor failure of engine No. 2. The debris damaged the airfoil and thus the hydraulic system. Consequence of this incident was groundings of several other A380s with engines by Rolls Royce to identify possible nonconforming oil pipes. Furthermore, Rolls Royce released an engine control software update, which included a turbine overspeed protection system. In the unlikely case a disc would be in danger to overspeed again, the protection system would shut down the engine (ATSB 2013).

The second uncontained engine failure occurred on the Air France Flight 66 from Paris to Los Angeles on September 30 in 2017. The aircraft made an emergency landing at Goose Bay Airport in Canada, after the Engine Alliance GP7270 engine No. 4 fan hub had separated in several parts. It was caused by a **cold dwell fatigue crack** in the part’s surface. Two pieces were ejected, leaving the engine case at high speed, and hitting the wing and airframe. However, the impact caused no major damage. At the time of the certification, it was not known that the used alloy could be affected by cold dwell fatigue (Beall 2020).

Despite these incidents, the Airbus A380 is considered a **safe aircraft**. Furthermore, a ranking of the safest airlines 2021 revealed, that seven of the 15 airlines, who have an A380 in service, are under the top 20 safest airlines (Pallini 2021).

Another critical point for the health of passengers is the **cabin air**. According to a study conducted by EASA 2017, cabin air quality is similar or even better to any other closed environment such as schools or offices. However, there have been numerous incidents, in which fume development in the cabin and resulting negative health impacts was reported by passengers and the cabin crew. Documents in Scholz 2021a explain the problematics in detail.

Since the external conditions in cruise altitude are not survivable for human beings, it is indispensable to provide air supply constantly during the flight for crew and passengers. In most of modern-day airliners the air supply is achieved by removing so-called **bleed-air** from the engine compressors located upstream of the cabin. The high temperature and high-pressure air withdrawn from the high-pressure compressor is directed to the air conditioning packs, in which the air is cooled down and dehumidified and pressure is reduced. In the mixing chamber the bleed air is mixed with recirculated and filtered air from the cabin and then directed into the cabin to provide fresh air (Voth 2018).

In some cases, it can happen that passengers and crew notice a smell or even see fume. These cases are called "**smell events**" or "**fume events**". This can be caused by the lubricated bearings in the engine shaft, which is used for cooling, corrosion protection, and wear reduction. To prevent the oil from leaking, sealing systems such as labyrinth seals or carbon seals are installed. Nonetheless, small amount of oil constantly leaks out by design (Voth 2018). However, larger amounts could be caused by abrasion of the bearings by physical and thermal stress during engine power setting changes, or by mechanical failure. Not only the oil in the main engines can cause air contamination but also the APU can be the starting point. De-icing, and hydraulic fluids can be ingested by the APU through leaking or spilling from a worn part or a burst line. In the compressor of the APU or the main engines, the leaked oil heats up and transforms into **toxic** fume (Anderson 2021). The oil contains additives such as tricresylphosphate (TCP) – which can cause neuropathies among other things when ingested or inhaled – and various other Volatile Organic Compounds (VOC), which are formed from the pyrolysis during the compression (Scholz 2019). When these substances are delivered to the cabin zone via ventilation system, it can cause **acute symptoms** such as irritation of the eyes and respiratory system, nausea, confusion or even unconsciousness and which subsequently can compromise flight safety. Flight crew members even are reporting chronic health problems consistent with the symptoms from an exposure to TCP or other toxic substances (Shehadi 2015).

Although being observed already since the 1950s, there is still a debate in the aviation industry, how frequently these incidents happen and how serious the effects on the health on passengers and crew is. Since airlines do not need to disclose fume events to authorities, when happening during ground operations or without any identified mechanical fault, there is evidence that a large number of incidents were never reported (Anderson 2021).

A study by the German Federal Bureau of Aircraft Accident Investigation (BFU) 2014 of incidents in relation with cabin air quality between 2006 and 2013 names 663 reports of incidents, from which 460 included smell and 188 smoke development. Health impairment was reported in 180 cases and long-term health effects in 10.

In a study conducted by Shehadi 2015, the frequencies of bleed air contamination incidents of different aircraft models are analyzed. The conclusion is that incidents occur in **all type of aircraft models** and are widely spread across all major engine and APU manufacturers. Furthermore, it is determined that incidents occur with an average frequency of 2.1 per 10,000 flights and the highest frequency for one specific aircraft is 7.8 incidents per 10,000 flights.

Smell or fume events have also occurred in the A380. In 2018 for instance, Lufthansa flight D-AIMJ from New York to Frankfurt had to land in Boston due to a fume event. It was reported that at least two crew members had health problems afterwards as well as one passenger (Austrian Wings 2018). In 2016, in a British Airways flight from London to San Francisco a fume event occurred as well, which let some crew members confused, oblivious and not able to conduct a normal conversation. Few crew members were not able to work for months (Eiselin 2017).

It can be noted that fume or smell events occur on a daily basis and can occur in all types of aircraft. There are no reports presuming that smell or fume events occur with higher frequency in an A380, but incidents have happened in it as well. In 2020, Airbus announced to conduct a study about fume events with the goal to develop a retrofit system with improved air filters in the A320 (Airliners 2020).

5.2.2.14 Passengers - Comfort

Apart from possible effects on health and safety, indicators referring to **comfort** and accessibility of a product are of interest for passengers. The well-being of a passenger during the entire flight is influenced by several different parameters such as available space, cabin noise, cabin air, light, and vibration.

The A380, provides with its two passenger decks a total size of 550 m^2, has 50 % more **floor space** than the Boeing 747 but only 35 % more seat capacity. The 15 % remaining floor space can be used for **customization** of the cabin and provide higher comfort for passengers (Carey 2008).

Another parameter for comfort is the **noise level** in the cabin. If a certain limit, which can be very subjective, is exceeded, it leads to discomfort and annoyance among passengers and crew members. Quite often, the comfort of the passenger stands in contrast to ecological and economical aspects. This is also true for cabin noise since noise reduction measures often mean more weight and thus more costs and fuel consumption. Nonetheless, since the introduction of jet airplanes, the cabin noise has decreased significantly. As described in Subchapter 5.2.2.5, one reason for this is the reduced engine noise, for instance due to the high bypass ratio of newer models. This also affects the cabin noise level since a major cabin noise source are engines - especially for seats in the rear section of the cabin. Not only the engines but also the airflow over the aircraft surface contributes to the cabin noise, induced by a turbulent boundary layer (Thomas 2019). For larger aircraft models, the **turbulent boundary layer noise** is responsible for most of the cabin noise. Apart from the **external**, also **internal noise sources** exist such as ventilation system, lavatories, or the public address system, as can be seen in Figure 5.12 (Kletschkowski 2020).

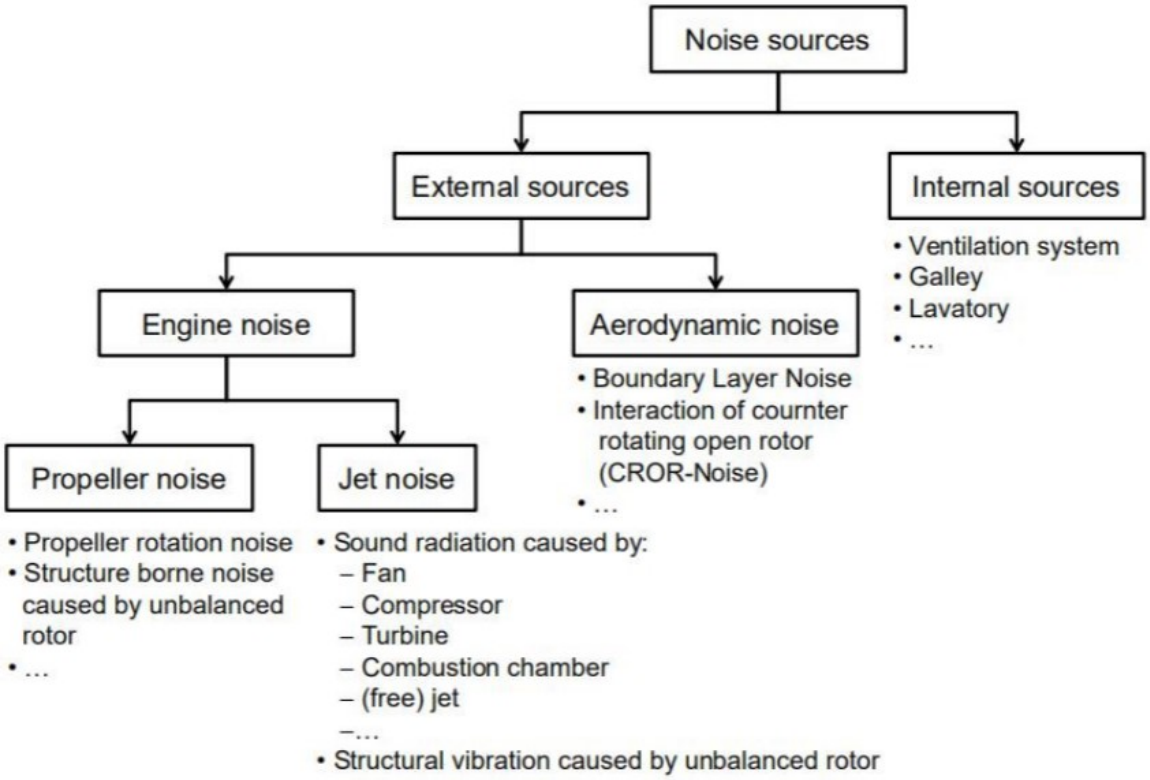

Figure 5.12 Sources of Cabin Noise (Kletschkowski 2020)

To research in the field of cabin noise reduction, Airbus has developed a flightLAB Demonstrator, which can be used as alternative to flight tests to decrease costs and ecological impacts. In the flight laboratory new measures for noise reduction can be tested. A focus of the research lies on noises below 300 kH since their reduction would usually be accompanied by an increase of structural weight. While noises with frequencies above 1 kH can be reduced by using the primary insulation glass wool, new technologies have been developed to decrease low frequent noises, such as multilayer insulation with plate transducers, resonant masses, Helmholtz resonators, or Acoustic Black Holes (Thomas 2019). But not only **passive** but also **active noise control** can be used, especially for low frequency noise in order to save weight. This can be achieved by applying the principle of destructive interference of primary noise with a canceling signal as seen in Figure 5.13 . The active noise control system usually consists of loudspeakers as actuators and microphones as sensors (Kletschkowski 2020).

