UTRECHT UNIVERSITY

Contribution of Single European Sky to efficient air transport

Master Thesis

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Preface

This report is the result of my research during the last six months of the Master Sustainable Development at the Utrecht University. Moreover, it is also the end result of my internship at Ecorys within the department of Transport & Mobility.

Hereby I would like to thank Wina Graus, Assistant Professor at Utrecht University, for the supervision during my research. I am thankful for the time and effort she put in my research during the past months. The interim meetings were of importance for the progress of the research, because it helped me to stay on track and improve the quality of the final report.

I would also like to express my gratitude to the consulting company Ecorys, where I did my internship, and especially Robert Piers who supervised my research at Ecorys. It has been a great opportunity to work within a company and be part of the project team. During the past months at Ecorys, I have learned a lot about project work, the transport sector, the company and about myself. This is made possible by the support, confidence and guidance Robert gave me during the project and research. Thank you Robert for the interim meetings, the brainstorm sessions and for letting me be part of the project team, which have been of added value for my research.

The things I have learned during the research and internship can give me direction on challenges in the future.

Caroline Moes

Soest, June 2013

Executive summary

With an average air traffic growth of 2.8% per year in Europe, the aviation sector is growing rapidly. Currently there are about 9.8 million flights per year in Europe and the projection is that this will increase to about 16.9 million flights in 2030. This growth leads to increased fuel burn and increased greenhouse gas emissions, where carbon dioxide (CO_2) emissions emit by far the most (99.3%) of all greenhouse gasses. CO_2 emissions from aviation are responsible for 3.5% of the total CO_2 emissions in Europe, with the expectation that this share will increase to 7-12% in 2050.

In order to cope with the increasing CO_2 emissions and to make aviation more sustainable, the Single European Sky (SES) is introduced in 2000. The purpose of this study is to investigate how current air transport and air traffic management in Europe performs and what contribution Single European Sky can have in lowering the environmental impact. Therefore the research question is:

What is the performance of current air transport in Europe and how can Single European Sky contribute to more efficient and sustainable air transport, in terms of reducing delay and greenhouse gas emissions?

Through the increased pressure that is put on the capacity of airspace and the use of airspace, there is also more pressure for the air traffic management (ATM) and air traffic controllers. This causes ATM inefficiencies, due to the 38 air navigation service providers (ANSPs) in Europe which operate within their national boundaries and all have their own operations and characteristics, combined with the lack of communication between the ANSPs and the lack of a common and up-to-date ATM system. Moreover, the European airspace is fragmented, because 70% of all flights in Europe are concentrated into 14% of the available airspace.

In 2011 18% of all flights in Europe were delayed by more than 15 minutes, of which the total delay due to air traffic flow management (ATFM) constraints amounted 17.9 million minutes. 47% of this delay is en-route ATFM delay, equivalent to 8.4 million minutes. An important remark is that 17 out of the 67 area control centers are responsible for 90% of the total en-route ATFM delay. Inefficiencies in ATM cause about 7-11% additional fuel burn. Through comparing this performance to the performance of the US, with one single air navigation service provider, it can be concluded that performance in Europe is not optimal and a lot can be improved.

Therefore the Single European Sky initiative is introduced, with the objective to achieve ‘more sustainable and performing aviation’ through improving ATM efficiency. It is hereby the idea to operate within a single sky in Europe with common rules, standards, procedures and air traffic management systems. The European Commission has set the following goals in 2005 to be met by 2020 with full implementation of SES:

- Safety improvement by a factor of ten

- Tripling airspace capacity
- Reducing costs of air traffic management by 50%
- Lowering the environmental impact of aviation by 10%

This research focuses on the environmental goal and examines whether this goal can be achieved. The initiatives within SES that aim at lowering the environmental impact are:

- Performance Scheme
- Functional Airspace Blocks
- Network Manager
- Charging Regulation
- Single European Sky ATM Research

Lowering the environmental impact of air transport is essential, because it is seen that there has been rapid growth in CO_2 emissions over the past years, both for civil and international aviation. The total CO_2 emissions from aviation increased from 83 Tg CO_2 in 1990 to 149 Tg CO_2 in 2010. In order to determine the environmental impact of SES, two scenarios are developed in this research. Firstly, a baseline scenario without the implementation of SES and secondly a ‘desired’ future scenario with full implementation of SES, because this research reasons from the fact that implementing SES is desirable. Within these scenarios, the development of CO_2 emissions over the period 2000 to 2030 is assessed. In the baseline scenario it is expected that CO_2 emissions increase from 135 Tg CO_2 in 2000 to 218 Tg CO_2 in 2030 in Europe.

The idea of SES is to improve performance, improve efficiency, reduce route extension and reduce delays. This will lead to increased capacity, less fragmentation and less cross-border inefficiencies, which is beneficial for the environment since this results in a reduction in fuel burn and CO_2 emissions. For the desired future scenario, the possible improvements due to SES and the initiatives are determined. This is done through literature study and through comparing the performance with the US in terms of what can be improved.

For the period 2000 to 2012 there have been no or small environmental benefits due to SES, which leads to no sufficient impact in this period. For the period 2013 to 2030 significant environmental benefits are expected. The projection is that there will be an overall emission reduction in air transport of about 14.5 Tg CO_2 in 2020 and a reduction of about 18.7 Tg CO_2 in 2030. In the desired future scenario CO_2 emissions increase from 135 Tg CO_2 in 2000 to 199 Tg CO_2 in 2030 in Europe, which is lower than for the baseline scenario. The environmental impact of SES will thereby be 7.55% CO_2 reduction in 2020 and 8.56% CO_2 reduction in 2030, compared to the baseline scenario.

This means that Single European Sky will definitely contribute in lowering the environmental impact of air transport. However, the environmental target of 10% emission reduction from 2005 to 2020 will not be reached. This is due to the fact that implementation and operations are lacking behind and that it takes time to adapt the air traffic management system, whereby environmental benefits are expected on the long term.

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List of abbreviations

ACC	Area Control Centre
ACE	Air Traffic Management Cost-Effectiveness
ANS	Air Navigation Service
ANSP	Air Navigation Services Provider
ASMA	Arrival Sequencing and Metering Area
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Service
CANSO	Civil Air Navigation Services Organisation
CNS	Communications, Navigation, Surveillance
CO_2	Carbon dioxide
CRCO	EUROCONTROL Central Route Charges Office
EASA	European Aviation Safety Agency
EC	European Commission
ESSIP	European Single Sky Implementation Plan
EDCT	Expect Departure Clearance Times
EU	European Union
EU ETS	Emissions Trading Scheme
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration of the U.S.
FAB	Functional Airspace Block
FUA	Flexible Use of Airspace
GDP	Gross Domestic Product
IFR	Instrument Flight Rules
KPA	Key Performance Area
KPI	Key Performance Indicator
LSSIP	Local Single Sky Implementation Plan
PRR	Performance Review Report
PRU	Performance Review Unit
R&D	Research & Development
RTK	Revenue Tonne Kilometres
SES	Single European Sky (EU)
SESAR	Single European Sky ATM Research Programme

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1 Introduction

1.1 Background and problem definition

The aviation sector is growing rapidly, with an air traffic growth of 3.1% for the year 2011 in Europe. There are about 9.8 million flights in total in 2011 in Europe (Eurocontrol, 2012a, p.8). The expectation is that air traffic will grow on average with 2.8% per year, with the forecast for 2018 to have 11.1 million flights (Eurocontrol, 2012b, p.9). This growth is having environmental, economical and social consequences, both positive and negative. Through increased air transport there are economic benefits, but there is also increased fuel burn that cause increased greenhouse gas emissions. If the current trend continues, it is expected that carbon dioxide (CO_2) emissions from aviation become three times higher between 2000 and 2050 (Macintosh & Wallace, 2008, p.264). Models of global warming determined the contribution of aviation emissions about 3.5% of the total, with the expectation that this share will increase to about 7-12% in 2050 (Pham et al., 2010, p.1738).

Carbon dioxide emissions of a flight are depended on different factors, such as travel distance, weather conditions (wind direction), cargo load, passenger load and flight altitude (Jardine, 2005, p.2). Moreover, emissions at altitude are more damaging, because it can incite chemical and physical processes which have climate change consequences (Jardine, 2005, p.2). This implies that air transport is becoming a bigger player in contributing to global warming and climate change, which makes air transport not a sustainable mode of transport as it is now.

Through the growth of the aviation sector, more pressure is put on the capacity of airspace and the use of airspace. Air navigation service providers (ANSPs), the air traffic managers of the aviation sector, need to deal with the growing demand and they need to deliver increased capacity (Holt et al., 2006, p. 251). However, in Europe 18% of all flights were delayed by more than 15 minutes over the year 2011, with a total Air Traffic Flow Management (ATFM) delay of 17.9M minutes (Eurocontrol, 2012a, p.8). This has to do with inefficient use of airspace by the 38 different air navigation service providers for Europe. When looking at the US it is seen that the performance of air traffic management there is better with one single air navigation service provider (Eurocontrol & FAA, 2012).

In order to deal with the delays and inefficiencies in the European airspace, the Single European Sky (SES) initiative is introduced in 2000 by the European Commission with the objective to achieve ‘more sustainable and performing aviation’. The European Union will coordinate the design, management and regulation of airspace in Europe. Improving the overall efficiency of the way the European airspace is organized and managed and improving the overall performance of air traffic management (ATM) and air navigation services (ANS) in Europe is the goal of Single European Sky (SESAR, 2012, p.11). In 2005 the European Commission set the following goals to be met by 2020 with full implementation of SES:

- Safety improvement by a factor of ten

- Tripling air space capacity
- Reduction of cost of air traffic management by 50%
- Lowering the environmental impact of aviation by 10% (European Commission, 2012, p.1).

Lowering the environmental impact is the most important issue of this research and that is where the focus of this research is. The environmental goal is to enable a 10% reduction in the effects flights have on the environment from 2005 to 2020, which means an emission reduction of 10% compared to the baseline scenario. Due to ANSPs that differ in altitude and direction preferences of an airplane, there are cross-border inefficiencies which lead to fragmentation of the European airspace. There is a lot time lost in these inefficiencies which lead to delays, also known as cross-border congestion. This en-route air traffic management delay has its reflection on the delays and situation on the ground and on the departing flights. Diminishing these inefficiencies evolves in less (cross-border) congestion, less delay, less fuel burn, less energy use and fewer costs. This is beneficial for the environment, because less fuel burn brings fewer emissions. The implementation of SES and the division of the airspace in Europe in ‘functional airspace blocks’ (FABs) can have a contribution here, because it brings more efficient use of the available airspace. Therefore SES can contribute in aviation becoming more sustainable and having a lower impact on climate change (SESAR, 2010, p.17).

In order to improve current ATM with the implementation of Single European Sky (SES), several initiatives are introduced. These initiatives were first introduced in the policy package SES I in 2004. In 2009 additional regulations and initiatives were implemented by the SES II package. In order to strengthen the SES initiative, especially the Single European Sky ATM Research (SESAR) Programme is of importance, where a new generation air traffic management system and advanced technologies is developed (SESAR, 2010, p.9). This research focuses on the current performance of air transport in Europe and how Single European Sky can contribute in improving the performance, especially the environmental performance. The development in CO_2 emissions are thereby determined for scenarios with and without the implementation of SES, through which the environmental impact of SES can be assessed.

1.2 Research question and sub questions

The research question of this research is:
What is the performance of current air transport in Europe and how can Single European Sky contribute to more efficient and sustainable air transport, in terms of reducing delay and greenhouse gas emissions?

This research question is divided in the following sub questions:

- How is current air transport and air traffic management organized in Europe?
- What is the current performance of air transport and air traffic management in Europe?
- What are the air traffic management inefficiencies and cross-border delay/congestion where Single European Sky could have an effect on?

- How does European air transport and air traffic management perform in comparison to the US?
- What is the environmental impact of current air transport?
- How will the airspace and air traffic management in Europe be organized with full implementation of Single European Sky?
- What initiatives of Single European Sky focus on a reduced environmental impact?
- What contribution to reducing the environmental impact of air transport will Single European Sky have with the key initiatives?

The performance of air transport and air traffic management will be based on the indicators safety, capacity/delay, environment/flight efficiency, fuel burn, emissions and cost-efficiency.

1.3 Set-up of report

The report is made up in chapters that reflect upon the sub questions. First, the theoretical and methodological framework will be addressed that is used to build up the chapters and the scope of the research will be defined here. For introducing the air transport and air traffic management in Europe, an overview of the current organization is given in chapter three. The performance of the air transport sector is given in chapter four, with a special focus on congestion and delays, which can be used for answering the questions regarding cross-border delay/congestion. In order to reflect upon the performance of Europe, there will be a comparison in chapter five with the US and something will be said about the cost-efficiency of air transport in Canada and New Zealand in chapter five. The environmental impact of current air transport is assessed in chapter six. Chapter seven elaborates on the concept of Single European Sky and the key initiatives with regard to the environment. The environmental impact of full implementation of Single European Sky (with the key initiatives) is given in chapter eight, through looking at the baseline and ‘desired’ future scenario, with special focus on (reduced) fuel burn and emissions per initiative. Points of discussion are elaborated in chapter nine and the study ends with answering the research question in chapter ten. A reference list and appendices are added in the end.

2 Theoretical & methodological framework

2.1 Aim of research

This research has the aim to investigate the implementation of a different structure of air traffic management, a single sky, that is introduced under the name Single European Sky (SES). The European Commission states that SES will contribute to sustainable development in a way that it brings improved safety, greater reliability of services, more direct flights, civil-military coordination, lower charges to airspace users and lower fares to passengers and freight users (European Commission, 2012). The focus of this research is on the environmental impact of SES and what effects the implementation of SES will have on flight time, delay, congestion, efficiency, fuel burn and emissions.

Through SES there will be a shift in airspace management from dominating national boundaries to so called 'Functional Airspace Blocks' (FABs), where Eurocontrol will be a central player. Optimized flight patterns mitigate current inefficiencies and will lead to improved safety, efficiency and capacity. The main purpose of this research is to determine the relation of the implementation of SES to delay/congestion and CO_2 emissions and to assess the contribution of SES to more efficient air transport. More efficient air transport leads to a lower contribution of air transport to climate change and global warming. It is essential to mitigate this contribution, reduce greenhouse gas emissions and become more sustainable.

2.2 Scope research

Determining the scope of the research is of importance for good understanding of the research and for collecting the necessary data. The effects of SES are being examined for Europe, because the single sky will be implemented in the European airspace. The environmental impact of air transport in Europe will be determined, with special focus on delays, (cross-border) congestion, air traffic management inefficiencies and greenhouse gas emissions. Therefore, an evaluation of the current situation (baseline scenario) and an evaluation of the 'desired' future scenario with full SES implementation is needed. The baseline scenario contains the development in emissions with no influence of SES. The impact of SES is assessed in the 'desired' future scenario, because the objective of this research is that SES will be implemented in the future and therefore this is the desired situation. Those two scenarios are given for the period 2000 to 2030 in order to fully include the effects of SES. The deployment of Single European Sky ATM Research is essential and the success of SES is depending on this deployment.

This research focuses on the environmental impact and environmental efficiency, 'more efficient air transport' from the research question therefore refers to the environment and not to costs. Flight efficiency is hereby an important parameter, with regard to changes in direction and altitude. Social and financial aspects, such as the associated and mitigation costs, of SES are not of interest for this research and are thus given little attention. The implementation of other technologies and drastic changes in the aviation sector and air traffic management is disregarded in this study.

In order to determine the performance and efficiency of the European airspace, there is a comparison with the performance of the airspace of the US. In this way conclusions can be drawn with regard to the functionality of air navigation service providers, because Europe is currently having 38 different ANSPs and the US is having only 1 ANSPs. Eurocontrol and the Federal Aviation Administration of the U.S. Department of Aviation provided a comparison between Europe and the US for 2010 with regard to air traffic management, which is used for this research.

2.3 Concepts

This section provides a description of important concepts that are used within this study. The first is the term of ‘Air Navigation Service’, which are the services provided in order to ensure the safety, regularity and efficiency of air navigation and the appropriate functioning of the air navigation system. An ‘Air Navigation Service Provider’ (ANSP) provides these services and organizes the flow of traffic. ‘Air Traffic Management’ ensures the safe and efficient movement of aircrafts during all phases of operation through a system consisting of a ground part and an air part. The interactivity between the ground part and the air part is essential (Eurocontrol, 2012a).

The indicators that are used for examining the performance of air transport and air traffic management are operationalized in order to have a common understanding. The indicator safety is based on the number of total accidents with air traffic management contribution per year in Europe, both fatal and non-fatal accidents. The indicator capacity/delay is operationalized by the total delay in minutes per year. The indicator environment is based on the environmental impact, where environment is limited in this study to fuel burn and greenhouse gas emissions. Fuel burn is displayed by the total amount of jet fuel for Europe and the greenhouse gas emissions is displayed by the total amount of CO_2 emissions in Europe. For cost-efficiency the total air navigation costs is determined and also the average costs per composite flight-hour (in €). A composite flight-hour is the en-route flight hours plus IFR airport movements divided by a factor that reflects the relative importance of terminal and en-route costs in the cost base. The U.S. Dollars are converted to € using the currency of 1 U.S. Dollar = 0.7487 €. (Eurocontrol, 2012a, p.93).

An important topic in this study is (cross-border) delay/congestion in air transport. The focus of this study is congestion in the air, especially the en-route and cross-border congestion. This congestion is operationalized via delays, which is caused by cross-border inefficiencies due to different operations of air navigation service providers. This delay in the air has its reflection on the delay (and congestion) on the ground, because there are strict schemes and planning. This relation is addressed in this study, but there is no in-depth research on the last topic.

The EU States are the following 27 Member States: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and the

United Kingdom. The Single European Sky (SES) States are these 27 plus Norway and Switzerland, which is also where the focus of this research is. The term ‘Europe’ in assessing the environmental impact in this research reflects therefore the EU27+2 States.

The Eurocontrol Member States contain 39 States, which are Albania, Armenia, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Monaco, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, FYROM, Turkey, Ukraine and the United Kingdom. These Eurocontrol Member States are included in the Functional Airspace Blocks (FABs) and their performance is reflected in the Performance Review Report of air transport in Europe. An overview of the division is given in the figure below (Eurocontrol, 2012a). For the indicator cost-efficiency there is only data available for the EU27+2 States.