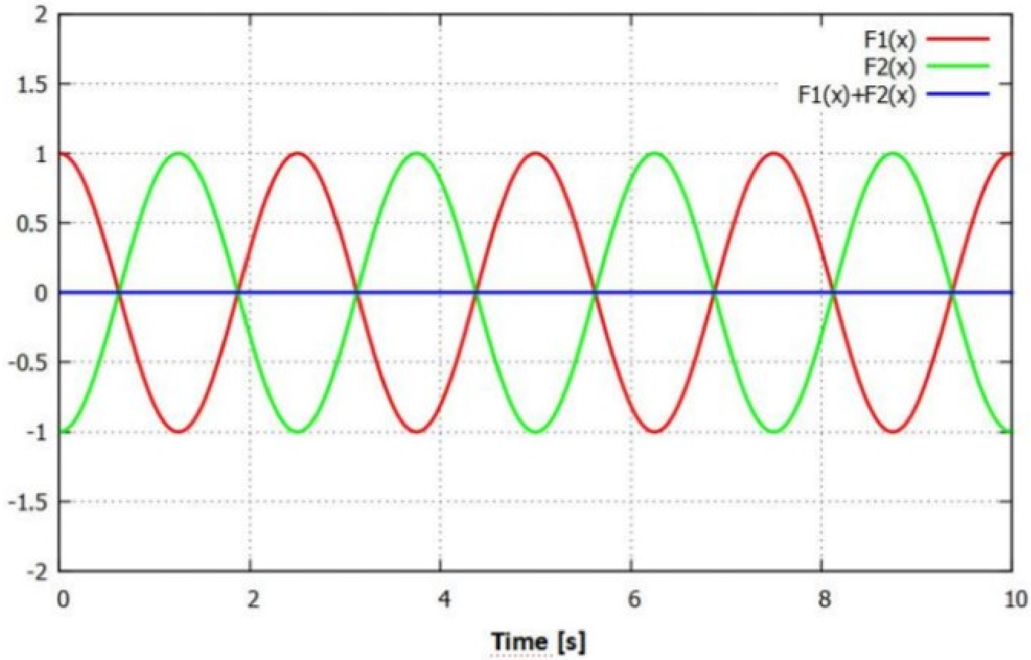

Figure 5.13 Destructive interference of noise (red) and anti-noise (green) (Kletschkowski 2020)

The A380 is supposed to have the quietest long-haul cabin (Flaig 2008). There are even reports of pilots complaining about the lack of so-called **white noise**. Instead, random noises from passengers or the lavatory were audible (Demerjian 2008). A noise reduction could be achieved by relatively thick walls of the fuselage (McCartney 2019) and an optimized nose shape to offer the best compromise between visibility for the pilots, drag and cabin noise (Flaig 2008). Furthermore, noise cancelling chips have been installed in headsets on the A380 (Clarke 2007).

In a report by GAO 2017, studies on cabin noise in different aircraft types are collected. A study regarding the A380 is listed as well, in which the cabin noise levels of the A380, together with the B737-300, 737-700, 747, 767, and 777, was examined in 83 flights (each aircraft type at least five flights) with a fixed sound level meter. The result was that the average noise level in these aircraft types is between 67 and 76 dB. More precise data could not be found regarding the noise level in the A380 cabin.

During cruise flight, a commercial aircraft operates in **extreme environmental conditions**. The atmospheric pressure reduces from around 1013 hPa during ground operations to 200 hPa during cruise. Reduced atmospheric pressure respectively reduces the oxygen partial pressure of the air and thus lowers oxygen saturation in the blood of an exposed human body. At cruise altitude of over 10,000 m, individuals would suffer from severe **hypoxia** and would lose consciousness within seconds. To protect passengers from external conditions, the **environmental control system** (ECS) of the aircraft pressurizes the cabin. To reduce the load on the fuselage, cabin pressure cannot be as high as at sea level. Commonly, the pressure is expressed to the **equivalent altitude**. Typical pressure level in an aircraft cabin is around 750 hPa which is equivalent to an altitude of around 2,500 m. A study conducted by Muhm 2007 concluded that a cabin altitude above 2,134 m increases the discomfort of passengers significantly due to lowered oxygen saturation. Thus, by increasing the cabin pressure, the comfort of passengers increases (Bagshaw 2019). The cabin pressurization of the A380 is equivalent to 1,868 m, which is relatively low and should reduce the mild symptoms of hypoxia and thus discomfort (Wikipedia 2021f). The ECS also controls the **temperature** inside the cabin. Recirculated air from the cabin and conditioned bleed air are mixed in the mixing chamber and according to the lowest temperature demand (which is usually in the economy class with a high number of passengers) temperate. The conditioned air is distributed to the different temperature zones and air for zones with a demand for a higher temperature is warmed up by adding trim air (NRC 2002). To regulate the temperature in the A380, the cabin is divided into 15 different zones with temperature variations between 18 °C and 30 °C. It has the lowest number of passengers per temperature control zone (Carey 2008).

The A380 offers over 5,000 different light scenarios to create specific cabin ambience, using multi-spectral LEDs. Furthermore, it has larger windows than the Boeing 747 (Carey 2008).

It can be noted that the A380 offers a relatively **comfortable cabin** with low noise levels, relatively high cabin pressure and more leg room than comparable aircraft.

5.2.2.15 Society - Public Commitment for Sustainability Issues

A matter of importance for different stakeholders is corporate responsibility. For this reason, it needs to be analyzed if there are **sustainability policies** implemented at corporate level. These policies should have the goal to contribute to sustainable development of society by reducing possible negative or strengthen positive impact of their products on the communities (UNEP 2013).

Airbus has released numerous policies based on international sustainability standards, such as the UN Sustainability Development Goals or UN Global Compact. Not only for environmental but also for social issues policies have been implemented. On the Airbus webpage are numerous policies listed, such as the Modern Slavery Statement, Code of Conduct, or Supplier Code of Conduct. Furthermore, Airbus has conducted a “Materiality

Assessment” since 2017, in which sustainability issues of importance have been identified and prioritized with the help of 12 stakeholder groups (Airbus 2021i).

It should be noted that the aeronautical industry is facing an increased responsibility for sustainability commitments. The product aircraft is responsible for almost 4 % of the global man-made CO_2 emissions and thus partly for the **global warming**, which has enormous negative impacts on the environment and human well-being (EC 2021b).

For the evaluation of different aircraft regarding their environmental impact, an **ecolabel** has been developed by Professor Scholz and some of his students, most notably Daan Hurtecant. Purpose of an ecolabel is to give passengers information concerning environmental impacts of common aircraft types. In this way, passengers can choose the **most eco-friendly flight**. Based on an LCA, four different categories of impact are being considered for the evaluation: fuel consumption, global warming effect (CO_2 equivalent emission), local noise pollution, and local air pollution. By using normalizing factors, different aircraft types can be compared with each other. Each impact category contribute to the overall rating of the environmental impact of the aircraft and a rating scale from A to G is implemented. Furthermore, the different travel classes are being evaluated based on their space occupied per seat and thus by their fuel performance (Scholz 2021b).

The Airbus A380 received an overall rating of E, based on the weighing factors of **fuel performance** (D rating), **global warming** (G rating), **local noise level** (A rating), and **local air pollution** (G rating) (see Figure 5.14). While the economy class has a fuel performance rating of A, both business and first class only received a rating of G. This is because more space consuming seats have proportionally larger impacts. For the rating of the Airbus A380, a standard seating configuration of 555 seats was chosen. Typical seating configurations of the A380 include around 90 seats in the business and first class (SeatGuru 2013). Both impact categories - fuel performance and global warming - are dependent of the number of seats, thus the high number of business and first class in an A380 has a significant impact on the overall rating. 300 more passengers could travel in an all-economy configuration (where the fuel performance rating is A). There is the potential to significantly improve the overall environmental impact of the A380, but in the standard configuration it is below average. In comparison, the average rating of the world fleet of passenger aircraft is a “B”, which is based on the three most common aircraft types Boeing 737-800, Airbus A319/A320/A321, and Airbus A320neo, accounting for 78 % of all flying aircraft.