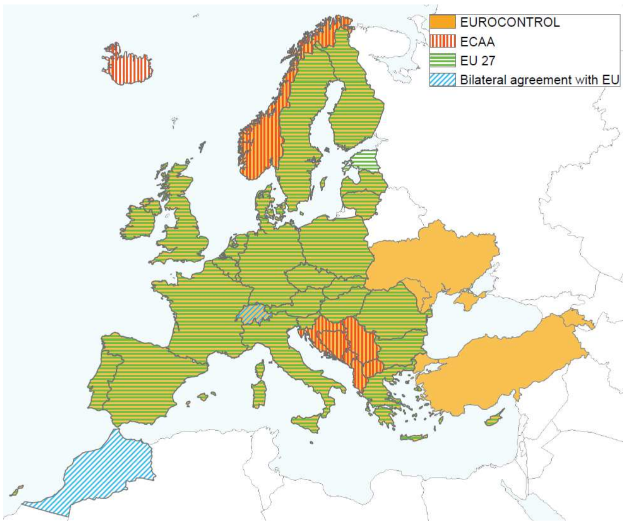


Figure 2.1: EU-27 and Eurocontrol Member States (Eurocontrol, 2012a)

2.4 SES and relation environment

The main focus of this research is what benefits full implementation of Single European Sky will have and especially on the environment, focusing on greenhouse gas emissions. Greenhouse gas emissions are assessed via carbon dioxide (CO_2) emissions, because they emit by far the most in air transport. The aim is to lower the environmental impact of aviation by 10% over the period 2005-2020 through the implementation of SES. The feasibility of this forecast is assessed in this study, with looking at the concepts and timeframe of determining the impact. The contribution of SES in aviation becoming more sustainable is an important topic, because through its sustainable contribution it would be likely to implement SES faster.

In order to determine the environmental impact, there is a close look into the fuel burn and greenhouse gas emissions over the period 2000 to 2030. The recent fuel burn and greenhouse gas emissions are compared to the desired future scenario, with full implementation of SES. The timeframe 2000-2030 is chosen in order to comprise the major impacts of SES, because in this period SES will develop and deploy further. Especially after 2020 major benefits are expected, because then SES and all its (environmental) initiatives are expected to be operational.

While determining the environmental impact, the amount of CO_2 emissions is given for the past and the future. This is done in grammes or tonnes, depending on the unit that is used in the specific source. One million tonne (Mt) is equivalent to one teragram (Tg), which are the most common units in this research.

2.5 Data collection

In order to investigate the effects of full implementation of Single European Sky on the environment and to answer the research question, a literature study has been done. In combination with an internship at Ecorys, these are the main sources of gathering input for this research. The literature study is based on scientific journals and reports, but also aviation related organizations have been approached (for instance for annual reports and specific information). The list below reflects on organizations that are approached for gathering data on performance, congestion, energy use and CO_2 emissions:

- European Commission
- Eurocontrol, the European Organisation for the Safety of Air Navigation
- International Energy Agency
- EASA, the European Aviation Safety Agency
- SESAR Joint Undertaking, which is managing the development phase of the Single European Sky ATM Research (SESAR) Programme
- Air traffic control centers in Europe
- The U.S. Department of Aviation, Federal Aviation Administration

For the indicators of measuring the performance, the ‘Performance Review Report’ of 2011 is used for Europe (Eurocontrol, 2012a). For the comparison with the US there is the report ‘2010 U.S./Europe Comparison of ATM-Related Operational Performance’ of the Federal Aviation Administration (Eurocontrol & FAA, 2012). The document ‘Global Air Navigation Services Performance Report 2011’ of the Civil Air Navigation Services Organisation (CANSO) is useful for determining the ANSP performance globally (CANSO, 2011). Especially for the indicator cost-efficiency there is the study ‘ATM Cost-Effectiveness (ACE) 2010 Benchmarking Report with 2011-2015 outlook’ from Eurocontrol (Eurocontrol, 2012c). In some cases assumptions and estimations have been made, but this is only done with sufficient argumentation.

Next to this literature study, a set of interviews are conducted with stakeholders in order to gather specific information on topics and views on SES, which is done during the internship at Ecorys. The interviews are of added value to the literature study, because the theoretical information can then be put in practice and the experiences and insight information contributes to a broader perspective.

The quantitative and qualitative analysis gives a reflection of the extent of this research of 45 ECTS with literature study, interviews and being part of the project team at Ecorys.

3 Current air transport and air traffic management in Europe

3.1 Introduction

The aviation sector is essential in terms of connecting people, countries and cultures, whereby there is access to the global market and there are benefits for trading and tourism. Europe has 11.5 million km^2 of geographical area available for air transport. Currently there are about 9.8 million flights handled per year in Europe, with an average length of flights of 1,032 kilometer (Eurocontrol & FAA, 2012, p.8). The aviation sector in Europe contributes to European GDP with direct, indirect and induced benefits of about €365 billion and it provides about 5.1 million jobs all over Europe (air traffic controllers, suppliers and manufacturers included) (AEA, 2012, p.3). The figure below illustrates the average daily movements per State in 2011, with the changes (in percentages) with respect to 2020.

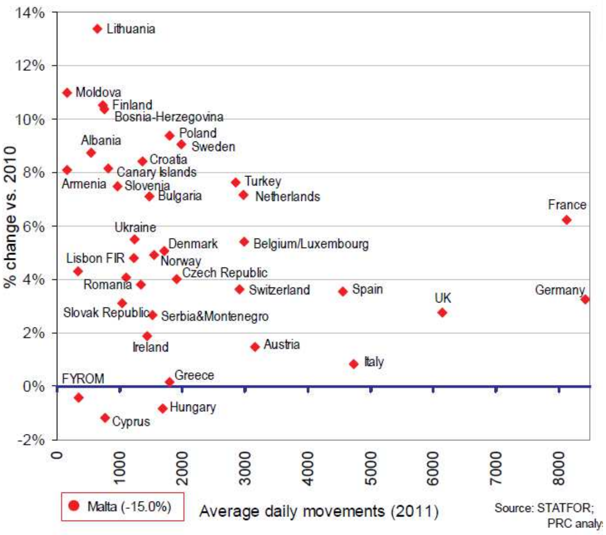


Figure 3.1: Traffic variation 2010-2011 by State (Eurocontrol, 2012a)

It is seen that especially in eastern European States there are high growth rates observed in air transport from 2010 to 2011 (Eurocontrol, 2012a). In 2011 total traffic in air transport in Europe grew by 3.1% (see Table 3.1).

Table 3.1: Total flights per year in Europe (Eurocontrol, 2012a)

	2008	2009	2010	2011
Flights (M)	10.1	9.4	9.5	9.8

Figure 3.2 illustrates the forecasts for traffic growth for the period 2011-2018, with specific average annual growth per State.

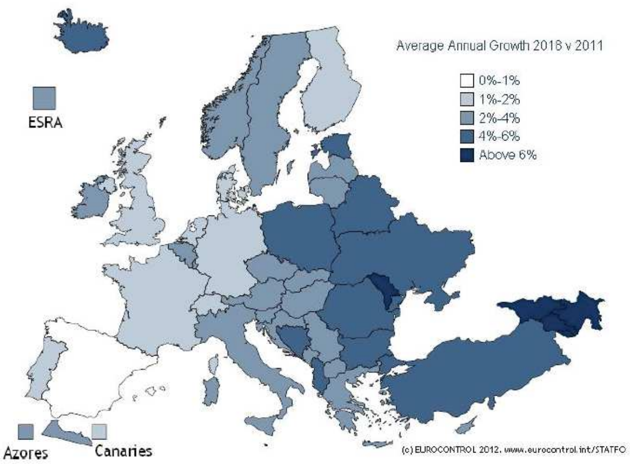


Figure 3.2: Forecast traffic growth 2011-2018 per State (Eurocontrol, 2012a)

The expected growth in air transport in total in Europe is given in the graph below. Continuing the current trend leads to the baseline scenario, whereby there will not change that much in air traffic management and air transport will continue to grow at a high rate.

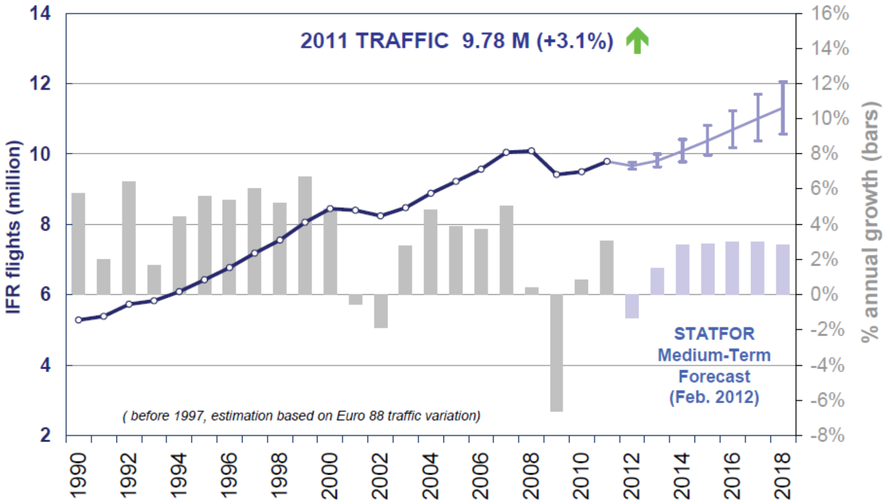


Figure 3.3: Evolution of air traffic in Europe with expectation until 2018 (Eurocontrol, 2012a)

Eurocontrol, the European organization for the safety of air navigation, provides forecasts for both the short and long term with regard to air traffic growth. The expectation is that air traffic will increase with 2.8% per year from 2014 to 2030. The forecast for 2019 is that there will be 11.2 million movements in the air and 16.9 million movements in 2030 in Europe (Eurocontrol, 2010, p.1). This growth in air traffic can lead to increased delays in specific areas, which has negative effects such as associated costs, time loss, additional fuel burn and increased greenhouse gas emissions. Both passengers and the environment are confronted with these negative effects (Eurocontrol, 2012a, p.8).

3.2 European Union's Emissions Trading Scheme (EU ETS)

Due to rapid growth and increasing greenhouse gas emissions in the aviation sector, adjustments in the whole system are essential. The aviation sector has the objective to become more sustainable since it is incorporated in the European

Union’s Emissions Trading Scheme (EU ETS) in 2012 (Preston et al., 2012, p.48). This legislative instrument has the goal to encourage measuring and reducing emissions (Leggett et al., 2012, p.3). Eurocontrol is an intergovernmental organization that is actively involved in finding solutions for reducing greenhouse gas emissions. These solutions are air navigation related and include more efficient routes, optimizing the fuel flight profile and routes, increasing the load factor and capacity (Eurocontrol, 2012a, p.6).

The EU ETS includes all airlines departing and arriving from/to countries in the EU. Emissions will be reduced with this scheme, whereby there is a system of emission allowances. Within such a fast growing sector, it is essential to make improvements, thus also improving efficiency. Through inclusion of aviation in EU ETS, airlines and stakeholders are forced to think about their emissions and possibilities to adopt climate mitigation measures. International aspects of the EU ETS are deferred with one year from April 2013, which means that current air traffic to and from the EU are not obliged to surrender emission allowances.

The available allowances within the EU ET scheme are set at 95% of historical emissions, with the average emission level for the period 2004-2006. Airlines are confronted with extra costs due to EU ETS, which is estimated to be about €1.1 billion for the first year (2012-2013) for the total sector. It is expected that airlines will process these costs to the passenger and increase the height of ticket prices, depending on the length of the flight. For a typical return flight the price could rise between €1.8 and €9 by 2020. In order to reduce costs, airlines can choose to replace their fleet by ‘cleaner’ models. These newer models emit about 30% less carbon than older models. In this way an airline has to buy less allowances and saves money. The expectation is that there can be CO_2 savings of about 46% per year by 2020 (Ares, 2012, p. 1-9). This study looks further on the contribution SES could have on the objectives and goals of EU ETS.

3.3 Air traffic management situation

Air traffic control controls the traffic and decides upon the access of an aircraft to specific airspace, which is managed and coordinated by the air navigation service provider (ANSP). Radar data and radar communication are essential for the operation of an ANSP. Airlines, military aviation and other actors in air traffic are depended on this air traffic management (ATM), which provides access to the airspace. Maintaining safety and capacity are thereby key objectives (Benderli, 2005, p.15). The next figure gives an overview of all phases and stages an aircraft undergoes from departure to arrival. This also reflects where delays can appear and under what name they are operationalized, where the most important for this study are reactionary delays and en-route air traffic flow management (ATFM) delays. En-route delay is important for this study, because this is the part where SES can play a role through reducing cross-border inefficiencies and congestion.

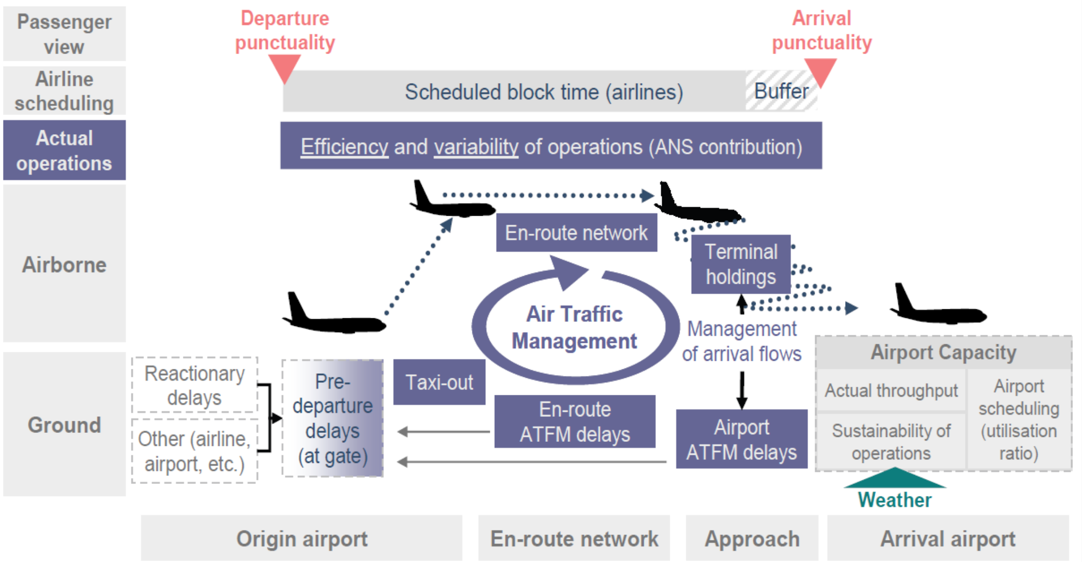
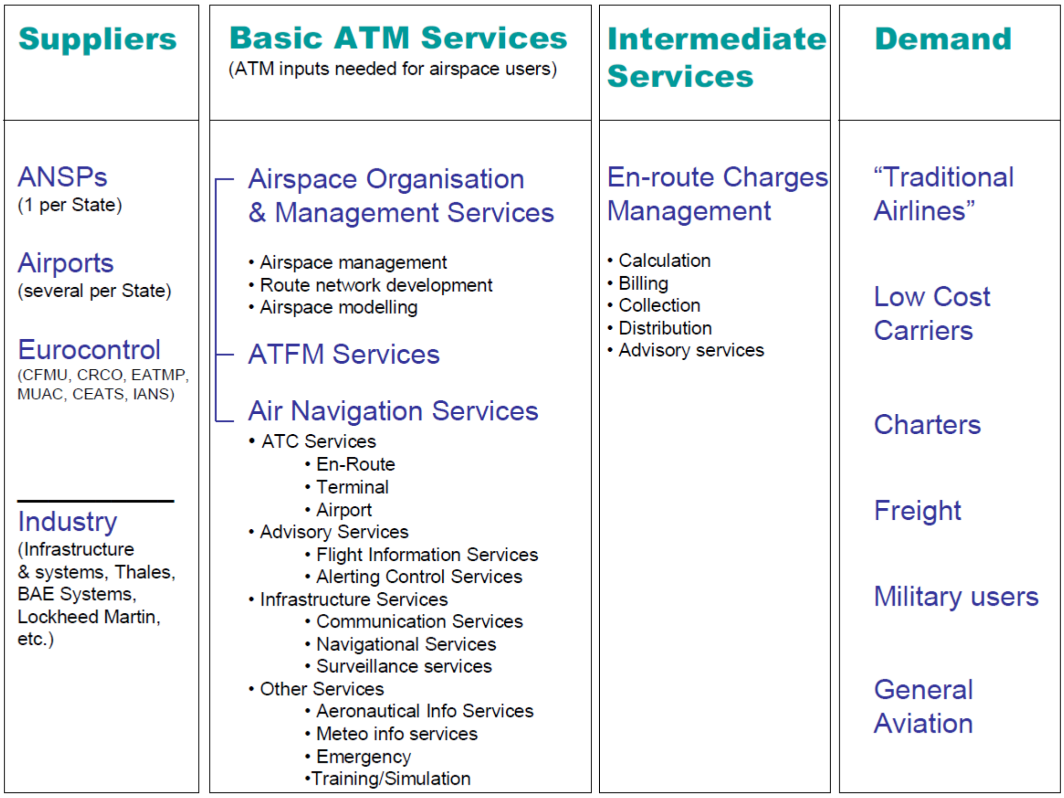


Figure 3.4: Phases from departure to arrival and position air traffic management (Eurocontrol, 2012a)

The air traffic management market is depended on several actors and services, which are given in Figure 3.5 and listed by suppliers, basic ATM services, intermediate services and demand.



Suppliers

ANSPs
(1 per State)

Airports
(several per State)

Eurocontrol
(CFMU, CRCO, EATMP, MUAC, CEATS, IANS)

Industry
(Infrastructure & systems, Thales, BAE Systems, Lockheed Martin, etc.)

Basic ATM Services
(ATM inputs needed for airspace users)

Airspace Organisation & Management Services

- Airspace management
- Route network development
- Airspace modelling

ATFM Services

Air Navigation Services

- ATC Services
  - En-Route
  - Terminal
  - Airport
- Advisory Services
  - Flight Information Services
  - Alerting Control Services
- Infrastructure Services
  - Communication Services
  - Navigational Services
  - Surveillance services
- Other Services
  - Aeronautical Info Services
  - Meteo info services
  - Emergency
  - Training/Simulation

Intermediate Services

En-route Charges Management

- Calculation
- Billing
- Collection
- Distribution
- Advisory services

Demand

"Traditional Airlines"

Low Cost Carriers

Charters

Freight

Military users

General Aviation

Figure 3.5: Overview of actors and services in the ATM market (Benderli, 2005)

In Europe each country takes care of managing the flight traffic within their national boundaries, air navigation is provided through their air navigation service providers (ANSPs). However, the current organization of air transport in Europe is fragmented and is becoming more inefficient, which is due to the organization of air traffic management in Europe. Eurocontrol defined fragmentation in air transport as ‘the impact of having a system that has developed within the constraints both of national boundaries, and of historical decisions that may have become sub-optimal with technological or demand changes’ (Eurocontrol, 2006a, p.79). The issues of fragmentation in aviation are:

- Piecemeal procurement
- Sub-optimal scale in maintenance and in-service development
- Fragmented planning
- Unsynchronized or inconsistent technological change (Eurocontrol, 2006a, p.25)

Currently there are 38 ANSPs in Europe, which all have their own operations and characteristics (Eurocontrol & FAA, 2012, p.8). These 38 ANSPs are subdivided into 75 centers and 400 sectors all over Europe (Benderli, 2005, pp. 29-30). Due to inefficiencies of air traffic control, the negative effects of air transport are becoming bigger. There is an increase in negative effects, such as additional costs, delays, noise and pollution for both travelers and the surroundings. Moreover, the air traffic system did not develop in line with the development and growth of the air transport sector in the past years. Technologies regarding navigation and management have not changed over fifty years and thereby cannot handle the economic growth and climate change. The 38 ANSPs need to have more efficient procedures for good coordination between the ANSPs and to smoothen international flights (SESAR, 2011, p.3).

3.4 Concluding remarks

In Europe there is 11.5 million km^2 available airspace, where about 9.8 million flights are currently handled per year with an average flight length of 1,032 kilometer. The aviation sector contributes to European GDP with benefits of about €365 billion and the sector provides about 5.1 million jobs all over Europe. The air transport sector is growing rapidly due to increased air traffic, with mainly high growth rates in eastern European States. The expectation is that in 2030 there will be 16.9 million movements in the air in Europe, with a growth rate of 2.8% per year. Since 2012 the aviation sector is incorporated in the European Union’s Emissions Trading Scheme (EU ETS) in order to become more sustainable. Through a system of emission allowances, the emissions may be reduced. An important issue in European aviation is that the airspace is fragmented. This is due to the 38 ANSPs in Europe that operate within their national boundaries and all have their own operations and characteristics. Combined with the lack of communication between these ANSPs and the lack of a common, up-to-date ATM system, procedures in Europe are becoming more inefficient and greenhouse gas emissions are increasing.

4 Performance air transport and air traffic management in Europe

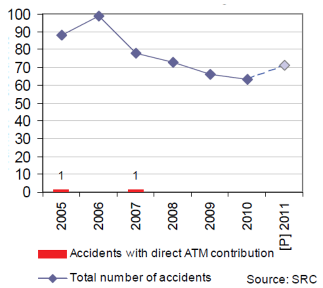
4.1 Performance air transport in Europe

European air traffic increased with 3.1% in 2011, with high growth rates in eastern Europe States (Eurocontrol, 2012a, p.7). The air transport mode accounts for about 8.5% of the total passenger transport volume in the year 2010, which is 524 billion passenger kilometer of the total 6176 billion passenger kilometer in total for transport (EEA, 2012a). Aviation is an important mode of transport, because it is relatively safe and very fast. Long distances can be bridged in a short time period. The average daily traffic amounts about 27,000 flights in Europe over the year 2012, with a peak in the months June to September. In the winter there is less daily traffic (Eurocontrol, 2012d). Air transport is becoming a bigger player in environmental impact, with a share of CO_2 emissions in Europe of 3.5% for the year 2011. This makes air transport the second largest energy consumer in the transport sector, after road transport (Eurocontrol, 2012a).

For the analysis of Single European Sky (SES) the performance need to be determined. The performance (the efficiency and quality) of the 38 Air Navigation Service Providers (ANSPs) of the current air traffic management can be expressed by certain performance indicators. In the Performance Review Report (PRR) 2011 the performance of Air Navigation Services (ANS) is determined for the 38 Member States of Eurocontrol for the year 2011. In order to give an overview of the performance of ATM a set of indicators is developed in the PRR. The PRR focuses on the indicators safety, delay/capacity, environment/flight efficiency and cost-efficiency for Europe (Eurocontrol, 2012a, p.9). That is also the set-up of this performance section. The indicator delay/capacity, where congestion and cross-border congestion are addressed, is essential for the chapters on SES.

4.2 Safety

The first indicator safety is based on the amount of accidents. The following figure gives an overview of the accidents in aviation in Europe and the ATM related accidents.



Source: SRC

Figure 4.1: Accidents with ATM contribution (Eurocontrol, 2012a)

There was a time of declining aviation accidents, from 2007 to 2010, but the accidents are increasing again. There have been no ATM accidents in 2011 in Europe and the last ATM accident was in 2007 (Eurocontrol, 2012a, p.14).

4.3 Delay/capacity and congestion in Europe

4.3.1 ATFM delay and congestion

Due to the rapid growth in the aviation sector, it is more crowded in the air with the consequence that at certain routes and at certain times it is busy. This can evolve in congestion and delays in the air. This section elaborates further on this, whereby congested areas are determined as well as cross-border congestion. Mainly the cross-border congestion is of importance, because SES will cause more efficient cross-border operations.

The Air Traffic Flow Management (ATFM) delay is pointed out first, which is the duration between the last take-off time requested by the aircraft operator and the take-off slot given by the Eurocontrol Network Management Directorate. In Europe 18% of all flights are delayed by more than 15 minutes over the year 2011, with a total Air Traffic Flow Management (ATFM) delay of 17.9M minutes. Overall, the en-route ATFM delay per flight is still more than 50% higher (1.6 minutes per flight) than the 1 minute summer en-route target set by the Provisional Council, which is expressed in the following figure. This figure shows the evolution of en-route ATFM delays over the past 14 years (Eurocontrol, 2012a, p.46).

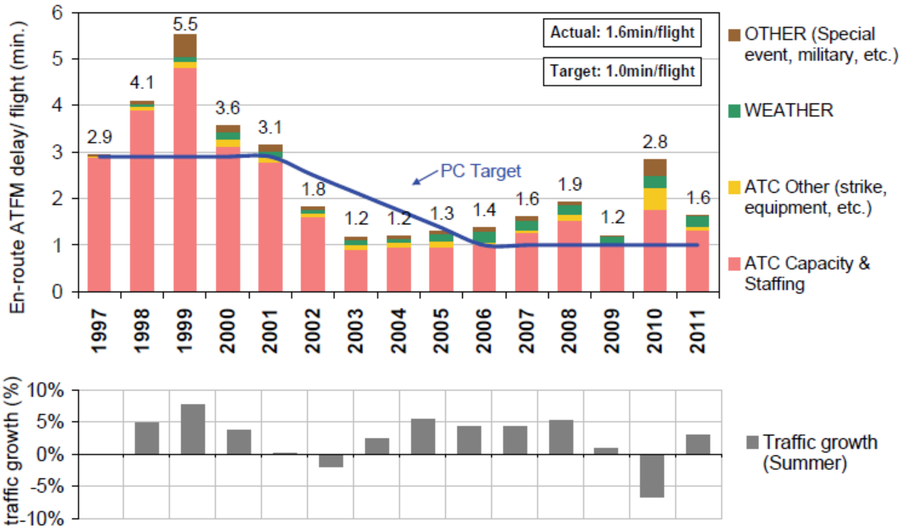


Figure 4.2: Summer ATFM en-route delay target (Eurocontrol, 2012a)

It is seen in this figure that there was a decrease of ATFM delay from 1999 to 2003 and since 2003 the ATFM en-route delay is quite stable, with an outlier in 2010. The decrease in delay from 1999 to 2003 has to do with the sharper targets for delays that are set by the Provisional Council, especially from 2001. It is seen that this has a positive effect on the total delays, because there is a decrease since then. The decrease in delays from 2001 can also be explained by the increase in capacity of available airspace in 2001 (Eurocontrol, 2002, p.10-11). The past years there have been substantial improvements in effective capacity, with a capacity increase of 50% from 1999 to 2011, while traffic increased with 23%. This explains the less delays assigned to ATC capacity and staffing, because the gap in capacity is smaller (Eurocontrol, 2012h, p.12).

There were less ATFM delays in the past years, it decreased with 35% in 2011. Figure 4.3 gives an overview of the departure delays with a comparison between 2010 and 2011 for Europe (Eurocontrol, 2012a, p.16).

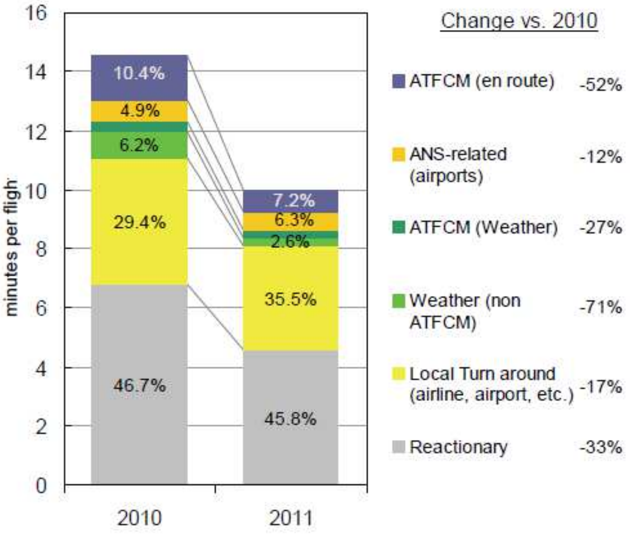


Figure 4.3: Departure delays by cause (Eurocontrol, 2012a)

The abbreviation ATFCM stands for Air Traffic Flow and Capacity Management and this is more or less the same as ATFM. ATFCM en-route delay is an important parameter for this research. ANS-related delays are delays that are caused by ANS inefficiencies, such as ATC capacity and staffing. ATFM weather delays are ATFCM delays that are due to weather circumstances. Activities regarding weather circumstances and evolve in delay, such as snow removal and de-icing, are assigned to weather (non ATFCM) delays. Another important parameter for this research is the reactionary delay, which is the delay that is due to delay of earlier flights which affects departing flights. As seen in Figure 4.3, the minutes delay per flight reduced significantly, from about 14.3 minutes in 2010 to about 10 minutes departure delay per flight in 2011. Local turn around and reactionary causes are the main contributors to the total minutes departure delay. ATFM (en-route) departure delays decreased with 52% from 2010 to 2011 (Eurocontrol, 2012a, p.16).

En-route ATFM delay has several causes, which can be seen in Figure 4.4. The main causes are air traffic control (ATC) related, where ATC capacity and staffing is the largest contributor. Another observation is that during the weekend the en-route ATFM delays are much (almost 2 times) higher than during other days of the week. This is remarkable since there are less flights during the weekend and the flight length increases. It is seen that the main cause of the increase in en-route ATFM delays during the weekend can be assigned to ATC capacity and staffing inefficiencies. The other causes (weather, ATC other) stay more or less at the same rate over the whole week (Eurocontrol, 2012a, p.47).

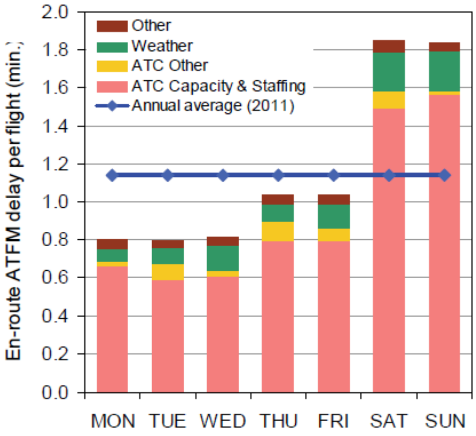


Figure 4.4: En-route ATFM delays during week (Eurocontrol, 2012a)

It is essential to do something about the increase in delay during the weekend. Improving the ATC capacity and staffing sector in general, but mainly on Saturday and Sunday, will have a large contribution in reducing the overall ATFM delay.

4.3.2 Congested Area Control Centres

A study of Jovanović et al. (2011) analyzed the performance of Area Control Centres (ACCs) and its congestion. An ACC is the part of Air Traffic Control that is concerned with en-route traffic coming from or going to adjacent centres. It provides air traffic control service to controlled flights in control areas under its jurisdiction. From the 67 ACCs in total there are 17 ACCs that account for 90% of the total en-route ATFM delays in 2010. These ACCs are frequently lacking capacity to match the demand, also since these 17 ACCs only generate 37% of the total flights hours in Europe (Jovanović et al., 2011, p.2). Therefore it would be beneficial to improve efficiency at those 17 ACCs.

Years 2011 and 2012

Delays occur at crowded areas at peak times in airspace. As can be seen in Figure 4.5 and Figure 4.6 the five most congested Air Control Centres (ACCs) are Madrid, Nicosia, Barcelona, Langen and Athinai + Makedonia, together accounting for a share of 52% of the total en-route ATFM delays in 2011 (Eurocontrol, 2012a, p.50).

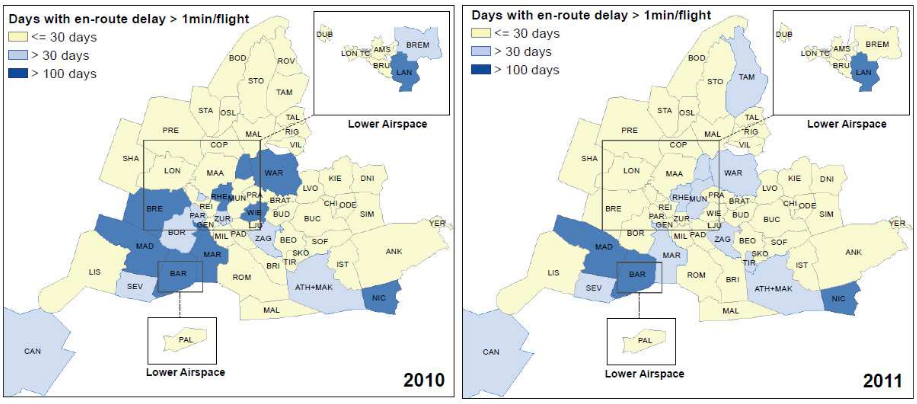
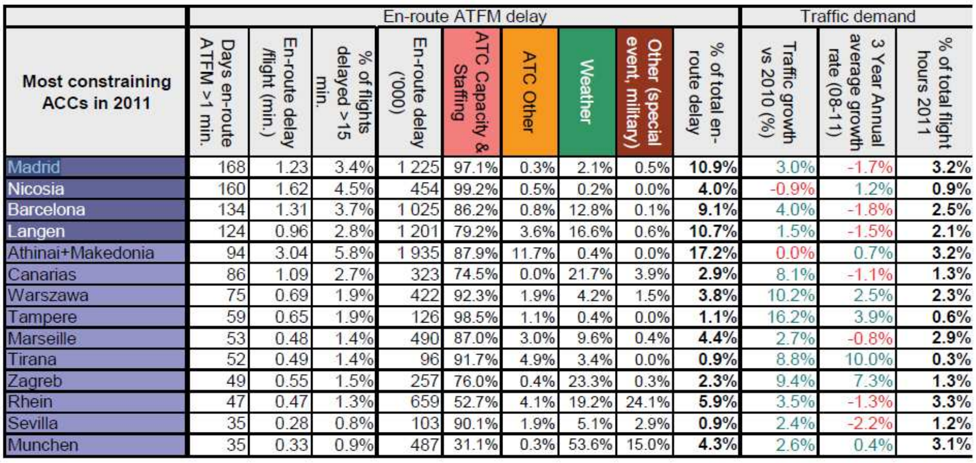


Figure 4.5: Geographical distribution of ACCs with most delays for 2010 and 2011 (Eurocontrol, 2012a)



Most constraining ACCs in 2011	En-route ATFM delay									Traffic demand		
	Days en-route ATFM >1 min.	En-route delay /flight (min.)	% of flights delayed >15 min.	En-route delay ('000)	ATC Capacity & Staffing	ATC Other	Weather	Other (special event, military)	% of total en-route delay	Traffic growth vs 2010 (%)	3 Year Annual average growth rate (08-11)	% of total flight hours 2011
Madrid	168	1.23	3.4%	1 225	97.1%	0.3%	2.1%	0.5%	**10.9%**	3.0%	-1.7%	**3.2%**
Nicosia	160	1.62	4.5%	454	99.2%	0.5%	0.2%	0.0%	**4.0%**	-0.9%	1.2%	**0.9%**
Barcelona	134	1.31	3.7%	1 025	86.2%	0.8%	12.8%	0.1%	**9.1%**	4.0%	-1.8%	**2.5%**
Langen	124	0.96	2.8%	1 201	79.2%	3.6%	16.6%	0.6%	**10.7%**	1.5%	-1.5%	**2.1%**
Athinai+Makedonia	94	3.04	5.8%	1 935	87.9%	11.7%	0.4%	0.0%	**17.2%**	0.0%	0.7%	**3.2%**
Canarias	86	1.09	2.7%	323	74.5%	0.0%	21.7%	3.9%	**2.9%**	8.1%	-1.1%	**1.3%**
Warszawa	75	0.69	1.9%	422	92.3%	1.9%	4.2%	1.5%	**3.8%**	10.2%	2.5%	**2.3%**
Tampere	59	0.65	1.9%	126	98.5%	1.1%	0.4%	0.0%	**1.1%**	16.2%	3.9%	**0.6%**
Marseille	53	0.48	1.4%	490	87.0%	3.0%	9.6%	0.4%	**4.4%**	2.7%	-0.8%	**2.9%**
Tirana	52	0.49	1.4%	96	91.7%	4.9%	3.4%	0.0%	**0.9%**	8.8%	10.0%	**0.3%**
Zagreb	49	0.55	1.5%	257	76.0%	0.4%	23.3%	0.3%	**2.3%**	9.4%	7.3%	**1.3%**
Rhein	47	0.47	1.3%	659	52.7%	4.1%	19.2%	24.1%	**5.9%**	3.5%	-1.3%	**3.3%**
Sevilla	35	0.28	0.8%	103	90.1%	1.9%	5.1%	2.9%	**0.9%**	2.4%	-2.2%	**1.2%**
Munchen	35	0.33	0.9%	487	31.1%	0.3%	53.6%	15.0%	**4.3%**	2.6%	0.4%	**3.1%**

Figure 4.6: Most en-route ATFM constraining ACCs (Eurocontrol, 2012a)

Figure 4.5 illustrates that next to the bottlenecks in crowded area in the airspace, the days with en-route delay with more than 1 minute per flight are decreasing significantly. Whether Athinai + Makedonia belongs to the light blue category in Figure 4.5, with more than 30 days, it is still one of the most congested areas since the average en-route ATFM delay per flight was at a high level in 2011, namely 3.1 minutes, especially for the amount of IFR flights (about 625,000) (Eurocontrol, 2012a, p.51).

The following table contains information on the five most congested ACCs with regard to delays. It is seen that Madrid has the most days with more than 1 minute en-route ATFM delay, namely 168 days. For the other (not top five congested) ACCs there is a range between 35 and 86 days with more than 1 minute en-route ATFM delay (Eurocontrol, 2012a).

Table 4.1: Most en-route ATFM constraining ACCs for the year 2011 (Eurocontrol, 2012a)

	Madrid	Nicosia	Barcelona	Langen	Athinai + Makedonia
Days en-route ATFM delay > 1 min	168	160	134	124	94
En-route ATFM delay/flight (min)	1.23	1.62	1.31	0.96	3.04
En-route ATFM delay/flight (min) in summer	1.65	1.65	1.92	1.45	4.81

From this table can also be derived that the height of the total average en-route ATFM delay is due to high en-route ATFM delay in the summer months, since in all cases the average delay in the summer is higher than the total average. For example in Athinai + Makedonia where the average delay was 3.04 minutes per flight and in the summer the delay was 4.81 minutes per flight in 2011. This means that the capacity of the airports and airspace is not resistant to the growing demand in summer time. The months included in the PRR report as ‘summer’ are the months May to October.