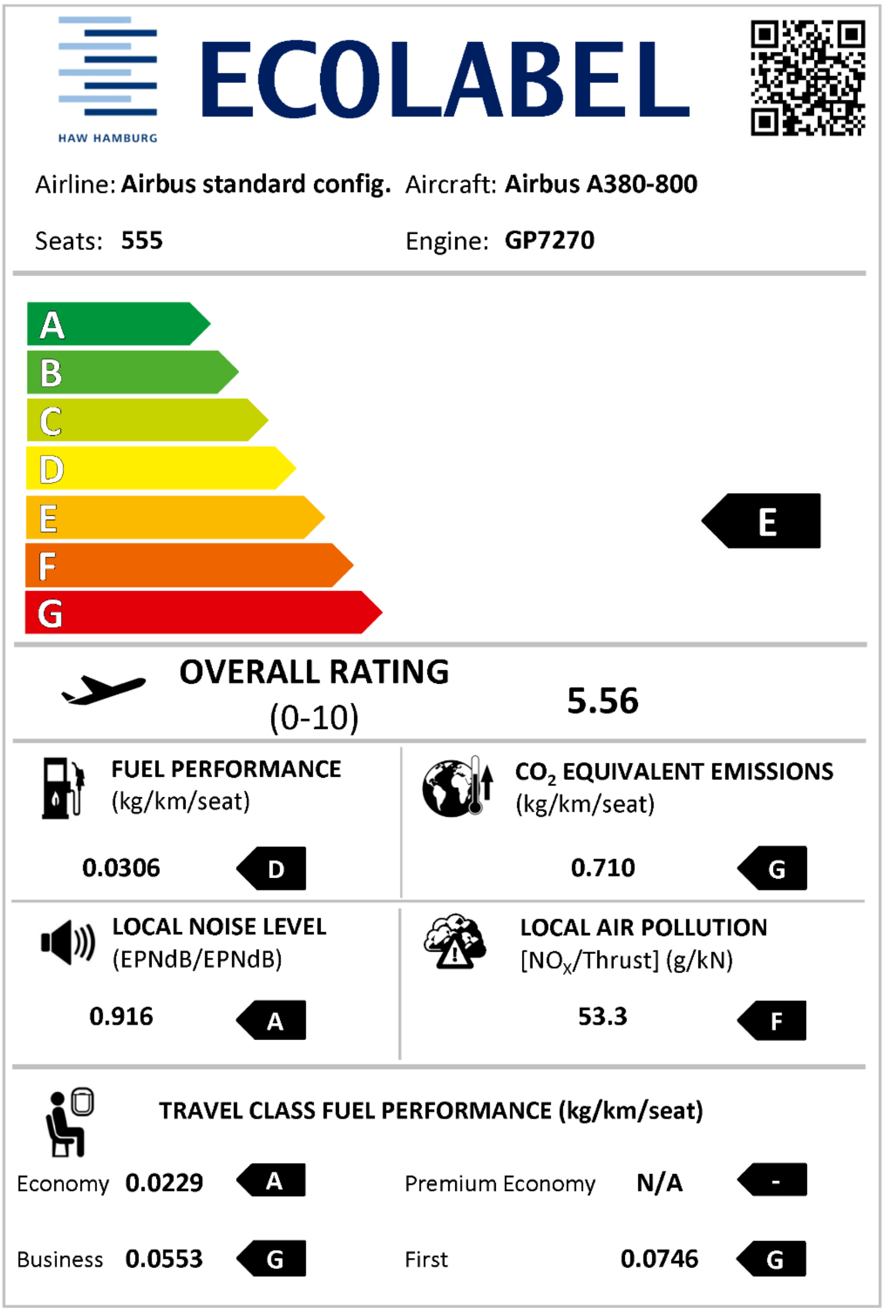

Figure 5.14 Ecolabel for A380-800 (Scholz 2021)

5.2.2.16 State – Political Power and Prestige

A particularity of the aerospace industry is the relatively big influence of **government institutions** though regulations, being a customer or being shareholder. This is also the case for Airbus as a European company, 11 % of its shares are held by the German and the French state respectively, as well as 4 % by the Spanish state (Airbus 2021c). Furthermore, the European countries are customers as well, for example the German Bundeswehr as buyer for the A400M.

Since aviation and aerospace industry belongs to the **high-tech sectors**, a highly developed industry also represents the knowledge and state of research of a nation. Besides, a highly developed aeronautical industry can also be an indicator for a strong military of a country. It can be noted that aeronautical industry is of high interest for a nation with respect to **political power**.

When the consortium Airbus was founded, it was a response to the dominating US aerospace industry around Boeing. After the Second World War, European countries became less relevant regarding technological advances but also political power, which led to **dependencies** on the United States. By 1951, 80 % of all commercial aircraft on the global market were built in the United States (Amir 2021). While France and Great Britain had a quite successful aerospace industry around the main companies Sud Aviation and Hawker Siddeley, Germany had to rebuild its industry completely after the Second World War. By establishing a consortium with other European countries and aerospace companies, Germany was offered the possibility to establish a successful aerospace industry itself (Krause-Nehring 2007).

By developing the Airbus A380, European aerospace industry surpassed its competitor Boeing. For leading European politicians, the A380 was a **symbol of European power**. The importance of this project for politicians could be seen at the ceremony of the reveal of the first A380 in January 2005. Leading politicians, such as by then Prime Minister Tony Blair, Former Bundeskanzler Gerhard Schröder, former French and Spanish presidents Jacques Chirac and Jose Luis Zapatero, were all attending and expressing the meaning of the A380 as symbol for European strength and unity (Clark 2006). For these reasons, it was highly desirable to be a main manufacturing site of the A380. The city of Hamburg spent over 700 million to ensure that in the Airbus Finkenwerder plant major parts of the A380 were developed. It could be assumed that being a delivery center to customers from Europe and the Middle East goes along with a high prestige for the city of Hamburg (Nimtz-Köster 2005).

5.2.2.17 State - Contribution to Economic Growth

Around 45,000 workers Airbus employs only in Germany, more 71,000 employers in other European countries (Airbus 2021f). Additionally, around 60 % of all Airbus suppliers are based in Europe. As can be seen in Toulouse, **induced effects** are notable in other sectors due to the presence of a major Airbus manufacturing site - hotels, restaurants, or bus transportations have been established for Airbus workers (Krause-Nehring 2007). Thus, it is of **high economic relevance**, where an aerospace company - such as Airbus - has a major production site. For this reason, and the above-mentioned political meaning, the extension of the Airbus plant was of high importance for the city of Hamburg to increase economic growth.

European countries granted Airbus **credits** totaling around 3.5 billion for the development of the A380, of that around 940 million from the German government. In the European aerospace industry, it is common practice to receive credits for projects from governments due to the fact that Boeing receives public funds from the United States on a regular basis. For the development of the Dreamliner 787 around 5 billion Dollar were granted. The funding of the aircraft projects with public money are a problematic topic since years because both companies, Airbus and Boeing, claim that the **governmental subventions** for the other company's projects result in distortion of competition. The repayment of the granted credit for the development of the A380 was linked to the sales of the A380, but since no more A380 are being sold, around 630 million euros have not been repaid to the German government and are thus missing in other parts for the taxpayers. However, according to Airbus, the A380 program guaranteed **tax revenues** and payments for social funds totaling around 2.5 billion as well as highly qualified employment at Airbus and suppliers (Schubert 2019).

5.2.2.18 Organization - Profit

The original 12 billion development costs for the A380 rose over time immensely, also due to several launch **delays** (Johnsen 2009). Around 25 billion euros were the development costs for the A380 in the end (Späth 2021b). However, around 3.2 billion were given as a **start aid** by the German, French and Spanish government and also supplier involvement was applied the first time. Since the costs of the A380 were significantly higher than other projects, Airbus initiated formations of partnerships and **joint ventures** with its suppliers to share risks and rewards (Johnsen 2009).

In 2006, the so-called **breakeven point**, which is the threshold to profit, when revenues are surpassing the development costs, was claimed to be at around 270 sold A380. However, due to the rising development costs of around 5 billion after several delays, Airbus announced a new break-even point of 420 sold aircraft (Haynes 2006). It can be assumed that the A380 never made profit. Instead, it is estimated that operating losses were up to 400 million euros in the first and last years of the A380 manufacturing, while the loss in 2017, the best sales year for the A380, was around 66 million euros (Lindner 2019).

5.2.2.19 Organization - International Teamwork

For Airbus, the A380 was the first project being developed and manufactured after the fusion of the different European aerospace companies to one unified multinational organization, EADS. But the different interests of the member nations posed some **logistical challenges**, since the A380 as a European project needed to be built in different manufacturing sites all around Europe to comply with the **work-share principle**. Because of the size of the A380 sections, it was partly not possible to transport them to the final assembly by traditional transportation methods. Instead, a route was established, called the *Itinéraire à Grand Gabarit*, on which sections from the different manufacturing sites were transported by water and road to Toulouse (Figure 5.15).

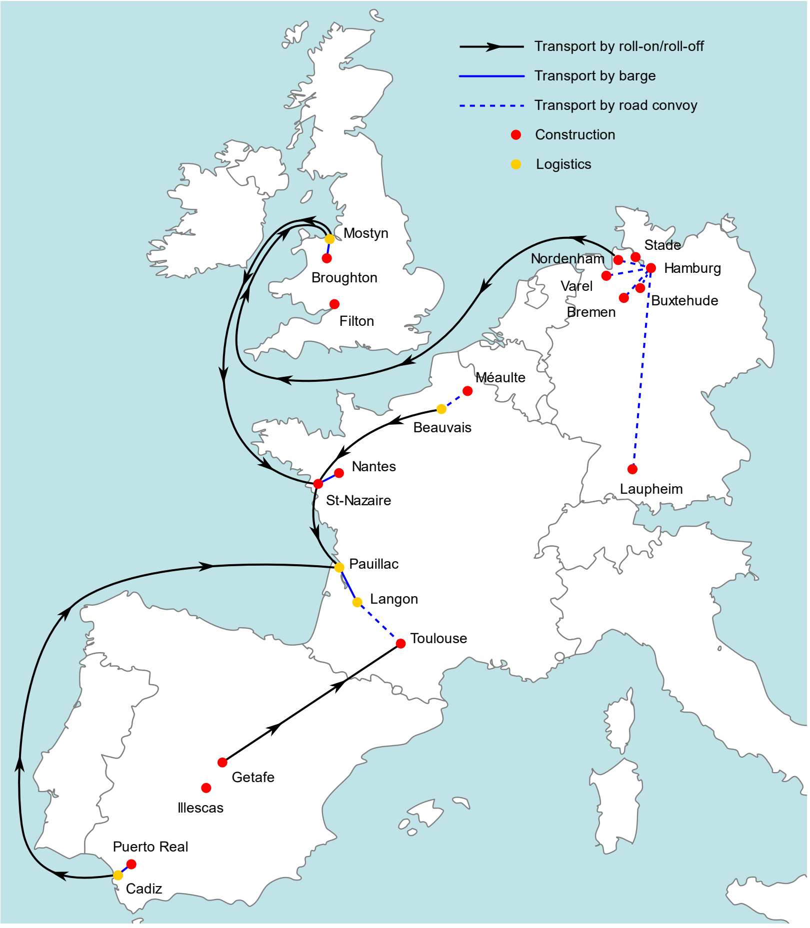

Figure 5.15 Route Itinéraire à Grand Gabarit (Wikipedia 2020a)

Roll-on-Roll-off ships from Hamburg, Cadiz and Mostyn brought major sections via Saint Nazaire to Bordeaux, from where they were transported via barge on the river Garonne to Langon. From Langon to Toulouse the sections needed to be transported by oversized road convoys, using the French national roads. Several reconstructions were necessary to make the roads fit for the oversized A380 sections. While the road convoy moved the sections at night, the road was closed for other road users (Wikipedia 2020a).

The development of the Route *Itinéraire à Grand Gabarit* caused **expenses** of around 171 million euros, from which 43 % were financed by the French government and 57 % by Airbus. While the construction increased **local employment**, for Airbus it was a highly complex logistical task (Wikipedia 2020b). The question arises, if it would not be more efficient to build one type of aircraft in one manufacturing site instead of following the "work-share" principals.

Challenges also appeared concerning software programs in the different manufacturing sites, caused by **cultural and industrial discrepancies** between French and German managements. While in the French plants the Computer Aided Design (CAD) programs Catia and Circa were used, in German engineers used Computervision. Although the former head of the A380 program requested from the Germans to change their CAD program, German managers refused. Former chief of aircraft programs at Airbus Tom Williams suspected it was a question of national pride (Clark 2006). While assembling major sections and installing all electrical cables, it became apparent that the wires were too short, which was caused using different computer modelling software. These wiring problems led to a delay of over a year and cost Airbus around 5 billion euros.

In the following aircraft programs, such as the A350, no mismatches occurred, which could lead to the assumption that the **experiences** made during the development of the A380 taught Airbus management to improve international teamwork.

An interviewee of Airbus commented that the international teamwork has been very fruitful and was conducted mostly in great harmony. The **multinationalism** of the organization has enabled employees to work in different parts of Europe and broaden the cultural horizon. Furthermore, it was stated that by sharing the work, every site has developed its own competencies, such as flight controls in the French site, wings in the English or data collection in the German site. Only by working together, Airbus has been able to compete successfully on the international aeronautics market.

5.2.2.20 Organization - Technology Development

An interviewee pointed out that during the development of the A380 many new technological advancements were introduced, which led to a significantly number of patents. According to the interviewee, some of the patents were later sold, for example to Boeing. Furthermore, extensive testing increased knowledge and experiences of the company for future projects. As an example, he mentioned the wake vortex test flights. Over 380 patents were filed by Airbus for the A380, among these is also the Zero-Slice inlet, mentioned in 5.2.2.5. Furthermore, an innovation concerning data communication was patented. All safety critical systems, such as flight controls, navigations, or air conditioning, has been integrated withing the avionics network. The communication is done via the avionics data communication network (ADCN), which is based on avionics full duplex switched ethernet (AFDX) (Wiegmann 2016). In this way, the data integrity and transmission speed could be improved significantly. According to Airbus, many patents have been adopted for the A350 XWB (Emerald 2008).

5.2.2.21 Potential Social Risks along the Supply Chain

The design of an aircraft is a highly complex task, since an aircraft is made up of a wide range of extremely **complex** components such as propulsion or air conditioning system. A typical aircraft consists of approximately one million parts (Weber 2019). Around 60 % to 80 % of the final cost of an aircraft derive from part and services provided by suppliers (Horng 2007). Like in other complex industries, the supplier network is hierarchically structured in **tier suppliers** as it can be seen in Figure 5.16. On the top of the supply chain are **the Original Equipment Manufacturer** (OEM), which are major aerospace companies such as Airbus, Boeing, or BAE Systems. Typically, the supply network is grouped into three tier suppliers. Tier 1 suppliers usually manufacture major components such as control systems, landing gear or avionics, which are supplied to the OEM. Tier 1 suppliers in turn are supplied by Tier 2 companies, who produce subsystem assemblies such as airfoils and tires. Tier 3 suppliers are responsible for production and shipping of components and parts to tier 2 suppliers (Hamilton 2021). Also included into the tier supply chain network are suppliers for raw material, forging or castings. This network shows the complexity of the supply chain for an aircraft.

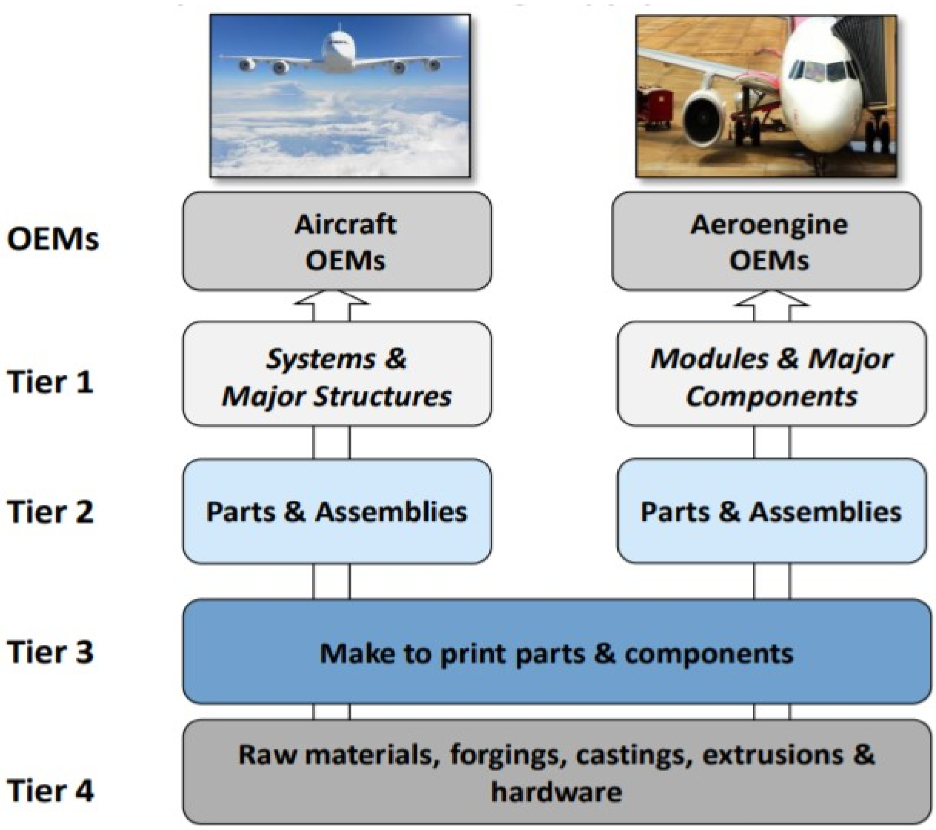

Figure 5.16 Aerospace Manufacturing Supply Chain Structure (Aboulafia 2018)

Airbus has **sourced out** around 80 % of its activity to its 12,000 suppliers for flying and nonflying parts (e.g., IT and office equipment) (Airbus 2021h). By building the largest aircraft of the world, the complexity of the A380 became even more challenging. It consists of around four million distinctive parts provided by 1,500 different companies from around the world

(Slutsken 2018). Due to the need for a **high degree of technology** and innovation, as well as highly qualified workers, the aerospace industry is focused on only few countries and regions, mainly in Europe and North America. But in recent years, also Brazil, India, Russia, China, and Japan have developed a growing aerospace industry (Buxbaum-Conradi 2018). However, most Airbus suppliers are still based in Europe (59%) and North America (27%), while only 8 % are based in Asia-Pacific and less than 1 % in Africa, Middle East, and Oceania respectively (Airbus 2020). A reason for that could be the restrictions due to regulations.

Approved Airbus suppliers are also located in countries such as India, China, Morocco, and Tunisia. In the past, these countries were linked to violations of labor rights. In Morocco and Tunisia for example, working hours are often extremely long and hourly wages do not exceed 2 $US, whereas employers prevent union formations (Industriall 2020).

It is not known to the author whether human rights violations have occurred in the aerospace sector as well, specifically for the supply chain of the Airbus A380. But there is a possible risk regarding violations of human or worker rights along the supply chain due to the involvement of numerous suppliers in different countries and the complexity of the product.

Due to confidentiality, the **material** data of the Airbus A380 are not available. Nonetheless, the mainly used materials can be found via web search and possible risks can be identified. The A380 consists to 61 % of commonly used aluminum alloys, 10 % of steel and titanium, 22 % of carbon fiber reinforced composites (CFRP) and 3 % of the then novel material Glare (glass fiber reinforced aluminum) (Späth 2021d).

The main aluminum producing countries are China, who provides more than half of all global aluminum output in 2020, Russia, India, Canada, and the United Arab Emirates. To produce aluminum, bauxite is extracted from the ground. It is then processed and transformed first into alumina and later in aluminum. Located is bauxite in tropical and subtropical regions, such as Africa, Oceania, and South America (Aluminum Association 2021). In a recently published report from Human Rights Watch 2021, the bauxite extraction and aluminum processing for the automobile industry was critically analyzed regarding human rights impacts. Aluminum producing companies in China and other parts of the world, source bauxite from countries with high occurrence of bauxite. Bauxite occurs on the surface, so that large areas of land are required for extraction. Consequences for that are commonly **forced resettlements** of whole communities and consequently poverty increase due to lack of access to food and farmland. Quite often, affected communities belong to Indigenous People (HRW 2021). Due to soil erosion caused by **mining**, sediments leaking into rivers and thereby blocking their flow. **Reduced water quality** can be a consequence. Not only during mining but also the refining into alumina can have grave consequences for the environment and local communities. A by-product of the refining is so-called “red-mud”, which is highly alkaline with contaminations of iron and metallic oxides. If it is not stored safely, it can be harmful for the environment and people. There have occurred accidents, where “red-mud” containers broke, causing hazardous mud flooding nearby areas (HRW 2021).

Not only during aluminum but also during steel production, human rights violation can occur. The “Broken Promises” investigation disclosed that major European steel producers such as ThyssenKrupp and Tata Steel Europe source coking coal from Mozambique, where communities were forcefully evicted for mining projects. They were then resettled to remote areas with very **limited access to water, food, and work** (Voller 2016). Similar social and environmental issues may occur also during the mining of other raw material used in aircraft, e.g., in aluminum alloys, such as copper or lithium.

Though the exact supply chain of the Airbus A380 as well as the aircraft material data are not known, the above-mentioned cases of human rights violations show that risks of negative social impacts do exist. Furthermore, it also shows the challenges to conduct an S-LCA of a highly complex and internationally produced product like an aircraft, since every social aspect in every life cycle stage should theoretically be relevant. Practically, it is almost impossible to follow every single part of an aircraft along the supply chain and detect all positive and negative impacts on all stakeholders.