The Network Management is created by the European Commission to optimize the performance of the aviation network in Europe. The Network Manager is involved in every technical and operational domain that is required in air traffic management. This institution publishes every month a Network Operations Report to reflect on the performance in air transport, with the last publication available for November 2012, which also reflects upon the year 2012 until November 2012.

In this report of November 2012 it is seen that Langen ACC and Marseille ACC are the locations with the highest proportion of total en-route ATFM delay over the year 2012, with respectively 7.4% and 5.3%. A cause for the delay of Marseille ACC was the industrial action on November 15th, which caused 49,000 minutes of delay (Eurocontrol, 2012d, p.8-12). Canarias ACC/FIC, Nicosia ACC and Lisboa ACC/UAC are the locations with the largest proportion of ATC capacity problems causing en-route delays, respectively 27%, 12% and 11% for November 2012 (Eurocontrol, 2012d, p.4). There are also Airport/TMA ATFM delays, where airport weather, airport infrastructure and airport ATC capacity are the reasons for the delay with airport weather being the most significant for November 2012. Over the year 2012 London Heathrow is the airport with the highest proportion Airport/TMA ATFM delays of the total ATFM delays, with 5.25% (Eurocontrol, 2012d, p.9).

Past years

The five ACCs Madrid, Nicosia, Barcelona, Langen and Athinai + Makedonia have been problematic for already a few years in terms of congestion and delays, where total ATFM delay per flight and en-route ATFM delay per flight are at a high rate. The only exception is Barcelona, which faced a steady increase in delays since 2010 (Eurocontrol, 2012a, p.99). When looking further back in time, a shift of the most delay-generating ACCs is observable, which can be seen in Figure 4.7 in a comparison between the years 2007 and 2008. Here it is seen that back then, the most delays were concentrated at eastern countries (Eurocontrol, 2009a).

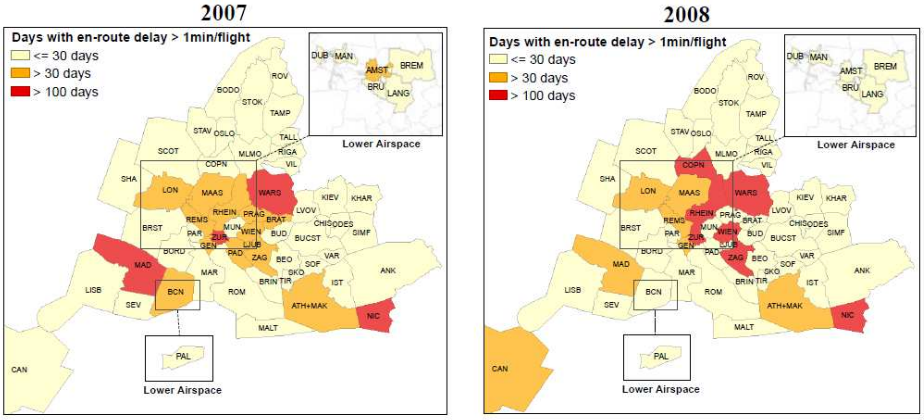


Figure 4.7: Geographical distribution of ACCs with most delays for 2007 and 2008 (Eurocontrol, 2009a)

In 2008 the most delay-generating ACCs were Warschau, Copenhagen, Wien and Rhein. The days with en-route ATFM delay in Copenhagen increased heavily to 251 days in 2008. This was due to the implementation of a new ATM system in the winter of 2007 and 2008 in Copenhagen, which caused most delays (Eurocontrol, 2009a, p.43).

Other issues

Moreover, three of the five largest Air Navigation Service Providers (ANSPs) had a substantial rise in ATFM delays, which are DSNA (ANSP of France), DFS (ANSP of Germany) and Aena (ANSP of Spain). These delays have their reflection on the economic costs, with DSNA having a share of 36% ATFM delay unit costs and Aena having a share of 28% (Eurocontrol, 2012a, p.95) (Eurocontrol, 2012c, p.21). As seen already in Figure 3.1, Germany and France are the two States in Europe with the most daily movements.

The regional and seasonal airports Cannes, Istanbul Sabiha Gokçen, Kos, Antalya, Rhodes, Nikos, Chania and Zakinthos are significantly contributing to the total ATFM arrival delays in Europe in 2011. This has to do with peak moments during summer time (Eurocontrol, 2012a, p.64). Besides, more than half of the 50 largest airports in Europe are already at their saturation point in terms of declared ground capacity with only few planned major developments or expansions (Madas & Zografos, 2010, p.274).

4.3.3 Cross-border congestion

Cross-border congestion is where Single European Sky could have an effect on, through better organized air traffic management and less cross-border differences. This evolves in less cross-border disruptions, efficiency improvements and a reduction in cross-border congestion and delay. In order to determine the impact of SES, the effect of the fragmented airspace and cross-border inefficiencies on the total congestion is examined.

The network operations report of November 2012 shows that compared to a year before, in November 2011, there is a reduction of 40% of the ATFM delays in Europe in 2012. This has to do with the lower level of traffic (decrease of 3.6%) and the reduction of airport ATFM delays. The distribution of ATFM delays in November 2012 is shown in Figure 4.8. En-route ATFM delay accounts for 47% of the total ATFM delay, equivalent to 8.4M minutes, with en-route ATC capacity, staffing and disruptions being the most significant with 45% of the 47%. En-route ATC capacity contributes the most to the total en-route delays with a share of 19.8%, which is about 3.5 M minutes of the total 17.9 M minutes (Eurocontrol, 2012a, p.8) (Eurocontrol, 2012d, p.2).

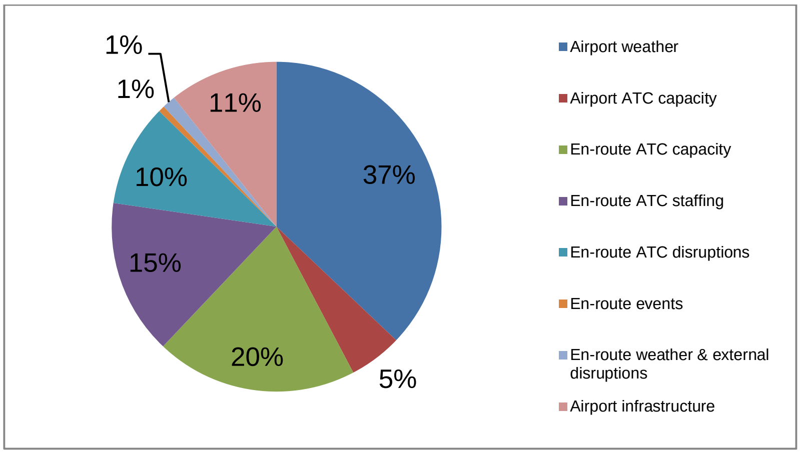


Figure 4.8: Distribution of ATFM delay in November 2012 in Europe (Eurocontrol, 2012d)

The en-route ATC disruptions percentage is an important parameter for cross-border congestion, because this are the ATM inefficiencies at national boundaries and the problems that can appear here. It is seen that these disruptions contribute for 10% of the total ATFM delays in Europe. Diminishing the en-route ATC disruptions via SES will reduce the total ATFM delays by 10%, which means a reduction of about 1.79 M minutes of the total of 17.9 M minutes ATFM delay. Furthermore, through SES there will be improvements in en-route capacity and staffing. This means that the delays caused by en-route ATC capacity (20%) and en-route ATC staffing (15%) will reduce. Removal of those two delays will evolve in 6.3 M minutes less delay.

4.3.4 Costs of air navigation services for users

This congestion and delay has its reflection on the amount of passenger traffic worldwide and also on the economic losses of airlines (Madas & Zografos, 2010, p.274). The Air Navigation Service (ANS) costs are presented in Table 4.2, with the largest share for en-route ANS provision costs with 6.9 of the total 13.5 billion € (2010) ANS-related economic costs to airspace users in 2011 (Eurocontrol, 2012a, p.27).

Table 4.2: Estimated ANS-related economic costs to airspace users (gate-to-gate) (in Billion €2010) (Eurocontrol, 2012a)

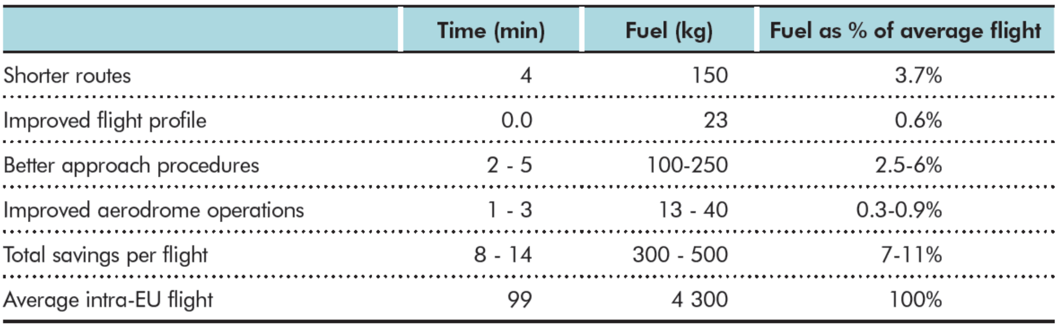
		2008	**2009**	**2010**	**2011**
ANS quality of service related costs	En-route & airport ATFM delays (capacity)	1.9	1.2	2.2	1.5
	ANS-related inefficiencies gate-to-gate (environment)	3.9	3.5	3.7	3.7
ANS-provision costs	Terminal ANS provision costs (charges)	1.5	1.5	1.5	1.4
	En-route ANS provision costs (charges)	6.8	6.9	6.7	6.9
Total		**14.1**	**13.1**	**14.1**	**13.5**

The total ANS costs in 2011 decreased in comparison to 2010 from 14.1 billion € (2010) to 13.5 billion € (2010), while IFR traffic increased with 3.1% in 2011 (Table 3.1). Because of the increase in ANS service quality in 2011, compared to 2010, there is a decrease of unit costs and a decrease of ANS-related service quality costs of 13% (Eurocontrol, 2012a, p.27).

4.4 Environment/flight efficiency Europe

Flight efficiency is of importance to the environment and therefore it is desirable for ANS to perform at a high level. Optimal routes and changing direction/ altitude (cross-border) are dependents of flight efficiency. This is a short section on the indicator environment, where further elaboration on fuel burn and emissions can be found in chapter six. Emissions from aviation have a share of 3.5% in the total CO_2 emissions in Europe, where 0.2% of these emissions is related to ANS inefficiencies (Eurocontrol, 2012a, p.20). These aviation emissions includes both domestic and international aviation. The sources of the ANS emissions are the taxi-out phase, ASMA (terminal) related issues and horizontal en-route flight efficiency. For this study the en-route flight efficiency is relevant (McCollum et al., 2009, p.7). Due to a decreased great circle distance, the en-route flight efficiency improved over the past years. The great circle distance is the shortest route between two points on a sphere. Due to an increase of 8% in ASMA (terminal) additional time, the ANS-related inefficiencies increased in 2011 (Eurocontrol, 2012a, p.9).

The International Energy Agency provided an overview of the flight (in)efficiency in ATM and airport operations and assessed the potential savings in time and fuel burn with improvements in ATM, which is given in the figure below.



	Time (min)	Fuel (kg)	Fuel as % of average flight
Shorter routes	4	150	3.7%
Improved flight profile	0.0	23	0.6%
Better approach procedures	2 - 5	100-250	2.5-6%
Improved aerodrome operations	1 - 3	13 - 40	0.3-0.9%
Total savings per flight	8 - 14	300 - 500	7-11%
Average intra-EU flight	99	4 300	100%

Figure 4.9: Potential savings in time and fuel burn with improvements in ATM and airport operations (IEA, 2009)

It is seen that 7-11% of the total fuel burn in aviation is due to ATM and airport operation inefficiencies. A part of this percentage can be saved through improvements in air traffic management, for example with SES. This research aims at improvements with regard to shorter routes (3.7% of potential savings in time and fuel burn), improved flight profile (0.6%) and better approach procedures (2.5-6%) (IEA, 2009, p.327).

4.5 Cost-efficiency Europe

For the cost-efficiency indicator the costs per service unit (SU) are determined. In Figure 4.9 it is seen that the costs decreased with 5.6% in Europe in 2011, due to decreased delays and decreased coupled costs with it (Eurocontrol, 2012a, p.88).

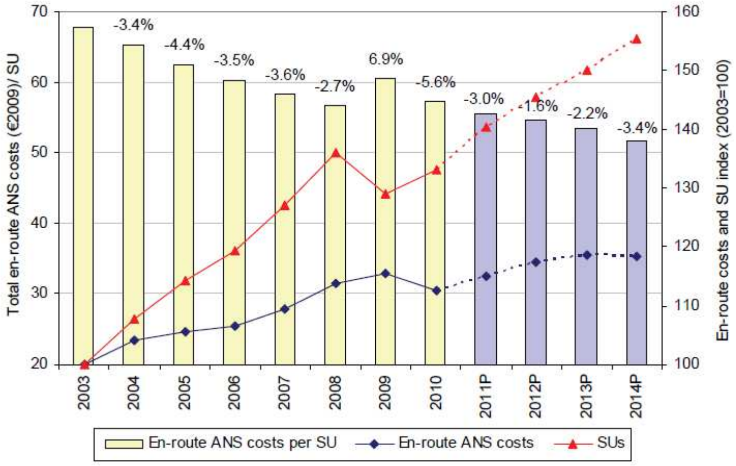


Figure 4.10: En-route ANS costs (per SU) (Eurocontrol, 2012a)

For these figures it is needed to keep in mind that there were several events and disruptions that caused fluctuations in aviation performance. In the year 2009 there was weak economic growth in Europe and in the year 20120 there were exceptional events (volcanic ash cloud) and unusual weather conditions that resulted in 111,000 cancelled flights in April and May 2010 (Eurocontrol & FAA, 2012, p.9).

In the year 2010 the total ANS costs amounted €8,570 M, where €7,480 M (87.2%) of this costs are assigned to the provision of gate-to-gate ATM/CNS, as can be seen in the table below (Eurocontrol, 2012c, p.18).

Table 4.3: Breakdown of total ANS costs at system level in 2010 (Eurocontrol, 2012c)

Gate-to-gate ANS costs (€ M)	2010	% total
ATM/CNS provision costs (including AIS & SAR)	7,476	87.2%
MET costs	437	5.1%
EUROCONTROL costs	516	6.0%
Payment for regulatory and supervisory services	84	1.0%
Payment to governmental authorities and irrecoverable VAT	60	0.7%
Gate-to-gate ANS costs	**8,572**	**100.0%**

For the indicator cost-efficiency there is the economic cost-effectiveness Key Performance Indicator (KPI) and the financial cost-effectiveness KPI, that adds a monetary value of the cost of ground ATFM delay to the controllable financial costs. The economic cost-effectiveness KPI in the European system is on average €544 per composite flight-hour in 2010, with a range from €179 for EANS (ANSP of Estonia) to €849 for Belgocontrol (the Belgian ANSP) (see Figure 4.10) (Eurocontrol, 2012c).

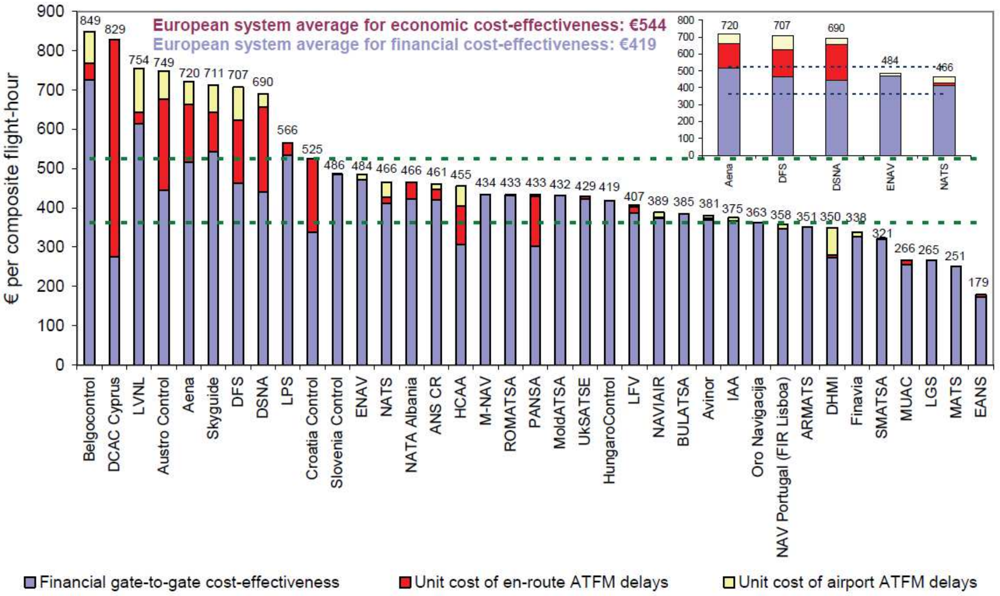


Figure 4.11: Economic gate-to-gate cost-effectiveness KPI for 2010 (Eurocontrol, 2012c)

The financial cost-effectiveness indicator can be divided into the following Key Performance Indicators:

- *Air Traffic Control Officer (ATCO)-hour productivity*, with a European average of 0.77 composite flight hours per ATCO-hour in 2010
- *ATCO employment costs per ATCO-hour*, with a European average of €96 ATCO employment costs per ATCO-hour in 2010
- *ATCO employment costs per composite flight hour*, with a European average of €125 ATCO employment costs per composite flight hour in 2010
- *Total costs per composite flight hour*, with a European average of €419 total costs per composite flight-hour in 2010 (Eurocontrol, 2012c, pp.44-54)

A composite flight hour is the en-route flight hours plus IFR airport movements weighted by a factor that reflects the relative importance of terminal and en-route costs in the cost base (Eurocontrol, 2012c).

Currently there are 57,800 people working at European ANSPs in 2010. In order to improve financial cost-effectiveness in 2010, a higher ATCO-hour productivity and lower employment costs per ATCO-hour were desirable, and were achieved with respectively 6.6% and -5.1% from 2009 to 2010 (Eurocontrol, 2012c, p.69).

4.6 Concluding remarks

The air transport sector provides 8.5% of the total passenger transport volume per year and is thereby responsible for 3.5% of the total CO_2 emissions in Europe. The performance of European air traffic management is determined by the indicators safety, delay/capacity, environment/flight efficiency and cost-efficiency for the 38 ANSPs. In 2011 there were no ATM accidents in Europe. The indicator delay/capacity is not performing optimal, because 18% of all flights in Europe were delayed by more than 15 minutes and the total ATFM delay amounted 17.9 million minutes in 2011. 47% of this delay are en-route ATFM delays, equivalent to 8.4 million minutes, where en-route ATC capacity and staffing problems is the main contributor. Noteworthy is that 17 of the 67 ACCs are responsible for 90% of the total en-route ATFM delay in 2010, with Madrid, Nicosia, Barcelona, Langen and Athinai+Makedonia being the five most congested ACCs. The environmental impact of aviation is increasing, mainly due to increased ATM inefficiencies. Furthermore, it is seen that the cost-efficiency differs per ANSPs, with a European average of €419 total costs per composite flight hour and an ATCO-hour productivity of 0.77 composite flight hours per ATCO-hour in 2010.

5 Performance comparison Europe and US

5.1 Introduction

5.1.1 Airspace, air traffic and airports in Europe and US

The US refers in this research to the United States of America with the 48 contiguous States located on the North American continent south of the border with Canada and the District of Columbia, excluding Alaska, Hawaii and Oceanic areas. The scope of the US is given in the following figure (Eurocontrol & FAA, 2012, p.4).

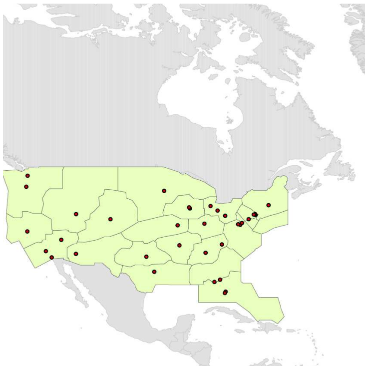
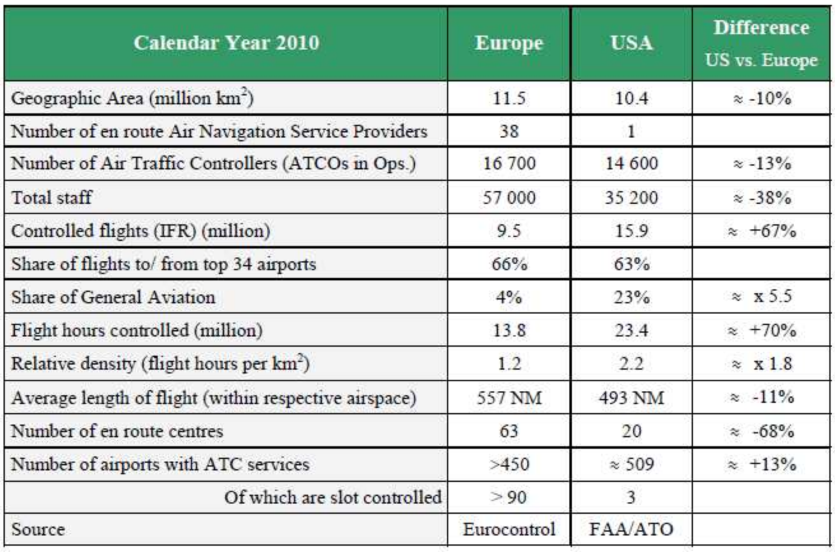


Figure 5.1: Scope of the US (Eurocontrol & FAA, 2012)

The airspace of the US is comparable with the European airspace, because it has approximately the same volume of airspace with 11.5 million km^2 European airspace and 10.4 million km^2 US airspace. The following figure gives an overview of the characteristics of the European and US airspace, also with regard to the ATM system.



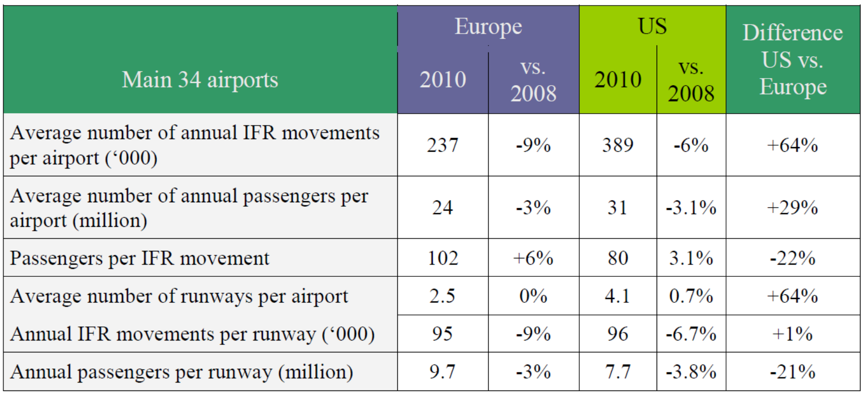
Calendar Year 2010	Europe	USA	Difference US vs. Europe
Geographic Area (million km^2)	11.5	10.4	≈ -10%
Number of en route Air Navigation Service Providers	38	1	
Number of Air Traffic Controllers (ATCOs in Ops.)	16 700	14 600	≈ -13%
Total staff	57 000	35 200	≈ -38%
Controlled flights (IFR) (million)	9.5	15.9	≈ +67%
Share of flights to/ from top 34 airports	66%	63%	
Share of General Aviation	4%	23%	≈ x 5.5
Flight hours controlled (million)	13.8	23.4	≈ +70%
Relative density (flight hours per km^2)	1.2	2.2	≈ x 1.8
Average length of flight (within respective airspace)	557 NM	493 NM	≈ -11%
Number of en route centres	63	20	≈ -68%
Number of airports with ATC services	>450	≈ 509	≈ +13%
Of which are slot controlled	> 90	3	
Source	Eurocontrol	FAA/ATO	

Figure 5.2: Key (ATM) statistics Europe and the US (Eurocontrol & FAA, 2012)

It is seen here that the US has only one ANSP, while Europe has 38 ANSPs. Moreover, the productivity of air traffic controllers is significantly higher in the US since the 15.9 million flight are controlled by 14,600 air traffic controllers, against

9.5 million controlled flights by 16,700 air traffic controllers in Europe. This is an important difference between the US and Europe, which can be explained by current inefficiencies in air traffic management in Europe.

The data from Figure 5.2 is based on all air traffic that uses air related services in Europe and the US, which can be as well domestic flights as intercontinental flights. Flights that go beyond the boundaries of Europe or the US are from that point not further included in this data. The following figure gives further elaboration on the characteristics of flights and airports in Europe and the US (Eurocontrol & FAA, 2012).



Main 34 airports	Europe		US		Difference US vs. Europe
	2010	vs. 2008	2010	vs. 2008	
Average number of annual IFR movements per airport ('000)	237	-9%	389	-6%	+64%
Average number of annual passengers per airport (million)	24	-3%	31	-3.1%	+29%
Passengers per IFR movement	102	+6%	80	3.1%	-22%
Average number of runways per airport	2.5	0%	4.1	0.7%	+64%
Annual IFR movements per runway ('000)	95	-9%	96	-6.7%	+1%
Annual passengers per runway (million)	9.7	-3%	7.7	-3.8%	-21%

Figure 5.3: Characteristics of flights and airports in Europe and the US for 2010 (Eurocontrol & FAA, 2012)

An important indicator is the passengers per movement. In Europe there are 102 passengers per movement and in the US there are 80 passengers per movements in 2010. This is a notable difference of 22% and is due to larger aircrafts and more seats per flight in Europe. Furthermore there are more movements per airport in the US, which can be explained by the higher number of runways per airport in the US (Eurocontrol & FAA, 2012, p.12-14).

5.1.2 Traffic density Europe and US

For the comparison it is also relevant to look to the traffic density within en-route centers in Europe and the US, which is shown in the following figure.

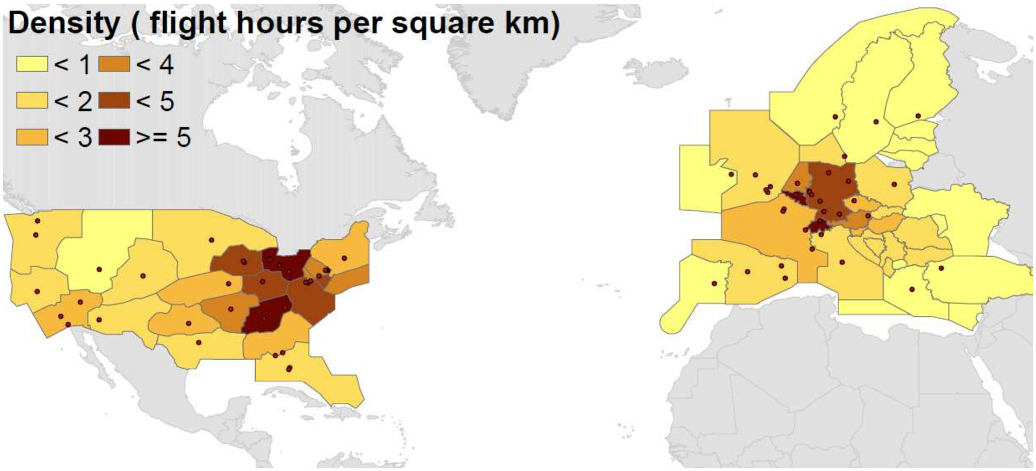


Figure 5.4: Traffic density in air transport in Europe and the US (Eurocontrol & FAA, 2012)

The density in air transport is given in flight hours per square kilometer. Both Europe and the US show specific areas where there is a higher traffic density. This density is concentrated to a 'center' within Europe and the US (darker areas in Figure 5.4). Remarkable is that Europe has more light brown and light yellow areas, which means that there are a lot areas with low traffic density, for instance in Norway, Sweden and Finland.

5.2 Performance air traffic management in US

In order to say something about the performance of the ATM system in Europe, a comparison with the performance of the ATM system in the US is done. Eurocontrol has made a comparison between the US and Europe ATM performance, in cooperation with the Federal Aviation Administration for the year 2010, which is useful for this research. Since there is a lack of commonly agreed and comparable performance indicators worldwide, it is not possible to give for each indicator the same figure for comparison. The US/Europe comparison addresses the indicators delay/capacity and environment/flight efficiency, but it does not address safety and cost-effectiveness. With the help of the 'ATM Cost-Effectiveness (ACE) 2010 Benchmarking Report', prepared by The Performance Review Unit (PRU), and the 'Global ANS Performance Report' for 2011 (with data concerning productivity, cost-effectiveness, price, revenue and profitability) for the 29 ANSPs over the world, it is possible to compare the ATM cost-effectiveness for the 37 ANSPs in Europe with other countries (CANSO, 2011). The performance for the year 2010 is assessed in the 'ATM Cost-Effectiveness (ACE) 2010 Benchmarking Report', as well as the progression over the period 2006 to 2010 (Eurocontrol, 2012c).

5.2.1 Comparison between service providers in Europe and the US

An important difference between Europe and the US is that the US controls way more traffic than Europe, namely about 67% more flights, with less air traffic controllers (see Figure 5.2). Moreover, Europe consists of 38 en-route ANSPs, while the US has one single service provider (Eurocontrol & FAA, 2012, p.8). The evolution of Instrument Flight Rules (IFR) traffic over the past 11 years for both Europe and the US is given in the following figure. It is seen that from 1999 to 2010 there has been an increase in IFR traffic in Europe, while the IFR traffic in the US decreased in this period (Eurocontrol & FAA, 2012).

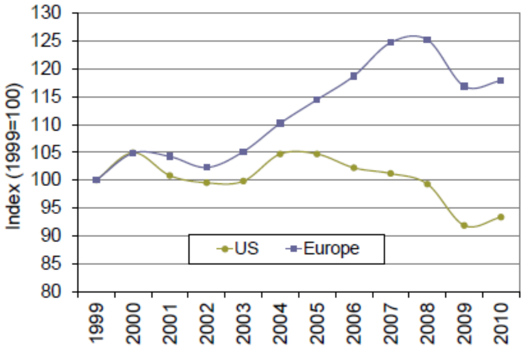


Figure 5.5: Evolution of IFR traffic in Europe and the US (Eurocontrol & FAA, 2012)

5.2.2 Safety US

The indicator safety cannot be compared, because there is no data available for the ATM related accidents in the US.

5.2.3 Delay/capacity US

The on-time performance for departures and arrivals is used to compare the performance of the ATM system with regard to the delays and capacity (Figure 5.6). In Europe the percentage on-time flights is lower than in the US, with in the year 2010 a nadir for Europe with a percentage of about 75.5% on-time performance, while the US performs better with 82% of its flights on-time in 2010 (Eurocontrol & FAA, 2012, p.27).

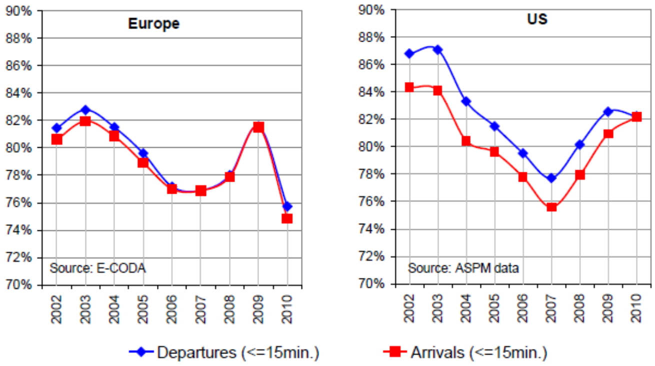


Figure 5.6: On-time performance for Europe and the US from 2002 to 2010 (Eurocontrol & FAA, 2012)

The ATFM/EDCT delay comparison between Europe and the US is shown in Figure 5.7. In Europe most flights are delayed due to ATFM/EDCT en-route causes, while in the US the biggest cause is AFTM/EDCT airport related. This means that there are in Europe more en-route inefficiencies and in the US there are more airport inefficiencies. An important message is that the overall ATFM/EDCT delays with more than 15 minutes are higher in Europe than in the US, with more fluctuations in Europe. The peak of en-route related causes in Europe occurs mainly in summer time (Eurocontrol & FAA, 2012, p.44).

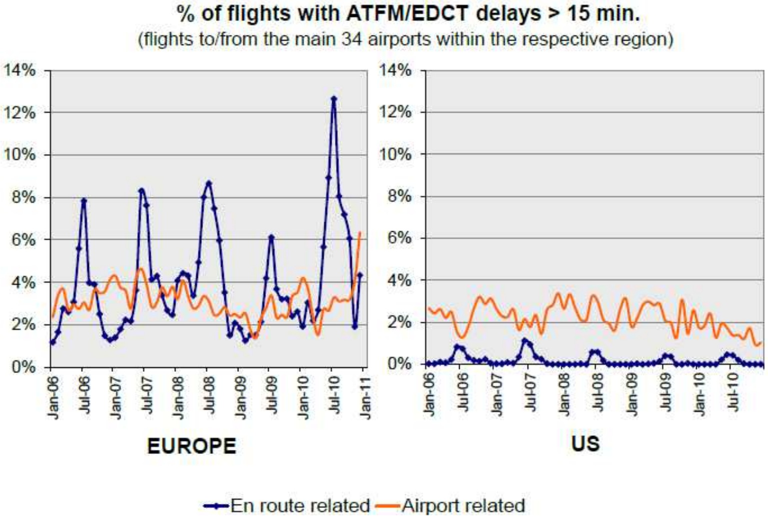


Figure 5.7: Evolution of EDCT/ATFM delays for the years 2006 to 2010 for Europe and the US (Eurocontrol & FAA, 2012)

5.2.4 Environment/flight efficiency US

During a flight there are all kind of factors of influence, where also inefficiencies can occur. The duration of flight phases for Europe and the US are displayed in Figure 5.8. In Europe the duration is mainly departure time depended, while in the US the taxi times and airborne times are also significant. This means that improving the departure time in Europe will have a big contribution to better overall performance. The US was quite stable in January 2011, while Europe observed an increased amount of minutes (Eurocontrol & FAA, 2012, p.39).

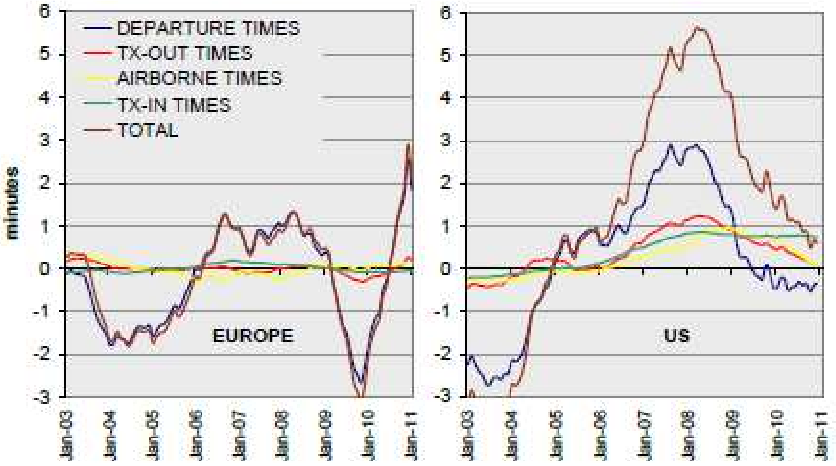
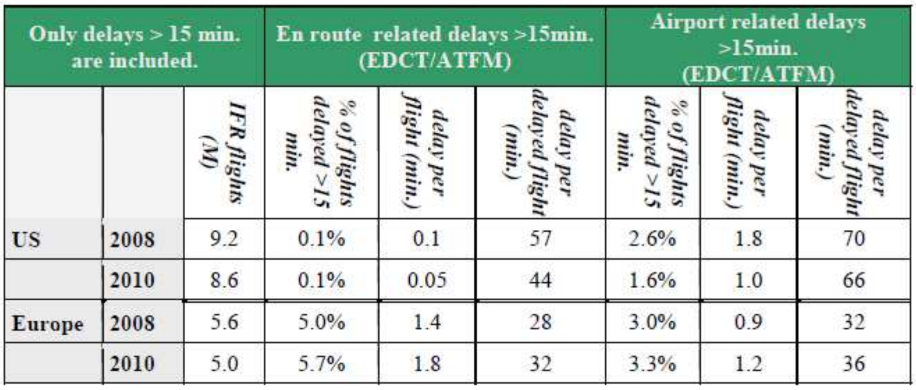


Figure 5.8: Duration of flight phases from 2003 to 2010 (Eurocontrol & FAA, 2012)

Within this study the contribution of ANS to the overall performance is of importance. The next table gives an overview of the relation between ANS-inefficiencies and departure delays. The conclusion from this table is that Europe has more ANS-inefficiencies than the US and that it is of influence to the delays in Europe. The departure delay of flights in Europe are 57 times more affected by ATFM/EDCT constraints than in the US, with respectively 5.7% and 0.1% of ATFM/EDCT en-route related delays of total departure delays with more than 15 minutes (Eurocontrol & FAA, 2012, p.42).



Only delays > 15 min. are included.			En route related delays >15min. (EDCT/ATFM)			Airport related delays >15min. (EDCT/ATFM)		
		IFR flights (M)	% of flights delayed >15 min.	delay per flight (min.)	delay per delayed flight (min.)	% of flights delayed >15 min.	delay per flight (min.)	delay per delayed flight (min.)
US	**2008**	9.2	0.1%	0.1	57	2.6%	1.8	70
	2010	8.6	0.1%	0.05	44	1.6%	1.0	66
Europe	**2008**	5.6	5.0%	1.4	28	3.0%	0.9	32
	2010	5.0	5.7%	1.8	32	3.3%	1.2	36

Figure 5.9: ANS-related departure delays in 2008 and 2010 (Eurocontrol & FAA, 2012)

The horizontal en-route flight efficiency is illustrated in Figure 5.10, with Europe having a higher percentage of total en-route extension. This means that flights in the US are more efficient than flights in Europe, because the flight route is more optimal. Aviation in the US is therefore less damaging to the environment, since the associated fuel burn and emissions per flight are also lower.