Airbus as the OEM has released a code of conduct for supplier, in which Airbus 2021j requires from suppliers the compliance with human and worker rights, anti-corruption, and product safety policies as well as laws and regulations. Social and environmental **business ethics** should be not only implemented by suppliers, but it is also expected to cascade these policies through their own supply chain. To monitor progress throughout the supply chain regarding the implementation of above-mentioned policies, a team for Sustainable Supply Chain Roadmap reporting has been formed. Furthermore, **social risk mapping** has been established since 2018 due to the possibility that the company does not gather all information from suppliers about complying all policies. The roadmap was established to identify social impacts such as child labor, working hours, wages, or people safety in the supply chain. 397 companies along the supply chain were identified, who pose high risk for violating above-mentioned policies. (Airbus 2020f). With the help of external consultants, Airbus conducted a human rights impact and gap analysis across its supply chain to have more insight into positive and negative social impacts. The analysis also identified Airbus salient areas of potential human risks, which are the following:

- Impact of products and services on the right to life and liberty (passengers and citizens)
- Privacy (individuals and their personal data)
- Impact of climate change on livelihoods (climate vulnerable communities)
- Forced and child labor (contractors and supply chains)
- Diverse and inclusive workplaces (Airbus workforce and contractors) (Airbus 2020)

5.2.2.22 End-of-Life Phase

Till recently, the end-of-life stage of an airplane was rather neglected, but due to growing environmental consciousness and a growing number of retired airplanes, the mindsets of OEMs and airlines have shifted to **recycle** and **reuse** retired aircraft. Before, it was common practice to store the aircraft in aircraft graveyards located in dry and hot environments like deserts. Either they were kept airworthy by trained personnel to bring them back into service or to be sold, or, if these options were unprofitable, they were **landfilled**, after scraping valuable parts such as engines or avionics. Landfilling have led to aircraft graveyards with thousands of airplanes stored in deserts. There even have occurred incidents where disposal of aircraft parts into the sea (Maaß 2020). Both Airbus and Boeing conducted studies about possible alternatives. Airbus initiated the so-called PAMELA project (Process for Advanced Management of End-of-Life Aircraft), in which it was demonstrated that 85 % of an aircraft weight can be recycled. While some parts such as engines, landing gears, avionics, auxiliary power unit (APU), ram air turbine (RAT), as well as parts of the cabin equipment usually can be sold and reused again, other parts can be dismantled and sorted by materials (Ribeiro 2015). By starting the **PAMELA project**, Airbus also formed the Tarbes Advanced Recycling and Maintenance Aircraft Company, a plant in France to dismantle retired aircraft. More recycling companies followed in Teruel, Spain, or in Toulouse, France. Till 2020 the latter one has recycled over 170 aircraft and 135 engines (Maaß 2020).

One of the challenges of aircraft recycling are the **missing regulations**. Although indirect directives do exist, such as electrical or chemical waste disposal, there is still no direct legislation of the end-of-life phase of an aircraft. Another challenge is the increasing number of **composites** used in aircraft. In order to reuse composite materials, a complex chain of processes needs to be applied. Most common composites in the aerospace sector are carbon fiber reinforced plastic (CFRP) and glass fiber reinforced plastic (GFRP). Different kind of **recycling technologies** need to be used depending on the materials of the composite. A distinction is made between mechanical recycling, which is cost-effective but affects the mechanical performance of the shredded pieces negatively, thermal recycling, which is divided into incineration, combustion and pyrolysis, the most common method currently, and chemical recycling. Chemical recycling allows the recycled carbon fiber to maintain their reinforcing capabilities and possibly to reuse the matrix. Nonetheless, technologies still need to be improved and economical profitable to advance in the field of aircraft recycling (Maaß 2020).

The A380 still consists to 60 % of **aluminum**, which is the material with the largest capability in the recycling market. Airbus already considered the end-of-life stage of the A380 while designing and was able to demonstrate that 98 % of metallic components could be recycled (Maaß 2020).

Despite just in service for 14 years, some airlines already retired some or all their A380 fleet, in some cases due to the ongoing **COVID-19 pandemic** (Figure 5.17). While the Lufthansa fleet is stored in Teruel, Spain, other airlines found creative solutions for reuse or recycle some A380 (Neuroth 2021). Singapore Airlines, who retired the first A380 in 2020, transformed one of its A380 into a restaurant but also brought back some of the retired aircraft back into service in November 2021. Also, British Airways, Qantas and Qatar Airways resume flying A380, after they were kept in storage (Flynn 2021). Emirates plans to reuse and recycle its first retired A380 by dismantling the aircraft and turn it into collectibles for sale (Bryan 2021). Over 190 t of material is supposed to be removed and recycled - including metal, plastic, and carbon fiber - by the company Falcon Aircraft Recycling (Kaminski-Morrow 2021).

Figure 5.17 Dismantled Airbus A380 (Aviationtag 2020)

New **end-of-life solutions** could lead to new job creation in the recycling sector. Pillain 2018 discusses the possible job creation in the French carbon fiber aeronautical recycling sector. While older aircraft mainly composed of aluminum, the share of CFRP has increased in recent years due to its excellent mechanical properties and low density, which can be already noted in the A380, which is composed of 22 % CFRP. While this currently poses a problem when it comes to recycling, since CFRP is commonly incinerated or landfilled, Pillain 2018 expects potential job creation by establishing a **pyrolysis recycling process**.

5.2.3 Social Life Cycle Impact Assessment

The Guidelines do not provide a methodology for the impact assessment of products since it is still **under development**. It still represents a challenge to interpret and evaluate social impacts, but few methods have been developed by different researchers. As described in 2.4.3, two different types of impact assessment are differentiated, however, neither of them has a clear methodology and are rarely described in detail (Pollok 2021). Since type II methods are mostly of quantitative nature and regarding the present study and collected data, it is more constructive to evaluate the social impacts by applying **type I impact assessment**.

In the following SLCIA, the **Subcategory Assessment Method** (SAM) is used to evaluate the collected data related to the subcategories. It provides a tool to evaluate the organization's social performance by assigning a level with a scale from A to D for each subcategory as it is shown in Table 5.8. During the assessment it is analyzed, if and in which extend an organization fulfills the **basic requirements**, which can be international agreements or national laws (Sanchez 2014a).

Table 5.8 Subcategory Assessment Method (Sanchez 2014b)

Level	A	B	C	D
Assessment	4	3	2	1

- Level A: The organization presents a **proactive behavior** in relation to the basic requirements – along all the supply chain related to each subcategory
- Level B: The organization fulfils the basic requirements
- Level C: The organization does not meet the basic requirement – it is located on **favorable context** to the fulfillment of basic requirements
- Level D: The organization does not meet the basic requirements – it is located on **unfavorable context** to the fulfillment of basic requirements (Sanchez 2014b).

According to Sanchez 2014c, the basic requirements for each subcategory (excluded are the ones not listed by the *Guidelines*) are the following:

Table 5.9 Basic requirements for subcategories according to SAM

Subcategory	Basic requirements
Delocalization and migration	There is an internal management system that prevents involuntary resettlement (where involuntary resettlement exists) or there is no evidence of resettlement caused by the organization
Community engagement	There is evidence that the community's environment, health, or welfare are of importance to the organization
Cultural heritage	Evidence that the organization contributes to the preservation of cultural heritage through contributions to cultural and artistic organizations, networks, or internal programs

Local employment	There is evidence of equal employment opportunities for local workers
Safe and healthy living conditions	The organization contributes to the health of local communities through environmental risk management systems or participation with local organizations in communicating the potential health and safety impacts of their operations on surrounding communities
Freedom of association and collective bargaining	In the organization, there is evidence of workers belonging to a labor union
Fair salary	The lowest salary is equal to or higher than the minimum wage in the sector/country where the organization is located
Hours of work	Average weekly hours worked do not exceed 8 in the day and 48 over the week
Health and safety	the organization has a policy/ guidelines or program related to health and safety
Equal opportunity / discrimination	The organization has a management system, policy, or actions to prevent discrimination and promotes equal opportunities for workers
Social benefits	The BR is that the organization offers more than two of the following types of benefits: social security, retirement, disability, dependent, survivor, paid maternity, and paternity leave (parental leave), paid sick leave, education, and training for all countries and/or the following types of insurance: medical, dental, paramedical, preventive medical, pharmaceutical and wage
Health and safety	The organization has a procedure regarding consumer product health and safety standards
Public commitment to sustainability issues	here is evidence of commitment or agreements related to sustainability that are disseminated through the organization's website, promotional materials, or other means
Contribution to economic growth	the organization provides a contribution to the economy that is disseminated through the organization's website, promotional materials, or other means

By applying the SAM, it is possible to transform qualitative into quantitative data by allocating numbers from 1 to 4, with 1 for worst assessment and 4 for best assessment) (Sanchez 2014a).

The collected data presented in previous chapters are now assed using the SAM method. In Table 5.10 the results are listed. As mentioned above, some subcategories could not be assessed with the Subcategory Assessment Method since there are no basic requirements regarding the additionally included subcategories *material assets*, *comfort*, *political power* and *prestige*, *profit*, *international teamwork*, and *technology development* (in the *Methodological Sheets technology development* is only a subcategory for the stakeholder group *society*).

Table 5.10 Impact evaluation with SAM

Stakeholder	Subcategory	Level	Assessment
Local community	Delocalization and Migration	B	3
	Community Engagement	B	3
	Cultural Heritage	B	3
	Local Employment	B	3
	Safe and Healthy Living Conditions	B	3
	Material Assets	NA	NA
Workers	Freedom of association and collective bargaining	A	4
	Fair salaries	A	4
	Hours of work	A	4
	Health and safety	A	4
	Equal opportunity / discrimination	A	4
	Social benefits	A	4
Passengers	Health and safety	A	4
	Comfort	NA	NA
Society	Public commitment to sustainability issues	A	4
State	Political power and prestige	NA	NA
	Contribution to economic growth	B	3
Company	Profit	NA	NA
	International teamwork	NA	NA
	Technology development	NA	NA

As it can be seen in Table 5.10, the organization Airbus engages in sustainability policies and social responsibility, particularly regarding the workers employed by the company. It can be stated that Airbus **complies with national laws and international standards** and has several directives and guidelines published, in which the company's policies are pointed out. The labor unions have a strong position inside the company and negotiate hours of work, salaries, and holidays among others. **Social security** is employed by the organization and exceed basic requirements by offering additional benefits such as company kindergarten, education and training and discounts. Apart from workers' rights in the company itself, Airbus employs a "Supplier Code of Conduct", in which expectations and requirements for suppliers regarding the worker right are defined. Suppliers must pay at least the minimum wage required by the country they are based in, and no form of child labor, defined by the ILO or forced labor tolerated. Furthermore, Airbus expects from its suppliers to promote inclusion and diversity as well as freedom of association and a safe working space. All the above-mentioned social issues should be cascaded down along the supply chain. By employing the "Supplier Code of Conduct", the organization **promotes good practices** in the supply chain and thus has a proactive behavior, which is required to be assessed with a level A.