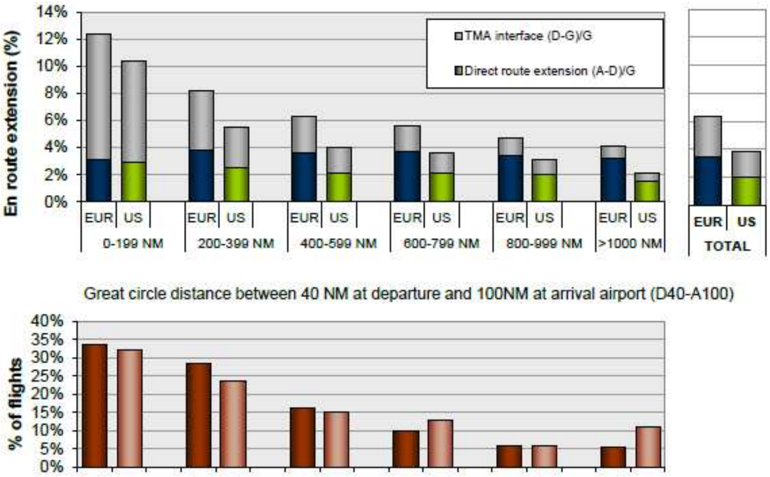


Figure 5.10: Comparison of direct en-route extension in 2010 (Eurocontrol & FAA, 2012)

The problem in Europe is the inefficient use of airspace and the fragmentation of airspace, which limits en-route functioning. The implementation of Functional Airspace Block (FABs) within SES will improve the en-route functioning. FABs, optimal routing and increased efficiency will cause a decrease in the great circle distance and a decrease in the en-route extension in Europe (Eurocontrol & FAA, 2012, p.48).

5.2.5 Cost-efficiency US

FAA ATO is the operating ANSP in the US, with the highest amount of IFR Flight Hours of all global ANSPs in 2010, namely 25,106,283 hours (CANSO, 2011, p.18). This has to do with the size of the airspace in which this ANSP is operating. The KPIs for cost-efficiency are given below. The FAA performs well in terms of cost-efficiency since the ANSP of the US controls 37% more IFR flights with fewer controllers than in Europe (Eurocontrol & FAA, 2012, p.2).

ATCO-hour productivity

For FAA ATO there are 1,803 IFR Flight Hours per ATCO in Operations for 2010, which is shown in Figure 5.11 (CANSO, 2011, p.28). The average annual working hours for ATCOs in Operations is 1,780 hours in 2010. The 1,803 IFR flight hours divided by the 1,780 ATCO-hours gives the average of 1.01 composite flight hours per ATCO-hour in 2010 for the US (CANSO, 2011, p.33). The composite flight hours per ATCO-hour for the US is thus higher than the 0.77 hours for Europe.

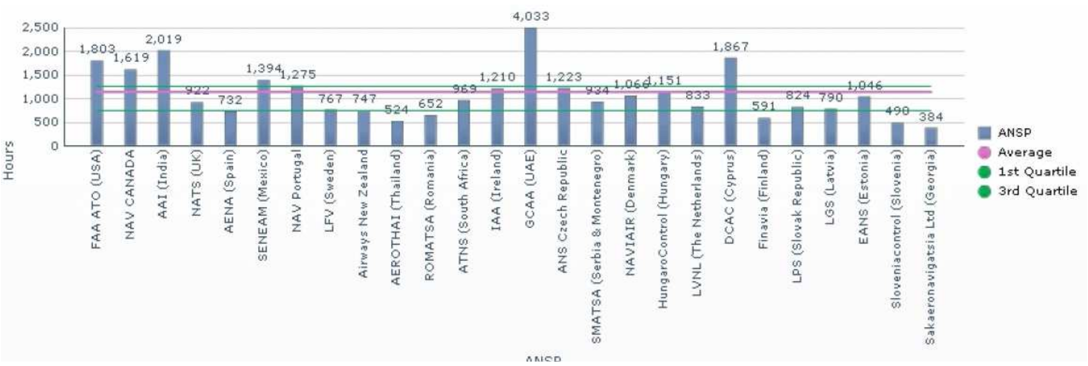


Figure 5.11: IFR Flight Hours per ATCO in Operations by ANSP 2010 (CANSO, 2011)

ATCO employment costs per ATCO-hour

For FAA ATO the ATCO employment costs per ATCO are 171,000 U.S. Dollars for 2010, which is equivalent to about €128,029. A reason for this is the high amount of controlled IFR flight hours. When dividing the costs by the 1,780 working hours per ATCO in the US, the employment costs per ATCO-hour are about €72 (CANSO, 2011, p.30). The US is thus having lower ATCO employment costs per ATCO-hour than Europe, which means that the ANSP (and ATCOs) of the US is operating efficiently and lessons can be learned from their operations.

ATCO employment costs per composite flight hour

The ATCO employment costs per composite flight amount 95 U.S. Dollars per hour, which is about €71 per hour for 2010. Compared to the €125 ATCO employment costs per composite flight hour in Europe, the costs are significantly lower (43%) in the US in 2010 (CANSO, 2011, p.29).

Total costs per composite flight hour

For FAA ATO the total costs per IFR Flight Hour (continental) are 429 U.S. Dollars. This is about €321 per composite flight hour, which is 23% less than the total costs for Europe (CANSO, 2011, p.28).

5.3 Performance air traffic management in New Zealand and Canada

In this section there is a performance comparison between Europe, New Zealand and Canada. This comparison is based on the indicator cost-efficiency, because the ‘Global ANS Performance Report’ of CANSO gives information mainly on this indicator. The CANSO Report evaluates upon the KPIs per ANSPs for 2010. The comparison with New Zealand is interesting since there is a strong user involvement in the investment planning. For Canada it is interesting, because the ANSP is controlled by a private sector service provider. Through comparing the performance of these ANSPs, conclusions can be drawn with regard to the structure of ANSPs (CANSO, 2011).

5.3.1 Cost-efficiency New Zealand

Airways New Zealand is the operating ANSP for New Zealand with about 351,680 IFR Flight Hours for 2010, for which the cost-efficiency indicators are displayed below (CANSO, 2011, p.18).

ATCO-hour productivity

In Figure 5.11 the ATCO-hour productivity is given. For Airways New Zealand there are 747 IFR Flight Hours per ATCO in Operations for 2010 (CANSO, 2011, p.28). In order to determine the composite flight hours per ATCO-hour, the average annual working hours for ATCOs in Operations is needed. For Airways New Zealand this is 1,364 hours in 2010. The 747 IFR flight hours divided by the 1,364 ATCO-hours gives the average of 0.55 composite flight hours per ATCO-hour in 2010 for New Zealand (CANSO, 2011, p.33).

ATCO employment costs per ATCO-hour

The CANSO Report is giving the ATCO employment costs per ATCO by ANSP for 2010. For Airways New Zealand the costs are 107,000 U.S. Dollars, which is equivalent to about €80,073. When dividing this by the 1,346 working hours per

ATCO in New Zealand, the employment costs per ATCO-hour amount about €59 (CANSO, 2011, p.30). This is 38.5% lower than for Europe.

ATCO employment costs per composite flight hour

The ATCO employment costs per composite flight amount 143 U.S. Dollars per hour, which is about €107 per hour for 2010. Compared to the €125 ATCO employment costs per composite flight hour in Europe, the costs are about 15% lower for New Zealand in 2010 (CANSO, 2011, p.29).

Total costs per composite flight hour

For Airways New Zealand the total costs per IFR Flight Hour (continental) 375 U.S. Dollars. This is about €281 per composite flight hour, which is about 33% less than the total costs for Europe (CANSO, 2011, p.28).

5.3.2 Cost-efficiency Canada

NAV Canada is the operating ANSP for Canada with a high amount of IFR Flight Hours in 2010, namely about 3,230,049 hours. The KPIs for cost-efficiency are given below (CANSO, 2011, p.18).

ATCO-hour productivity

For NAV Canada there are 1,619 IFR Flight Hours per ATCO in Operations for 2010, which is more than twice as much as for Airways New Zealand (CANSO, 2011, p.28). For NAV Canada the average annual working hours per ATCO in Operations is 1,609 hours in 2010. The 1,619 IFR flight hours divided by the 1,609 ATCO-hours gives the average of 1.01 composite flight hours per ATCO-hour in 2010 for Canada (CANSO, 2011, p.33). The composite flight hours per ATCO-hour for Canada is thereby higher than the 0.77 hours for Europe.

ATCO employment costs per ATCO-hour

For NAV Canada the ATCO employment costs per ATCO are 181,000 U.S. Dollars for 2010, equivalent to about €135,451. Dividing the costs by the 1,609 working hours per ATCO in Canada, gives about €84 ATCO employment costs per ATCO-hour (CANSO, 2011, p.30). This is lower than for Europe, but higher than for New Zealand.

ATCO employment costs per composite flight hour

The ATCO employment costs per composite flight amount 112 U.S. Dollars per hour, which is about €84 per hour for 2010. Compared to the €125 ATCO employment costs per composite flight hour in Europe, the costs are significantly lower (33%) for Canada in 2010 (CANSO, 2011, p.29).

Total costs per composite flight hour

For NAV CANADA the costs per IFR Flight Hour (continental) are 346 U.S. Dollars. This is about €259 per composite flight hour, which is 38% less than the total costs for Europe (CANSO, 2011, p.28).

5.4 Cost-efficiency comparison between European ANSPs, FAA ATO (US), Airways New Zealand and NAV Canada

The following table gives a quick overview of the key performance indicators on cost-efficiency for the European ANSPs, Airways New Zealand and NAV Canada for 2010. It also gives an indication of the share of the total costs that can be assigned to the ATCO employment costs per composite flight hour.

Table 5.1: Indicators for cost-efficiency for 2010

Cost-efficiency	Europe	US	New Zealand	Canada
ATCO-hour productivity (in flight hours per ATCO-hour)	0.77	1.01	0.55	1.01
ATCO employment costs per ATCO-hour (in €)	96	72	59	84
ATCO employment costs per composite flight hour (in €)	125	71	107	84
Total costs per composite flight hour (in €)	419	321	281	259
Share ATCO employment costs of the total costs per flight hour (in %)	30	22	38	32

A conclusion that can be drawn is that the ANSPs of New Zealand, Canada and the US perform better in terms of cost-efficiency than Europe. The share of ATCO employment costs of the total costs per flight hour is an important indicator for the performance of the ANSPs. The US performs best in terms of ATCO employment costs, since there it is only a share of 22% of the total costs. A reason for this can be that the ANSP in the US works efficient with less staff and more flight operations and it has the lowest ATCO employment costs per composite flight hour. New Zealand is having the largest share of ATCO employment costs of the total costs, which can be explained by the fact that there is strong user involvement in the investment planning, which will probably lead to reduced costs for other things.

Another remark when looking at the above table is that it needs to be considered that Europe, the US, New Zealand and Canada all fly with a different composition and size of aircraft (small, medium or large). Given this, the average seats per flight and the average passengers per flight differs. As see before in the beginning of this chapter, Europe flies with larger aircrafts and there are more passengers per movement in Europe than in the US. European aircrafts transport on average 22% more passengers per movement in comparison to the US. This can be an argument for the higher ATCO employment costs per composite flight hour and the higher total costs per composite flight hour in Europe.

5.5 Concluding remarks

This chapter elaborates on the performance of European air traffic management compared to the US, because the US has only one ANSP and the volume of the airspace is comparable with 10.4 million km^2 airspace in the US and 11.5 million km^2 for Europe. The conclusion is that ATM in the US performs more efficiently, because there are 67% more flights handled with less air traffic controllers than in Europe. However, in Europe more passengers are carried per flight, namely 102 passengers per movement against 88 in the US. In the US 82% of the flights are on time against 75.5% in Europe, which is due to the fact that there are 57 times more en-route ATFM delays in Europe (5.7%) than in the US (0.1%). Moreover, the horizontal en-route flight efficiency is lower in Europe, because there is 50%

more en-route extension than in the US. Furthermore, it is seen that the cost-efficiency in the US performs better, with €321 total costs per composite flight hour and an ATCO-hour productivity of 1.01 composite flight hours per ATCO-hour. The cost-efficiency is also compared with New Zealand and Canada, because New Zealand has strong user involvement in the investment planning and Canada is controlled by a private sector service provider. Canada has a higher air traffic controller productivity and they both have lower total costs per flight hour. Overall, this comparison will be used later in chapter eight upon assessing the environmental impact of full implementation of SES. Thereby is determined what benefits can be achieved, referring back to the performance of the US. Especially the better performance of the US in terms of en-route ATFM delay is hereby important.

6 Current environmental impact of air transport

6.1 Current environmental impact

This section elaborates further on the current environmental impact of air transport in Europe. The environmental impact is assessed via fuel burn and greenhouse gas emissions. Greenhouse gas emissions are carbon dioxide (CO_2), methane (CH_2), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_4) emissions all together. The most important emission in air transport is CO_2 emission, because they are the most detrimental since they emit by far the most of all greenhouse gasses in aviation (UNFCCC, 2012a, p.3). This is also elaborated in section 6.1.2. Therefore the focus of this study is on carbon dioxide (CO_2) emissions.

Through continuing the line of past development and past growth in environmental impact to the future, the baseline scenario is determined here. In order to be able to assess the impact of Single European Sky on the environment later on, this chapter provides data on past forecasts for the development of CO_2 emissions in aviation without the implementation of SES. This is done from 2000, where studies from around 2000 concerning forecasts for greenhouse gas emission development in aviation in Europe are useful. No radical technologies or innovations (such as SES) are taken into account in this scenario and no drastic changes are in place, also to be able to determine the impact of SES. The baseline scenario is given until the year 2030, because a long-term perspective is essential in order to determine the environmental impact with and without SES.

6.1.1 Fuel burn

First of all, further information on current fuel burn and past developments (in the period 1990-2010) in fuel burn in aviation is given here, because fuel burn is in direct relation to CO_2 emissions. The dominant fuel for aircrafts is kerosene, a substance based on crude oil. The most common fuel in Europe is Jet A-1, with a freezing point of -47°C, a flash point of 38°C and an auto-ignition temperature of 210°C (National Technical University of Athens, 2009). The environmental effects of jet kerosene are similar to those of gasoline and diesel, because the emissions per liter fuel are comparable (UNFCCC, 2012b). Jet kerosene emits about 3.15 tonnes CO_2 per tonne fuel (ATAG, 2010, p.5). Figure 6.1 gives an overview of the development in fuel burn in civil aviation over the period 1990 to 2010 for EU-27 (EEA, 2012b, p.887).

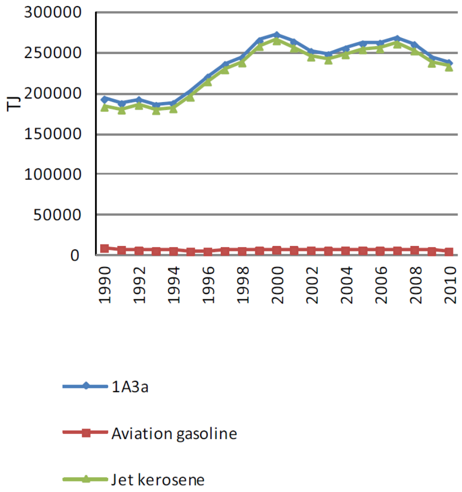


Figure 6.1: Fuel burn in civil aviation for the period 1990-2010 for EU-27 (EEA, 2012b)

From Figure 6.1 can be derived that fuel burn increased over this period, which is due to growth in the aviation sector and more flights per year. Fuel burn increased from about 193,922 TJ fuel in 1990 to about 239,167 TJ fuel in 2010 (UNFCCC, 2012b). The increase in fuel burn is mainly due to the period 1994 to 2000, in which there was steady increase. From 2000 to 2010 there were fluctuations in fuel burn between about 240,000 TF fuel and 270,000 TJ fuel. It is also visible in this figure that jet kerosene is the primary fuel in civil aviation and that aviation gasoline only takes a small part (EEA, 2012, p.887). The fuel burn per flight differs, because this is depended on the type of aircraft. Size, load and efficiency of the aircraft and the length of the flight are important parameters.

6.1.2 Emissions

As seen before in chapter four, the total CO_2 emissions from aviation have a share of 3.5% in the total CO2 emissions in Europe in 2011, with 0.2% of these emissions related to ANS inefficiencies (Eurocontrol, 2012a, p.20). Further elaboration on the CO_2 emissions in total and specifically for aviation is given here.

Greenhouse gas emissions in EU-27

Greenhouse gas emissions from air transport are increasing at a high rate, because air transport is a fast growing sector. The United Nations Climate Change Secretariat (UNFCCC) published data on the greenhouse gas (GHG) emissions for the European Union (27), with the development from 1990 to 2010. On the website of UNFCCC this data can be extracted and detailed by party and greenhouse gas. The greenhouse gas emissions per transport mode are given in the following table for the year 2010. Aviation is divided here in ‘civil aviation’ and ‘international aviation’. International aviation is extracted from so called ‘international bunkers’. International bunkers are treated separately, together with marine, due to the fact that the UNFCCC excludes these international bunker fuel emissions from national totals, because there are problems with allocating these emissions to national inventories (UNFCCC, 2012b).

Table 6.1: Annual greenhouse gas emissions for EU 27 per transport mode per greenhouse gas source for 2010 (in Gg) (UNFCCC, 2012b)

Greenhouse gas source	**CO_2**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
Civil aviation	17,196	0.39	0.57	66.97	70.56	5.42	4.85
International aviation	131,620	1.49	3.90	465.80	87.84	36.11	27.52
Road transportation	865,688	70.13	30.50	3,796	7,209	1,159	7.23
Railways	6,966	0.49	1.23	111.30	41.12	11.03	4.28
Navigation	18,975	2.91	0.93	334.92	451.82	131.87	154.34
Other transportation	9,809	1.41	0.67	40.93	114.18	15.01	0.34
Total	**1050,254**	**76.83**	**37.80**	**4,815**	**7,974**	**1,358**	**198.55**

For this study, only GHG data regarding CO_2 emissions is used, because this is by far the most emitted greenhouse gas in aviation, as seen in this table. For civil aviation CO_2 emissions are 17,196 Gg out of the total greenhouse gas emissions of 17,345 Gg emissions, which means that 99.14% of the greenhouse gas emissions in civil aviation are CO_2 emissions. For international aviation the CO_2 emissions are 131,620 Gg out of the total of 132,243 Gg emissions, which makes 99.53% of the greenhouse gas emissions CO_2 emissions in international aviation.

Total CO_2 emissions in EU-27

The following figure shows the shares in annual CO_2 emissions, assigned to the specific sectors for the year 2010 for the European Union (27), where international aviation is also incorporated (UNFCCC, 2013).

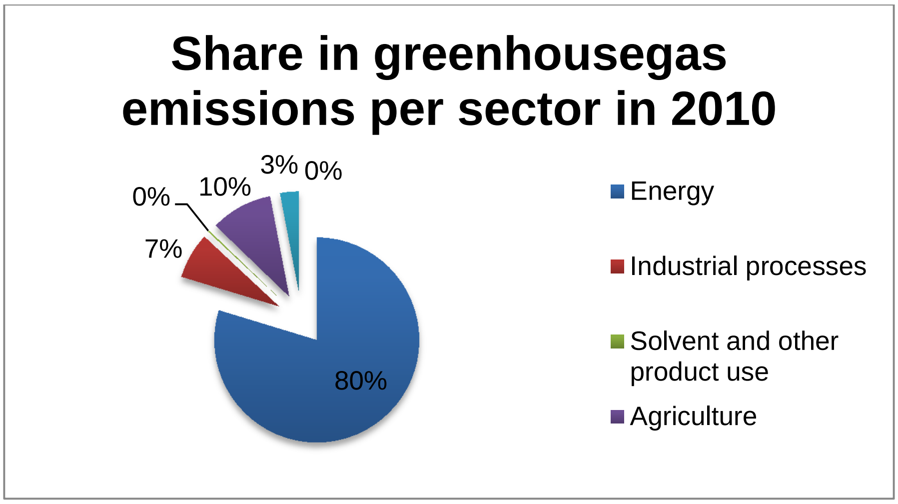


Figure 6.2: Share in greenhouse gas emissions per sector for 2010 in the European Union (27) (UNFCCC, 2013)

The distribution is grouped by ‘energy’, ‘industrial processes’, ‘solvent and other product use’, ‘agriculture’, ‘waste’ and ‘other’. Energy accounts for 80% of total greenhouse gas emissions. The total GHG emissions in EU-27 are 4,721 Tg CO_2 equivalent in total for the year 2010, of which 3,891 Tg CO_2 emissions (EEA, 2012b, p.viii).

Energy sector

The sector energy is divided into the categories ‘energy industries’, ‘manufacturing industries and construction’, ‘transport’, ‘other sectors’ and ‘other’. Figure 6.3 gives an overview of the share of these categories in CO_2 emissions within energy.

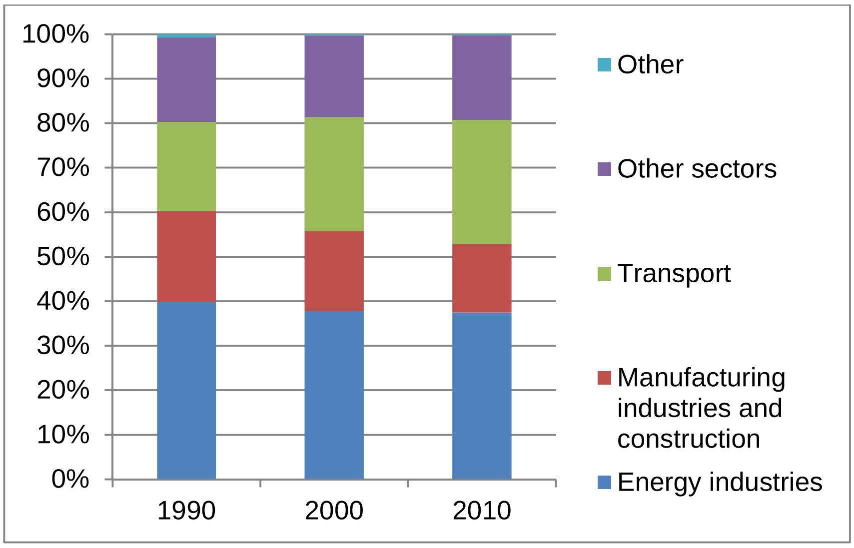


Figure 6.3: Share in CO_2 emissions per category within energy for 1990-2010 in the European Union (27) (UNFCCC, 2013)

Transport sector

The category transport is important for this study. It is seen that transport accounts for 27.91% of CO_2 emissions within the sector energy in 2010. Essential here is that the share of transport is becoming larger over time. In the base year 1990 the category transport had a share of 19.97%, a share of 25.71% in 2000 and a share of 27.91% of the total CO_2 emissions in fuel combustion in energy in 2010. Emissions in transport are thus increasing rapidly and this is an alarming case. The figure below gives an overview of the changes in total greenhouse gas emissions from 1990 to 2010 in percentages per sector (UNFCCC, 2011).

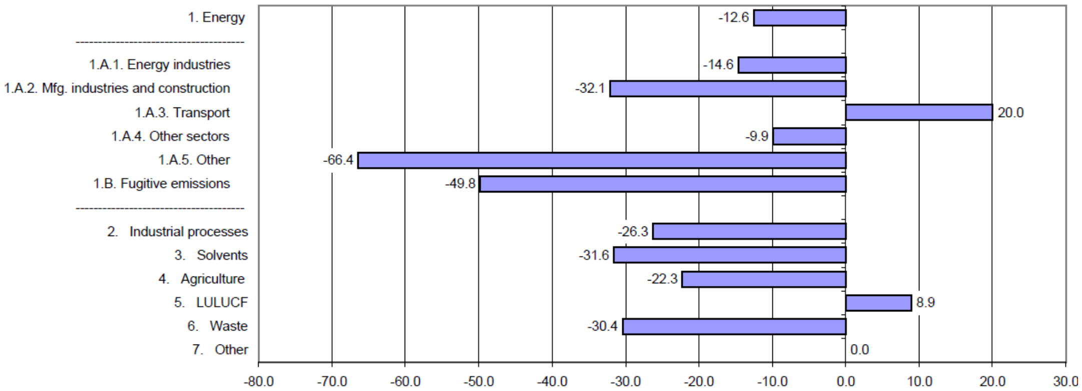


Figure 6.4: Change in greenhouse gas emissions from 1990 to 2010 in % (UNFCCC, 2011)

For the sector transport it is seen that greenhouse gas emissions increased with 20%, which is the highest increase of all sectors. The sector LULUCF increased also, but all the other sectors observed a decrease in greenhouse gas emissions from 1990 to 2010. This makes the transport sector even more interesting in terms of becoming more sustainable and making changes.

Aviation

In order to examine where the increase comes from, it is essential to look at the contribution of each specific transport mode. Figure 6.6 illustrates the contribution per transport mode, which are 'civil aviation', 'international aviation' 'road transportation', 'railways', 'navigation' and 'other transportation'. 'Civil aviation' is the part of aviation emissions that is incorporated in national inventories and 'international aviation' is the part of aviation emissions that are neglected in national considerations of emissions, due to difficulties in monitoring. Data for international aviation is retrieved from 'memo items – international bunkers - aviation' in the UNFCCC database (UNFCCC, 2013). The sum of 'civil aviation' and 'international aviation' gives therefore the total CO_2 emissions of aviation in the EU. The group 'navigation' includes the emissions from shipping.

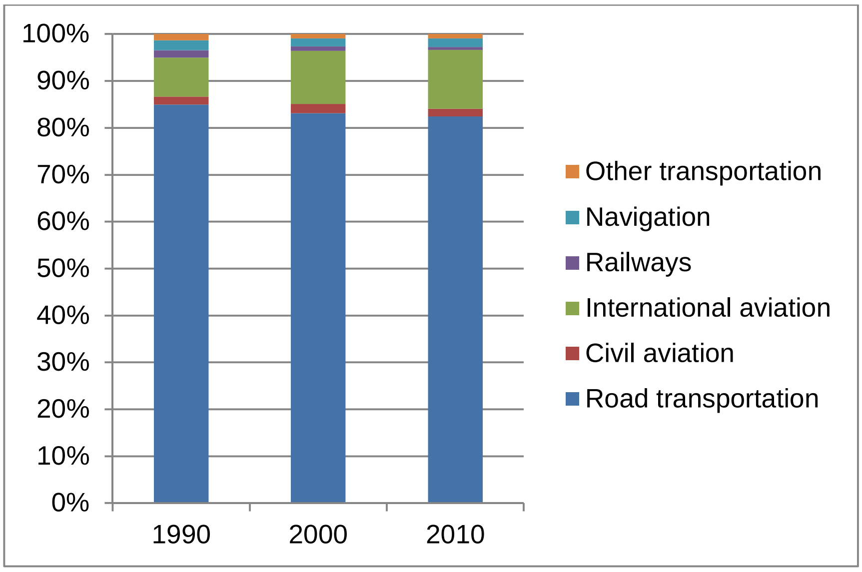


Figure 6.5: Share in CO_2 emissions per transport mode for 1990-2010 in the European Union (27) (UNFCCC, 2013)

From Figure 6.6 can be concluded that the share of civil aviation in total CO_2 emissions from transport did not increase from 1990 to 2010, which is also due to growth in road transportation and the higher emissions in total. The share of civil aviation in 1990 was 1.68% of total CO_2 emissions in transport in EU-27 and it did decrease to a share of 1.64% in 2010. CO_2 emissions from international aviation are also given in this figure, which takes a larger share in total CO_2 emissions in transport with an increase from 1990 to 2010. The share of international aviation was 8.32% in 1990 and increased to 12.53% in 2010. Figure 6.7 below gives an overview of the total annual CO_2 emissions in Tg for the European Union (27) in the transport sector. Table 6.2 provides the exact data for 1990, 1995, 2000, 2005 and 2010.

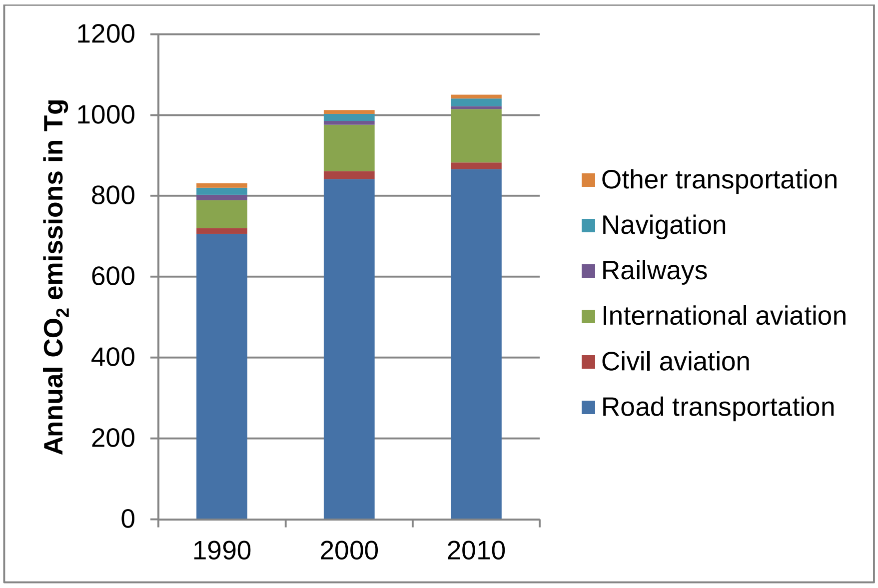


Figure 6.6: Annual CO_2 emissions for European Union 27 in transport (in Tg) (UNFCCC, 2013)

Table 6.2: Annual CO_2 emissions for EU 27 in transport (in Tg) (UNFCCC, 2013)

Category	1990	1995	2000	2005	2010
Civil aviation	13.95	14.53	19.68	18.87	17.20
International aviation	69.11	85.89	115.17	131.11	131.62
Road transportation	706.37	765.36	841.43	895.84	865.69
Railways	13.30	10.03	9.12	7.70	6.97
Navigation	17.56	16.99	17.27	18.27	18.97
Other transportation	10.82	9.30	9.57	10.52	9.81
Total	**831.12**	**902.09**	**1012.25**	**1082.31**	**1050.25**
Total aviation	**83.06**	**100.42**	**134.85**	**149.98**	**148.82**
Share aviation	**9.99%**	**11.13%**	**13.32%**	**13.86%**	**14.17%**

It is obvious that road transportation contributes the most to the total CO_2 emissions of transport, with 82.43% in 2010. Road transportation accounted for about 866 Tg, out of a total of 1050 Tg CO_2 emissions in transport in 2010. Aviation shows a steady increase in CO_2 emissions, both in civil and international aviation (IEA, 2012, p.66). Civil aviation increased from 13.95 Tg CO_2 emissions in 1990 to 17.20 CO_2 emissions in 2010, with a high increase from 1995 to 2000, where CO_2 emissions were 19.68 Tg for civil aviation in 2000. CO_2 emissions from international aviation increased more rapidly, since emissions almost doubled from 1990 to 2010. In 1990 CO_2 amounted to about 69 Tg and in 2010 there were about 132 Tg CO_2 emissions from international aviation. In total the CO_2 emissions from aviation increased with 79% from 1990 to 2010. It is alarming that the CO_2 emissions increase at such a high rate in aviation over a time period of 20 years. This is due to the rapid growth in air transport, where radical changes are needed in order to diminish the environmental impact of aviation.

In 2010 the emissions from civil aviation contributed for 1.64% to the total CO_2 emissions in transport and international aviation contributed for 12.53% of the total CO_2 emissions (UNFCCC, 2013). The share of total aviation emissions from total transport emissions increased from 9.99% in 1990 to 14.17% in 2010. The

European Commission also published statistics on greenhouse gas emissions of international aviation in 2005, where they stated that there was an increase of 73% in greenhouse gas emissions of international aviation from 1990 to 2003 (European Commission, 2005, p.2).

The development of CO_2 emissions from civil aviation is displayed in the following figure for the period 1990-2010, where the increase in CO_2 emissions is visible.

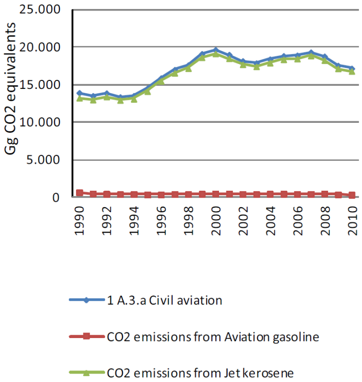


Figure 6.7: CO_2 emissions of civil aviation for the period 1990-2010 for EU-27 (EEA, 2012b)

A sharp increase in CO_2 emissions is visible in this figure from 1994 to 2000. It is seen that the majority of CO_2 is emitted through the combustion of jet kerosene, because aviation gasoline is not that much used. From 1990 to 2010 CO_2 emissions from jet kerosene in civil aviation increased with 27% in EU-27 (EEA, 2012b, p.887). Figure 6.8 is in line with the previous section on jet kerosene and the fluctuations over the years are similar, because the total CO_2 emissions is a factor of the total fuel burn. The emission factor is 71.92 tonnes CO_2/TJ, which makes the total CO_2 emissions a multiplication of 239,167 TJ consumption and 71.92 tonnes CO_2/TJ, with the outcome of 17.20 Tg CO_2 emissions from civil aviation in 2010 for EU-27. As seen before, for 1990 the CO_2 emissions from aviation accounted much less, namely 13.95 Tg CO_2 (UNFCCC, 2012b).

The emissions of CO_2 in aviation are divided in two categories of operations, namely the Landing and Take-Off (LTO) cycle and the Cruise cycle. The LTO cycle includes all activities lower than 1,000 meter, which operate closely to the airport. As can be seen in Figure 6.9, this is the taxi-in, taxi-out, take-off, climb-out and approach landing phase. The cruise cycle includes the activities above 1,000 meter, which are the climb to cruise altitudes, cruise and descent from cruise altitudes (Reynolds et al., 2009). Most emissions in aviation, 90% of the total, occur in the Cruise phase at high altitudes. The LTO cycle and ground procedures only account for 10% of total emissions in aviation (IPCC, 2006, p.3.56).

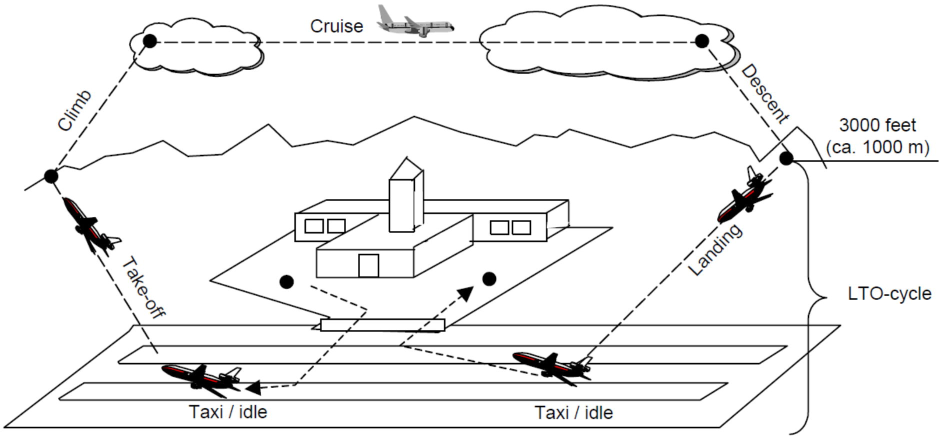


Figure 6.8: Landing and Take-off (LTO) cycle and the Cruise cycle in the flying cycle (Reynolds et al., 2009)

Air traffic management

The essential part of this study is to investigate what part of these emissions can be assigned to additional fuel burn due to inefficiencies in air traffic management, which can be cross-border congestion and not flying optimal routes. Further elaboration on air traffic management inefficiencies is in chapter eight.

6.2 Environmental targets and goals

Due to growth in the aviation sector and increased emissions, it is essential to respond to this and make changes. Several studies are conducted about what needs to be done and targets and goals are set in order to mitigate the impact on the environment. The European Commission focused both on transport in general as aviation in particular. The targets and goals that are of importance for aviation are elaborated below.

6.2.1 Challenges of Growth 2013 and White Paper on Transport 2011

Eurocontrol publishes once every 4 or 5 years a ‘Challenges of Growth’ study, with the last publication in 2013. This study provides useful information for decision makers on long-term planning decisions in aviation in Europe. It also reflects on other studies that set (sustainable) goals for aviation (Eurocontrol, 2013, p. 3). In 2011 the White Paper on Transport is published, where capacity optimization and efficiency improvements in transport are the main objective. Aviation related goals from this study are:

- 60% CO_2 reduction from 1990 to 2050
- 40% of low-carbon sustainable fuels in aviation by 2050
- Completion of the European Common Aviation Area (SES) by 2020
- Deployment of the modernized air traffic management infrastructure SESAR in Europe by 2020 (European Commission, 2011a, p.9).