Assessing the behavior of the company towards the local community is more complex. The company presents proactive behavior in a way that human rights are being respected by the company itself and all suppliers. While there did not take arbitrarily expropriation place in this case study, the company did not display proactive behavior to protect interests of the local community or halt the parliament to issue an expropriation law. No local community member was resettled involuntarily, since in the end, all property owners sold their property voluntarily. But even though basic requirements were met by following national law and even promoting human rights in its Supplier Code of Conduct, a rating for level A cannot be applied due to the specific context of this study. As it can be seen in 5.2.2.2, community engagement has occurred. On the Airbus website it is described that the company engages with local communities and NGOs to contribute to the UN Sustainability Goals by partnering with schools and universities to enable higher education for community members, or by providing humanitarian help in the case of disasters (Airbus 2021k). There has been found some evidence during the case study that Airbus contributes to the preservation of cultural heritage, for example the protection of the St. Pankratius church against the wake vortices produced by the A380, or the donation of a heating systems for the village's cultural center. During a web search, other initiatives to promote artistic programs could be found, such as the sponsoring of the art award Finkenwerder (Kulturkreis 2021). For this reason, a rating of level B is applied. As it can be seen in 5.2.2.4, there is strong evidence for local employment but no direct proactive behavior along the supply chain could be found. The organization contributes to safe and healthy living conditions of the local community by employing an environmental risk management system. Since 2007, Airbus has obtained the **ISO 14001** certification, which depicts how to establish an efficient environmental management system in a company (Airbus 2010). Since the subcategory *Access to Material Resources* was changed to *Material Assets* to include a social impact mentioned by some interviewees and the low relevance of the original subcategory in this specific case study, as described in 5.1.2.5, it is difficult to assess this subcategory with SAM.

From the subcategories of the stakeholder *passenger* only *health and safety* were evaluated with SAM since there are no basic requirements for the subcategory *comfort*. As described in 5.2.2.13, all aircraft need to be certified by aviation authorities, otherwise it is not **airworthy**. By achieving a certificate of airworthiness, the company meets the basic requirements. Furthermore, Airbus expects from its suppliers to ensure continued airworthiness and to report any possible product safety issues (Airbus 2021j).

The organization **commits to sustainability** by engaging in the GRI and UN Global Compact. Airbus reports annually in the Universal Registration Document about its sustainability data and expects responsible business practice and sustainable development from all its suppliers.

The subcategory *contribution to economic growth* is evaluated as level B, since there are **financial results** and annual reports published regularly and accessible for the public on their website (Airbus 2021l).

Out of the 20 subcategories assessed with the SAM, 40 % received an A, 30 % a B and 30 % were not assessed. Impacts on the stakeholder group *local community* is evaluated with a 3, workers and passengers with a 4, as well as society. Thus, three out of four assessed stakeholders received the **highest possible score**, while local community received the second highest score.

As a result of the impact assessment using SAM, it can be said that Airbus as the organization is committed to sustainability issues, including social performance and expects its suppliers to engage in best practices as well. It provides local employment, and workers of the organization have full rights and are offered a secure employment with several social benefits. Besides, risk assessments are carried out by the organization to further improve social and environmental performance.

SAM is a method, which highlights the **company's social performance** rather than the product itself. According to Dreyer 2006, the social impact of a product depends mostly about the company producing it. Not the individual industrial processes have an impact on people, but the behavior of the company. For the social evaluation of a company, SAM offers an objective way to analyze qualitative data and transform it into quantitative data. The disadvantage of this method is that the product is not in the focus and thus possible positive and negative aspects are falling short, such as the comfort of customers or the tax burden on society by giving "start-aid" by European governments. Besides, even though no human rights were violated, and basic requirements were met regarding socially relevant topics for the local community, the product A380 still had **negative impacts**, which could not be evaluated with the SAM and are difficult to quantify in general.

Another disadvantage of this method is that large companies have advantages due to more **financial resources**. Supporting local communities, providing social benefits for its employees, or performing risk assessments is more possible for companies with large revenue.

5.2.4 Interpretation

By performing an S-LCA of an aircraft, in this case, the A380, key concerns during the life cycle can be determined. The long and **complex supply chain**, mostly during **raw material extraction** poses social risks since human rights could be in danger to be violated. Another key concern is the impact manufacturing sites have on local communities. Although in the case of the plant extension Hamburg Finkenwerder only one expropriation of an agriculturally used land took place, but it disclosed that governments are willing to issue laws of expropriation for the **benefit of private companies**.

Furthermore, a beneficial social impact is the **local employment**. The aerospace industry is an important employer in Hamburg, Germany and Europe and can improve human well-being by offering secure jobs. Lastly, although there were no infringements or risks of violation in this case study, a **safe product** is another key concern since an unsafe product in this case could have grave consequences.

The present study focuses on site specific data of the manufacturing site in Hamburg Finkenwerder. Social impacts occurring in other manufacturing sites in Europe were not included due to time limitations. Furthermore, the assessment of the supply chain posed difficulties since no data could be found regarding the supply chain, and a SHDB was not accessible. Since the production of an aircraft is outsourced to suppliers by up to 80 %, it effects the completeness of the assessment. Besides, not all subcategories were included in this study.

Stakeholders participated in this study were local community members as well as workers, but no participant from political decision-makers or the organization. In future research it would be important to **include these stakeholders** in the study as well to complement the present study.

6 General Application of S-LCA of Aircraft

In this chapter, the findings of the previous chapter are applied to generate a **general framework** for S-LCA of aircraft. Before, possible differences between the specific case study of the A380 and an aircraft in general are pointed out.

6.1 Possible Differences to S-LCA of an Airbus A380

The processes to produce a commercial aircraft do not differ greatly between different aircraft types, as can be seen in the work share of Airbus for different aircraft. Nevertheless, the A380 differs in a way that it is the largest commercial aircraft of the world, thus the process steps **needed to be adjusted for its size**. Longer runways and larger assembly halls had to be built, as described in 4.6, but also the way the different sections of the aircraft were brought to the final assembly site in Toulouse had to be adjusted. Some sections did not fit into the Airbus Beluga, so that a route via roads through France had to be established. Furthermore, due to the scale of this project**, financial aid** was offered from European governments, but for reasons explained in 4.3, sales of the A380 fell short of expectations, so that credits were not paid back to the government (taxpayer) by the organization. All these measurements to build the largest aircraft have had social impacts, which would not necessarily occur by building a medium-range aircraft and using already existing infrastructure.

As it could be already noticed with the A380, the percentage of CFRP used as material to build an aircraft has increased significantly in recent years. This reduces the quantity of aluminum so that possible negative impacts during raw material extraction could be reduced.

6.2 General Framework for S-LCA of Aircraft

In this subchapter, a framework is established to guide future S-LCA research regarding an aircraft. The present case study is used as a reference complemented with necessary steps along the assessment, which could not be performed for the S-LCA of an A380 due to time and resource limitations.

Every S-LCA should be done according to **ISO 14040/14044**. First, the goal and scope are defined, in which system boundaries, the life-cycle stages included in the assessment, and if possible, the functional unit are determined. Preferably the whole life cycle is being assessed, which include all stages from raw material extraction, component manufacturing, the transport to the assembly sites, as well as the use phase including airport procedures, such as refueling or maintenance and finally end-of-life scenarios (see Figure 6.1). Depending on the scope of the study, life cycle stages may be neglected. Furthermore, stakeholders proposed by the *Guidelines* may be **complemented by others**, such as passengers, aircraft manufacturers, airlines, airport operators, political decision-makers, aviation authorities, investors, NGOs, or future generations.

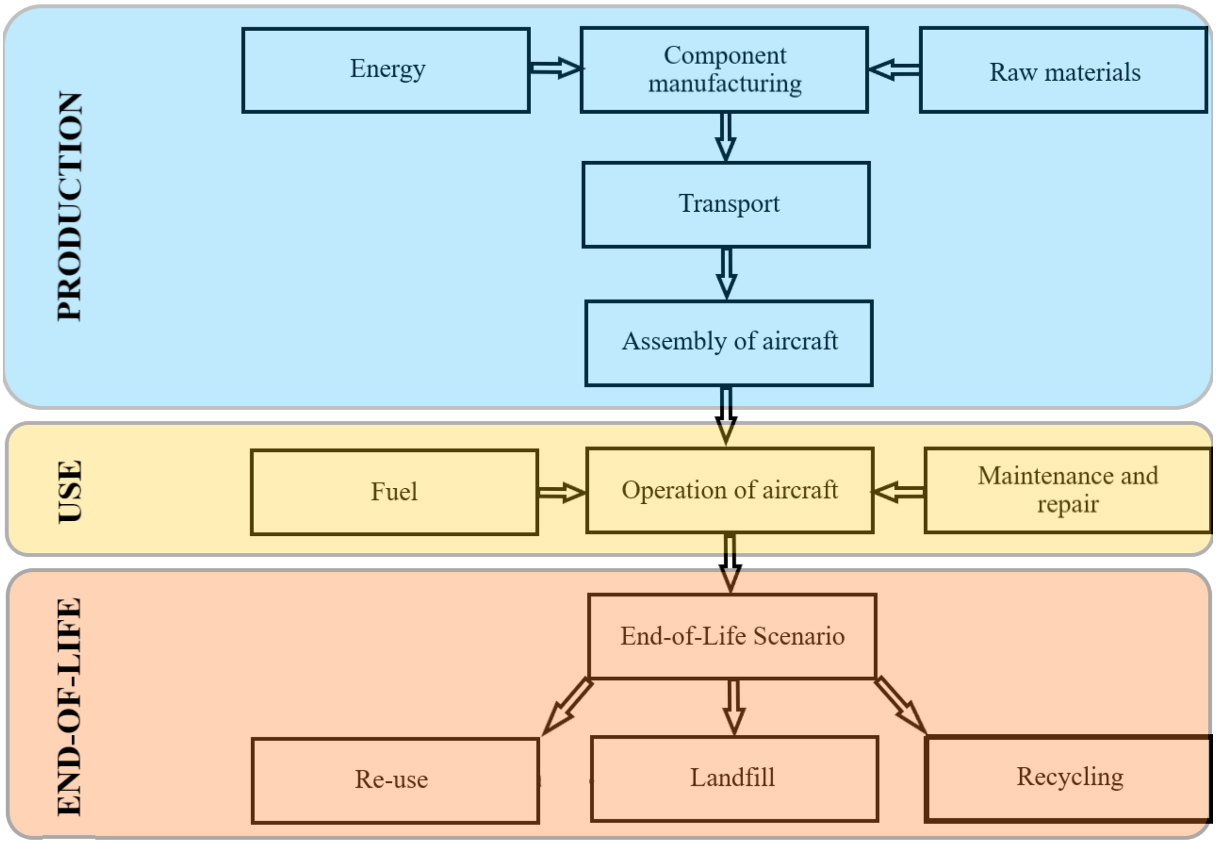

Figure 6.1 Life-cycle stages of an aircraft

The second step is the data collection. Generic as well as site-specific data should be provided. Generic data help to assess the whole supply chain, where primary data are missing and thus identify possible social hotspots along the supply chain. To obtain data, especially for the aeronautical industry with very complex supply chains, the **use of a SHDB** would be of great advantage, which was not possible in the present study. Furthermore, site-specific data needs to be collected, since it provides information about true social impacts at company level. Gathering site-specific data can be achieved by **performing interviews** with stakeholder members or webs searches. Since aeronautical companies usually do not divide their workforce per aircraft type, inventory data for the subcategory workers might not be directly related to the specific product but provide general information about the company's behavior towards its workers. However, local community members and society at large, as well as passengers might be directly affected because of a specific type of aircraft design. Thus, a focus should lie on **possible health impacts** due to local air pollution produced by engine emissions, noise levels, cabin air quality, and overall climate impact, but also the level of **comfort** is a relevant topic for passengers. By assessing these aspects, it is possible for decision-makers to recognize **improvement potential** already at **aircraft design level**.

Furthermore, it should be analyzed, if new **infrastructure** needed to be developed to manufacture an aircraft and if this infrastructure has impacts on local communities. Questions need to be addressed, if expropriation, real estate value changes, or other social issues occurred because of the plant.

Another crucial topic is contribution to economic growth. Does the product increases prosperity and employs local community members?

As pointed out before, there is no recommendation made by the *Guidelines* concerning the impact assessment. The collected specific data should be **aggregated and quantified**, so that an objective evaluation can take place in the end.

7 Summary and Conclusions

Although social impacts along the life cycle of a product have been rather neglected in the past, a rethinking in society and companies has taken place recently. For this reason, systematic and scientific methods to assess a product's social impacts along its life cycle have been developed, though these Social Life Cycle Assessments still lack standardized methodology. Besides, organizations start to establish concepts to assess their product's social impacts.

While conducting a systematic literature review, the **lack of research** on S-LCA of aircraft became evident. Following these research needs, an S-LCA of aircraft was conducted with the Airbus A380 as example and based on the framework provided by the United Nations Life-Cycle Initiative. The proposed stakeholders and subcategories by the framework were **complemented by aerospace-specific stakeholders and subcategories**. Data was collected by extensive web searches and interviews with stakeholder. By applying the subcategory assessment method, the collected data was evaluated. The results of this assessment were used to provide a general concept for assessing social aspects of an aircraft in a life-cycle approach.

It could be shown that an aircraft is a product with multiple and diverse impacts on the life of different stakeholders. While the function of an aircraft has a significant influence on human quality of life by providing **mobility**, the development can also have positive impacts on society by providing economic growth and **employment** in a high-tech industry. Large organizations, especially the ones located in Europe, often provide **secure jobs** with social benefits, where worker rights are respected and commitments towards sustainability are part of the company's policy.

Nonetheless, the production poses **risks of human rights violations** along the supply chain. The investigated organization is located on top of the supply chain as OEM, the influence it has on its suppliers weakens further downstream of the supply chain. Although the organization has implemented requirements for its suppliers regarding human and worker rights and is committed to sustainability issues, the complexity of the supply chain as well as the main materials for an aircraft increase the possibility of social hotspots, especially during raw material extraction.

There can also be a **discrepancy** between best practice policies established by the company and real social impacts. While conducting this study, it became evident that, although the organization follows national law and international standards as well as implementing best practice policies, its behavior can still negatively impact some stakeholders, in this case the local community. Specifically, the interference of another stakeholder of the assessed product - the state or political decision-makers - produced the negative impact by poor communication and ignoring concerns of local community members. Thus, it can be said that the complex relationship between the state and the organization can pose a risk to other stakeholders that their concerns regarding the product are neglected by political-decision makers.

8 Recommendations

While conducting the S-LCA of the A380, several challenges and limitations occurred. An S-LCA is based on **sufficient data**, both primary and generic. However, without a SHDB, the collection of generic data was rather insufficient. This poses an even greater problem since the company sourced out around 80 % of the investigated product to suppliers. No information from suppliers could be obtained.

Furthermore, the impact assessment posed a challenge since the collected data partly consisted of highly subjective experiences and opinions by the interviewed stakeholders. While applying SAM, the overall score of the company was very high, because it could not assess social impacts such as mental health problems due to social pressure, losing a home (although considered voluntarily), or the mistrust in politicians due to the conflict. Generally, the **lack of quantitative data** makes it difficult to assess the product, and thus to link social indicators to a functional unit. Furthermore, the SAM could not be applied for the additional subcategories since no basic requirements could be proposed.

Another difficulty of assessing an aircraft is the **long lifespan** of up to 40 years. For the A380, which is only 15 years in service, the end-of-life phase could not be sufficiently investigated, since only a few A380 are already out of service. Furthermore, relevant social topics and the overall social context can change over the course of 40 years, thus makes it more difficult to evaluate an aircraft.

Due to time limitations, some subcategories and stakeholders have been neglected, although usually every subcategory should be assessed according to the *Guidelines*. Also, the number of conducted interviews was limited.

Nonetheless, this study can be used as a **guide** and basis for further research in the field of S-LCA of an aircraft to set aside the above-mentioned limitations.

Because of above mentioned limitations, the focus on future research should lie on the **access to good data sources**, both generic and site-specific. The involvement of the investigated organization could help to not only bring another view of a stakeholder into the study, but also receive further data concerning the supply chain. Furthermore, a standardization of social indicators and the improvements of impact assessments should be in the focus of further research.

The present study shows that an S-LCA can be applied for the social evaluation of aircraft but due to the complexity of the product, is very time consuming and in the present situation still limited by data availability. Nonetheless, it can help decision-makers to further improve their product already at aircraft design level, for example by evaluating different engines regarding their noise and air pollution level, or by improving comfort in the cabin. In terms of **image and integrity**, a socially responsible company can increase its value concerning its customers and its value chain.

By applying an S-LCA of an aircraft, all **three pillars of sustainability** can be now assessed regarding the aerospace industry and further improve the product for its customers, shareholder, the environment, and society at large.

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Appendix A – Questionnaire for Local Community Members

Table A Interviews local community members questions and answers

How many people were affected by the plant extension?	
Interviewee 1	Many people, quite a lot had to sell their houses
Interviewee 2	In Rosengarten (the interviewees were one of them) and Hasselwerder Straße people needed to sell their houses, 62 units in Hasselwerder Straße
Interviewee 3	Already in 2000, the city started negotiating with people from Hasselwerder Straße for selling their houses, almost all houses in this street were affected
Interviewee 4	People not only in Neuenfelde but also in Nienstedten
Interviewee 5	A lot of community members, people had to sell their houses, around 200, but also other people who sued and paid a lot of money for lawyers
Interviewee 6	Many people affected, not only the ones who had to sell their houses, but also whole community (it came to conflict within families and the community, pressure from media)
Interviewee 7	Interviewee is from north shore of Elbe, people affected there by the view and noise of plant extension, while people from Neuenfelde were affected significantly more by selling of their houses and immense pressure by press and politicians
Did the city or the organization offered compensation?	
Interviewee 1	Yes, they bought the houses
Interviewee 2	Yes, the city offered money and guaranteed to fulfil 19 demands of farmer Quast
Interviewee 3	Yes, the city offered money, but no property available in Neuenfelde, so that they had to leave their home village
Interviewee 4	Yes, they offered money
Interviewee 5	Yes, they offered money
Interviewee 6	Yes, they offered money
Interviewee 7	Yes, they offered money
Was the compensation sufficient?	
Interviewee 1	Compensation money would have convinced everybody, it took the city 15 years to re-rent houses in Hasselwerder Straße
Interviewee 2	The offered price was very good, but there was no help at all from the city to find new property in Neuenfelde and the building authority made problems after they had found a property in Neuenfelde; not all compensation areas for Mühlenberger Loch were established; they could negotiate to live one more year rent-free in their old house
Interviewee 3	First, it was not enough for them to sell, but after some negotiations the offered prize was sufficient
Interviewee 4	Yes, sufficient prizes were paid
Interviewee 5	Yes, city paid good prizes, but the psychological pressure was enormous, which no money would have compensated
Interviewee 6	The city paid a good price for the houses, some negotiated to push up the prizes
Interviewee 7	Yes, sufficient prizes were paid
How many meetings between representatives of the city and Airbus with members of the community occurred?	
Interviewee 1	Planning permission resolution announcement in public, one meeting with Ole von Beust

Interviewee 2	Not many, the planning permission announcement and public hearings, and the meeting with Ole von Beust
Interviewee 3	Interest representatives negotiated with the city for the compensations, not them directly, afterwards no meetings anymore with people who had sold already their houses
Interviewee 4	Informational meetings about planning resolutions, but very little communication
Interviewee 5	Informational meetings for local communities organized by Airbus and meetings with worker council members, meeting with mayor very late
Interviewee 6	Not many meetings, with the mayor only one meeting, but some smaller discussions between public authority members, Airbus workers and local community members
Interviewee 7	Airbus with an economic interest mostly negotiated with the city of Hamburg
How was the quality of the communication between the representatives of the city and Airbus?	
Interviewee 1	Poor level of information, feeling of enforced conformity of the local press by politicians, doubt in democracy, misinformation by local politicians, when local community members wanted to discuss technical issues, one leading politician forbade his experts to talk freely; Airbus communicated mostly with the city, interviewee criticism of missing communication by the city, not with Airbus
Interviewee 2	Politician faced community members with a fait accompli; no communication; feeling of betrayal by the city; hearings were perceived as just a farce because not any of the arguments by the local community were heard; Airbus as a company with economic interests communicated with city mostly, no bad feelings towards Airbus
Interviewee 3	No direct contact with representatives of the city, thus no comment
Interviewee 4	Poorly, doubt in democracy; without notice city and Airbus planned to remove the main dike
Interviewee 5	Senate tried to split communities (communities of the northern shore against the southern shore of the Elbe / environmentalists against farmers), also by instrumenting the media; without notice they tried to remove the dike; senate started with removals of dike and houses before the court made a clear decision; vacancy of Hasselwerder Straße used as blackmailing by the city to stop lawsuits
Interviewee 6	Poorly, local community members felt that they were not heard by the politicians; communication with Airbus described as “normal”
Interviewee 7	Misinformation and exaggeration regarding possible job creation by the city; politicians with own interests for prestige pushed the plant extension through; experts, who assessed possible job creation for the city stood in relation with some politicians (biased); Airbus economic interests valid, and communication mainly between senate representatives and Airbus, no bad feelings towards Airbus, main “enemy” was the senate
Have there been any community engagement activities by the organization?	
Interviewee 1	More positive development in recent years, donation by Airbus for community center
Interviewee 2	Donations for kindergarten, school, and local sports club
Interviewee 3	No knowledge about this topic
Interviewee 4	Ventilation system sponsored
Interviewee 5	No knowledge about any engagement activities
Interviewee 6	Some donations, does not really know
Interviewee 7	No knowledge about any engagement activities, but Airbus tried to make halls for

	A380 as unobtrusive as possible as a compromise for the people in Nienstedten
Was there any damage to the cultural heritage by the plant extension?	
Interviewee 1	Church is in approach corridor, there were plans to resettle church; traditional farmhouses were destroyed;
Interviewee 2	Community in Nienstedten lost their view on nature, beautiful old houses in Rosengarten were removed; the ring dike on their old property was part of the European hiking trail
Interviewee 3	Ghost town in Hasselwerder Straße due to vacancies, otherwise no knowledge about that
Interviewee 4	One of the oldest and one of the last ring dykes of this area built by the Saxons was destroyed; city let beautiful old houses in Hasselwerder Straße deteriorate and traditional houses in Rosengarten were removed; destruction of 700-year-old cultural landscape
Interviewee 5	Ring dike and a lot of fruit trees were removed
Interviewee 6	Many fruit trees had to be removed
Interviewee 7	Traditional farmhouses and some fruit orchards were removed
Have there been measures to protect the cultural heritage by representatives of the city and Airbus?	
Interviewee 1	Securing of roof tiles of church
Interviewee 2	New fruit orchards for farmers as compensation
Interviewee 3	No knowledge about this topic
Interviewee 4	No knowledge about any protective measures
Interviewee 5	No knowledge about any protective measures
Interviewee 6	Compensation areas for farmers and their fruit trees
Interviewee 7	No knowledge about any protective measures
Are local community members preferred by the organization when it comes to new employments?	
Interviewee 1	A lot of people in surrounding areas work at Airbus
Interviewee 2	They personally know a lot of people working at Airbus and started working at Airbus when the A380 was produced, but more in Lower Saxony than in Neuenfelde
Interviewee 3	Airbus has both local workers as well as guest workers
Interviewee 4	Not so many Airbus workers in Neuenfelde but in the surrounding areas yes, mainly in Lower Saxony
Interviewee 5	Airbus is important in the area as employer, but no knowledge about how many new jobs were created by the A380, the old planning resolution from 2000 claimed that 4700 new jobs were created but, in a footnote, it was noted that existing capacities should be fully used before employing new workers
Interviewee 6	Airbus is an important employer in the area, knows family members and friends working at Airbus
Interviewee 7	Interviewee does not think the A380 created as many jobs as it was proclaimed by the senate, however Airbus important employer in the area, “everyone knows someone working at Airbus”
Does the organization affect employment in an indirect or induced way? (Renting of rooms for guest workers)	
Interviewee 1	Neuenfelde with many traditional large farmhouses is known for hosting guest workers, but not only for Airbus workers but also for workers from the port
Interviewee 2	Farmers renting rooms for guest workers; many smaller companies were founded on Rüsch-peninsula due to the extension of Airbus plant in Finkenwerder

Interviewee 3	No knowledge about that topic
Interviewee 4	A lot of guest workers from France
Interviewee 5	Farmers rent some rooms for all kind of guest workers, mostly for workers from the port but also from Airbus (e.g., workers from France)
Interviewee 6	A lot of suppliers for Airbus have settled in Finkenwerder and local farmers profit from guest workers
Interviewee 7	Many suppliers in Hamburg
Did the noise and air pollution increase due to the production of the A380?	
Interviewee 1	A380 not the problem when it comes to noise, single-aisle aircraft types louder
Interviewee 2	More noises due to increase of flight movement since the 90s, not because of the A380; kerosine residues in their garden, filed complaints about level of noise when they still live in Rosengarten
Interviewee 3	Since the interviewee does not live anymore in Neuenfelde, there was no comment on that
Interviewee 4	Smell of kerosine already strong before A380 was built
Interviewee 5	Increase of flight movements already before the plant extensions
Interviewee 6	In comparison to single-aisle aircraft movements, only few flights of the A380
Interviewee 7	Since the production rate of the A380 was not high, the noise and air pollution did not increase significantly. Noise emission was not one of the interviewee's concerns
Have there been any negative health and safety impacts on the local community due to the A380?	
Interviewee 1	Many people got sick because of the loss of their home; wake turbulences caused sunshades to fly around, which endangered people or roof tiles to fall; planned removal of main dike by city and Airbus, which caused fear for floods
Interviewee 2	Pressure from both community members to not sell their house and from politicians and press to sell the house and loss of family home and neighborhood led to mental health problems, such as depression and insomnia; kerosine residue known to cause cancer
Interviewee 3	Traumatic for parents, who had lived in Neuenfelde over 70 years,
Interviewee 4	Traumatic events to lose home and split of social fabrics due to conflicts within the community
Interviewee 5	Some people got death threats, and constant pressure by the media, which was very traumatic
Interviewee 6	Wake turbulences caused few incidents
Interviewee 7	There were concern about increased risks of floods, but interviewee could not comment if this concern has proven right or wrong; interviewee named it "psychological pressure", a lot of people suffered from mental health issues due to this enormous pressure
Have there been measures to protect the local community from negative health or safety effects?	
Interviewee 1	Airbus fixed roofs with loose tiles immediately
Interviewee 2	U-shaped wall around Airbus plant offers some protection against noise and air pollutions; no support from the city for protection against black residues due to the aircraft; city installed insulation and ventilation systems in houses lying in the approach corridor
Interviewee 3	No knowledge about that topic
Interviewee 4	Sponsored insulated glasses and ventilation systems
Interviewee 5	No knowledge about that topic

Interviewee 6	If incidents happened, for example falling roof tiles, Airbus fixed it immediately, otherwise the city was doing measurements of noise pollution and since there were no exceeding of the noise level limit, no further steps were taken
Interviewee 7	Measures are taken regularly by city and Airbus to evaluate noise and local air pollutions
Could a loss in value of real estate be observed after the introduction of the A380 and the runway extension?	
Interviewee 1	Yes, personally affected; lowest rent index in Hamburg
Interviewee 2	Probably yes
Interviewee 3	No knowledge about this topic
Interviewee 4	Sold their property and recognized a loss of value of 30 %, because of the runway and the vacancy of the
Interviewee 5	The interviewee knew about concerns of local community members but does not know exactly how the situation is. Interviewee know of one family who sued the city because of the loss of property value
Interviewee 6	The interviewee heard about that but no clear information
Interviewee 7	It was one of the main concerns of the community living in Nienstedten, but interviewee does not think that the loss in value of real estates has been a problem in this area
If yes, were there compensations offered?	
Interviewee 1	No
Interviewee 2	No
Interviewee 3	No knowledge about this topic
Interviewee 4	No
Interviewee 5	The lawsuit against the city is still pending, Interviewee has no further information about this topic
Interviewee 6	No knowledge about this topic
Interviewee 7	No knowledge about this topic

Appendix B – 1. Questionnaire for Worker

Table B Interview worker 1 questions and answers

Are the labor unions included in decision-making processes?	
Interviewee 1	strong position of IG Metall, they are included in decision-making processes. Labor unions very well organized and collaboration between employer and labor unions is good
Does the organization support labor unions by providing rooms etc.?	
Interviewee 1	Yes, Airbus is supportive towards labor unions and work council
Can the labor unions influence salaries, working hours and holidays?	
Interviewee 1	The labor unions determine the salaries, working hours and holidays by collective bargaining and with the organization
Is the salary paid by the organization sufficient?	
Interviewee 1	Yes, the salary is sufficient. In addition, there are bonuses
How often the organization requires from the workers to work extra hours?	
Interviewee 1	In his department only when there were upcoming deadlines for projects and only voluntarily. Normally, there were no extra hours to do
Does the organization offer compensation for extra hours?	
Interviewee 1	Yes, normally the employee can negotiate whether the additional work either gives rise to time off in lieu or to compensation
Does the organization offer flexibility when it comes to working hours and home-office?	
Interviewee 1	In the interviewee's department, working hours could be shaped very flexible
Does the organization comply with safety measures?	
Interviewee 1	Yes, it follows all rules regarding safety measures
Does the organization offer training and further education?	
Interviewee 1	Workers who change their working place are offered a training period, further education
How is the corporate culture?	
Interviewee 1	Interviewee perceived it as very good, social events are organized as team boosters, interesting work, and Airbus good employer
Are there social benefits offered by the organization?	
Interviewee 1	Yes, bonus payment, Christmas bonus, discounts

Appendix C – 2. Questionnaire for Worker

Table C Interview worker 2 questions and answers

How was the international communication within Airbus	
Interviewee 2	The communication was good, the sites in the different countries have specific competencies. Only by work sharing a product such as the A380 was possible. The communication was business like.
Have there been conflicts due to cultural differences?	
Interviewee 2	There have been usual discussions but nothing specific due to cultural differences
Have there been benefits due to different cultural perspectives?	
Interviewee 2	Yes, workers from different countries brought different views into discussions
Have there been new technological advances with the A380? (patents)	
Interviewee 2	Many patents have been filed in the development phase of the A380. Some patents have been sold and man innovations were adopted in other projects.
In your opinion, was the A380 a success or failure?	
Interviewee 2	The A380 was a success in the way that many new innovations were developed and made profit of by selling patents and by applying them to other projects.