6.2.2 Flightpath 2050

The targets and goals for aviation are further elaborated in the Airport Package of 2011 and the Flightpath 2050, published by the European Commission. The Airport Package consists of initiatives to improve the performance at airports, such as creating additional capacity. Flightpath 2050 is the long-term vision of aviation, with setting priorities in Europe in order to maintain growth and competitiveness worldwide, taking into account market needs and energy and climate challenges. The following goals are set in this vision on aviation (with the focus on sustainability) for the year 2050:

- 90% of European door-to-door flights are less than four hours
- Increase predictability of flights through setting a maximum of 1 minute difference between planned arrival time and actual arrival time
- Improving air traffic management in Europe so that it can handle 25 million flights per year
- 75% decrease in CO_2 emissions per passenger kilometer compared to 2000
- During taxiing aircraft movements need to be emission free (Eurocontrol, 2013, p.7) (European Commission, 2011b)

6.2.3 Environmental targets

Several organizations have set targets for European aviation with the focus on the environment. European Union's Emission Trading Scheme (EU ETS) set the goal for 2020 to reduce emissions with 10% with respect to 2005. The International Air Transport Association (IATA) has the following environmental goals for aviation:

- Improve fuel efficiency with 1.5% per year over the period 2009 to 2020
- Carbon-neutral growth from 2020
- 50% decrease in CO_2 emissions from 2005 to 2020 (Eurocontrol, 2013, p.11)

6.3 Expectations older studies and forecasts

Expectations and forecasts on the development of greenhouse gas emissions from older studies are described in this section. Lessons can be learned from older studies with respect to the expectations and the actual development in those years, which are now known. Older studies, such as from 2000, give the best view on expectations for CO_2 development that can be used for the baseline scenario, because possible impacts of SES are not included here. Right then, things can be said about the reliability of the expectations for the coming period.

6.3.1 Olsthoorn (2001)

In 2001 Xander Olsthoorn published an article called 'Carbon dioxide emissions from international aviation: 1950-2050' in the Journal of Air Transport Management, with an outlook to future emissions. The expectation is that CO_2 emissions from aviation will increase globally by a factor of 3 to 6 between 1995 and 2050. The expected development in global CO_2 emissions is given in Table 6.3 in indexes (Olsthoorn, 2001).

Table 6.3: Development in global CO2 emissions in aviation, compared to 1995 (in indexes) (Olsthoorn, 2001)

	1995	2000	2010	2020	2050
CO_2 emissions	100	121	167	216	440

Through comparing the data from this table with the actual CO_2 emissions until 2010, the reliability of the forecast can be assessed, as well as determining possible effects of Single European Sky in this period. The expectation of Olsthoorn (2001) is that in 2010 the annual CO_2 emissions are 67% higher than in 1995, which means that the CO_2 emission will increase from 100.42 Tg CO_2 in

1995 to 167.70 Tg CO_2 in 2010. It is seen in Table 6.2 that the actual CO_2 emissions in 2010 were less than expected, namely 148.82 Tg CO_2. A possible reason for this can be the implementation of SES, but an important remark is also that the expected development from Olsthoorn was for global CO_2 emissions and not for Europe. Global forecasts cannot directly be transferred to European forecasts, but it gives an overview of possible development.

The expectations from Olsthoorn are similar to the scenarios that are published by the Intergovernmental Panel on Climate Change (IPCC) in a report from 1999, called 'Aviation and the global atmosphere'. The IPCC summarized past studies on the development of global CO_2 emissions from aviation, with the emission inventories from NASA, ANCAT/EC2 and DLR being the most relevant. Global fuel burn in 1992 was about 133 Tg and the forecast is that this will increase to about 298 Tg in 2015 and 556 Tg in 2050. The CO_2 emissions are expected to grow from 115 Tg in 1992 to about 252 Tg in 2015 (IPCC, 1999, p.295-331). These expectations are also in the same range as the report 'Flying into the Future: Aviation Emissions Scenarios to 2050' by Owen et al. (2009). This report examines for different SRES market scenarios, A1, A2, B1 and B2, the expectations for 2100, which range from a factor of 1.1 to 7.5 more aviation emissions than in the year 2000 (Owen et al., 2009, p.E).

6.3.2 Amann (2010)

Amann (2010) published a report called 'Greenhouse gases and air pollutants in the European Union: baseline projections up to 2030' whereby it is estimated that passenger travel activity will increase with 35% from 2005 to 2030 in EU-27, with the highest increase in air transport. This means that the fuel consumption between 2005 and 2030 will also increase, especially in air travel. The expected development in fuel burn until 2030 is given in Figure 6.10 per transport mode for EU-27 (Amann, 2010, p.29).

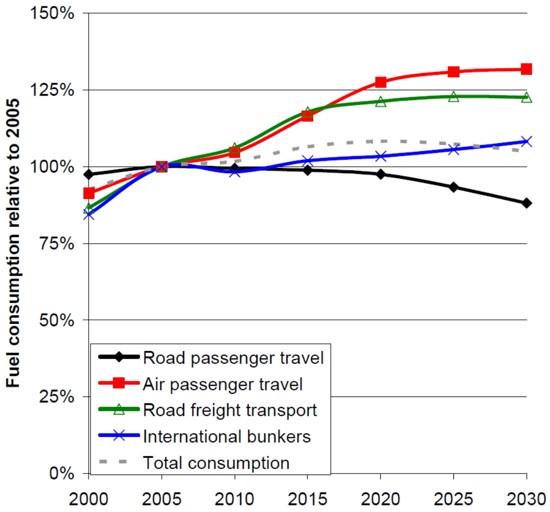


Figure 6.9: Development in fuel consumption per transport mode for EU-27 (Amann, 2010)

From this can be derived that Amann expects a steady increase in fuel burn in air passenger travel from 2005 to 2020. The forecast is that fuel burn will be 30% higher in 2030 in comparison to 2005.

6.3.3 EU Energy trends to 2030 (2009)

In 2009 the European Commission published an outlook for energy trends to 2030. CO_2 emissions are expected to grow in the transport sector, with the development for 1990 to 2030 given in Figure 6.11 below.

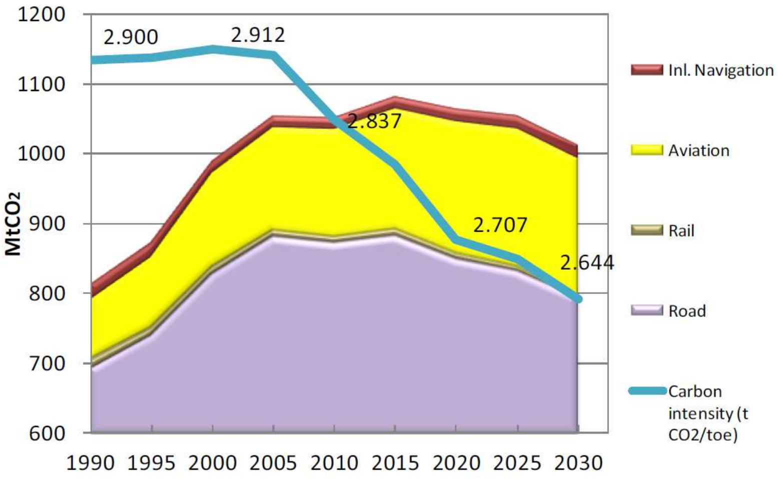


Figure 6.10: Development in CO_2 emissions in the transport sector in EU-27 (European Commission, 2010)

The yellow area in this area is of importance, because this reflects the aviation sector. This scenario is determined through current trends and policies from 2009 and it also includes EU ETS and energy efficiency measures. In the report upon energy trends it is assumed that there will be improvements, gains and innovations in the transport sector (European Commission, 2010). However, the implementation of Single European Sky is not taken into account here, but it will definitely be incorporated in the gains in the aviation sector in some way since the European Commission expects to fully implement SES in the future.

It is seen that it is the forecast of this study that CO_2 emissions from aviation will rise until 2030, with emissions of about 197 Tg CO_2 in 2030 (European Commission, 2010, p.10-47). The expectation is that the carbon intensity will decrease further until 2030. The figure is in line with the forecasts of Amann (2010), because 30% increase in fuel burn from about 150 Tg CO_2 emissions in 2005 leads to about 195 Tg (=195 Mt) CO_2 emissions in 2030. The exact data from Figure 6.11 is given in the table below.

Table 6.4: Annual CO_2 emissions in the transport sector in EU-27 (in Tg) (European Commission, 2010)

Category	1990	1995	2000	2005	2010	2015	2020	2025	2030
Road	691.1	739.1	826.1	879.7	870.8	881.1	847.8	830.9	793.7
Rail	12.9	11.3	10.7	9.5	8.8	9.8	8.3	6.5	1.2
Aviation	86.1	101.1	134.6	147.3	154.1	172.4	188.6	197.2	197.0
Inland navigation	21.9	21.4	17.1	16.6	16.8	17.5	18.3	19.0	19.6
Total	**812.7**	**872.9**	**988.5**	**1053.1**	**1050.6**	**1080.7**	**1063.1**	**1053.6**	**1011.6**

The category aviation includes civil and international aviation. The increase in CO_2 emissions in aviation from the study of the European Commission (2010) is given in Figure 6.12 below for the period 2000 until 2030, with a sharp increase from 2010 to 2020.

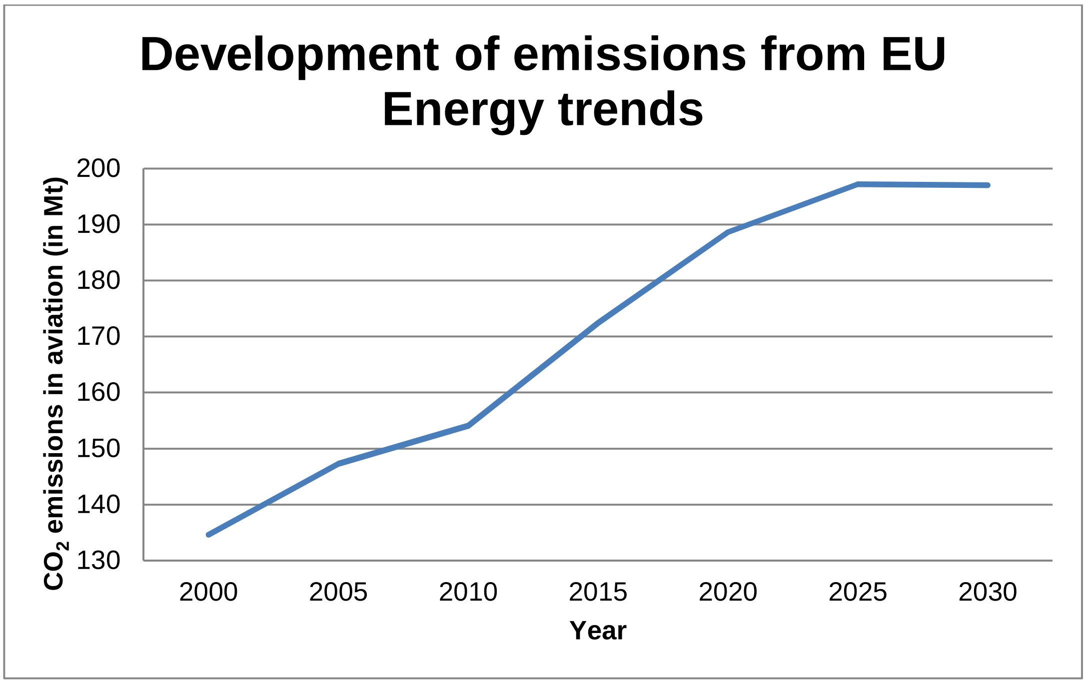


Figure 6.11: Development of CO_2 emissions in aviation in EU-27 (European Commission, 2010)

Table 6.5 below gives the increase in CO_2 emissions in percentages compared to the emissions in 2005, which amounted 147.3 Tg CO_2.

Table 6.5: Increase in CO_2 emissions in aviation in EU-27 (in %), compared to 2005

	2010	2015	2020	2025	2030
Increase in CO_2	4.6%	17.0%	28.0%	33.9%	33.7%

The data and forecasts from these data sources can be used to determine the baseline scenario in the next section. Especially the older reports are interesting, because these do not (or partially) take Single European Sky into account when making estimations. A better estimation of the impact of SES on emissions can then be given in the end. The only remark is that the assumptions from older reports are right now a bit outdated, as well as their indicators, so the forecast for 2015-2030 are not so relevant. The interesting part of these older studies is the forecast from 2000 until 2015.

6.4 Baseline scenario

6.4.1 Introduction

The baseline scenario contains forecasts for the development of CO_2 emissions in aviation in Europe, whereby current trends are extrapolated to the future. The starting year for the baseline scenario is 2000, because from this year on the impact from Single European Sky can be given since it was introduced in 2004. Thereby it is essential to use forecasts from other studies from 2000, because then the impact of SES can be assessed in the following chapter. The development is given until 2030 in the baseline scenario, because SES expects to be fully implemented and deployed by 2020 and major reductions in greenhouse gas emissions are expected to occur after 2020, which makes the period from 2020-2030 interesting with regard to the environmental impact.

No radical changes and innovations, such as Single European Sky, are taken into account in the baseline scenario. This baseline scenario assumes that the air transport sector maintains similar conditions as it is now. Fuel will still be available and there are no radical changes in technologies, aircrafts, ticket prices, demand and service availability. The impact from other travel modes will also not change. Indicators that do have an impact on this scenario for the development in CO_2 emissions are changes in gross domestic product (GDP), population development, flight efficiency (energy intensity) and passenger transport activity.

6.4.2 Overview forecasts for greenhouse gas emissions

In order to determine the baseline scenario, the data and estimations from the other studies from section 6.3 are used. An overview of the actual data and estimations from the UNFCCC (2013), Olsthoorn (2001), Amann (2010) and the EU energy trends of the European Commission (2010) is given in the table below.

Table 6.6: Development in CO_2 emissions in EU-27 from several sources (in Tg)

	2000	2005	2010	2015	2020	2025	2030
Olsthoorn (2001)	-	-	167.70	-	216.90	-	-
Amann (2010)	-	-	157.48	175.48	190.47	193.47	194.97
European Commission (2010)	*134.6*	*147.3*	*154.1*	172.4	188.6	197.2	197.0
UNFCCC (2013)	*134.85*	*149.98*	*148.82*	-	-	-	-

The actual CO_2 emissions are in italic and the other non-italic data are forecasts for the years until 2030. The CO_2 emissions of Olsthoorn (2001) and Amann (2010) are calculated by multiplying the expected increase in percentages by the current CO_2 emissions in Tg. It is seen that mainly from 2010 to 2020 CO_2 emissions are rising at a high rate, whether for the period 2020 to 2030 this growth weakens. For Amann (2010) this is due to the assumption that for the period 2020 to 2030 the economic annual growth rate reduces in this period, accompanied with a lower annual growth rate for population (Amann, 2010, p.16-18). It is assumed in the EU Energy Trends report that for the period 2020 to 2030 EU GDP growth and population growth will slow down, followed by less growth in transport activity in the aviation sector in this period (European Commission, 2010, p. 67).

6.4.3 Indicators from different sources

As can be seen in the previous table, the predictions differ per source. This is due to different assumptions for several indicators that are essential for the estimations, such as gross domestic product (GDP), population development, energy intensity and travel activity. The assumptions that are made for the indicators are given per source in the table below in order to track where difference come from. These assumptions are also used for determining the baseline scenario and later for the ‘desired’ future scenario with predictions on the impact of SES.

Table 6.7: Assumptions on indicators for EU-27 from several sources

	GDP	Population development	Energy intensity (in TJ/million €)	Passenger transport activity (in passenger km)
Olsthoorn (2001) – global assumptions	2.4% annual growth from 1995 to 2050	-	-	-
Amann (2010)	1.69% annual growth from 2005 to 2030	0.24% annual growth from 2005 to 2030	0.96% annual decrease from 2005 to 2030	2.8% annual growth from 2005 to 2030
European Commission (2010)	1.7% annual growth from 2000 to 2030	0.27% annual growth from 2000 to 2030	1.1% annual decrease in passenger transport from 2000 to 2020 and 1.6% annual decrease from 2020 to 2030	2.83% annual growth in aviation from 2000 to 2030

It is seen that not all indicators are defined in the sources or have been made accessible. The assumptions from Amann (2010) and the European Commission (2010) are similar, which is seen back in the forecasts for the development of CO_2 emissions.

For the baseline scenario in this research, assumptions are done based on the previous table. The data on the assumptions is averaged per indicator in order to give the most reliable scenario, where the assumptions from Olsthoorn (2001) are left aside. The assumptions from Olsthoorn (2001) are outdated and too aberrant from the others, which makes them not reliable for this scenario. The assumptions for the baseline scenario are given in the table for the period 2000-2030, with differing assumptions for the period 2000-2020 and for the period 2020-2030 due to significant improvements in energy intensity in the period 2020-2030 (European Commission, 2010).

Table 6.8: Assumptions on indicators for the baseline scenario for the period 2000-2030

	GDP	Population development	Energy intensity	Travel activity
Baseline scenario 2000-2020	1.7% annual growth	0.26% annual growth	1.03% annual decrease	2.82% annual growth
Baseline scenario 2020-2030	1.7% annual growth	0.26% annual growth	1.53% annual decrease	2.82% annual growth

6.4.4 Scenario

The baseline scenario is based on the assumptions from Table 6.8, with special focus to the travel activity and energy intensity parameter that can be used to forecast the CO_2 emission development. The following formula is used for determining the CO_2 emissions in year X:

$$CO_2\ emissions_{2000+x} = CO_2\ emissions_{2000} * annual\ growth\ factor\ CO_2\ emissions^{x}$$

In order to determine the annual growth factor of the CO_2 emissions, the growth in air traffic per year is needed, as well as the decrease in energy intensity per year, because despite the growth in air traffic, there will also be improvements in CO_2 emissions per flight. GDP and population development are already incorporated in these growth percentages. Therefore the annual decrease in energy intensity is subtracted from the annual growth in air traffic, which is 2.82%-1.03% = 1.79% growth in CO_2 emissions per year. This makes the formula as follows:

$$CO_2\ emissions_{2000+x} = 134.73\ Tg * 1.0179^x$$

This formula can be used for the period 2000 to 2020. However, for the period 2020-2030 the annual growth factor of the CO_2 emissions will be lower, due to improvements in energy intensity. It is seen in the ‘EU Energy Trends’ from the European Commission that in this period the energy intensity decreases with an additional 0.5% per year. This means that for the period 2020 to 2030 the annual growth factor of CO_2 emissions will be 1.29%.

The following table gives an overview of the baseline scenario for the period 2000 to 2030, using the formulas above for the CO_2 emission development.

Table 6.9: Baseline scenario of development in CO_2 emissions from aviation in EU-27

Baseline scenario	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
CO_2 emissions (in Tg)	135	147	161	176	192	205	218

This baseline scenario gives a reliable reflection upon the development of CO_2 emissions, because the outcomes fall in a similar range as the forecasts described earlier in section 6.4.2. The EU energy trends report gives somewhat lower CO_2 emissions in the years 2025 and 2030, but this can be explained by the fact that it is a report by the European Commission and they will also incorporate SES in some way in their estimations, because the European Commission expects SES to be operational in the future. However, it is not specifically mentioned in the report.

In order to give a clear overview of the baseline scenario and the data from Table 6.9, the development of CO_2 emissions from aviation in the period 2000 to 2030 is given in a graph in Figure 6.13 below.

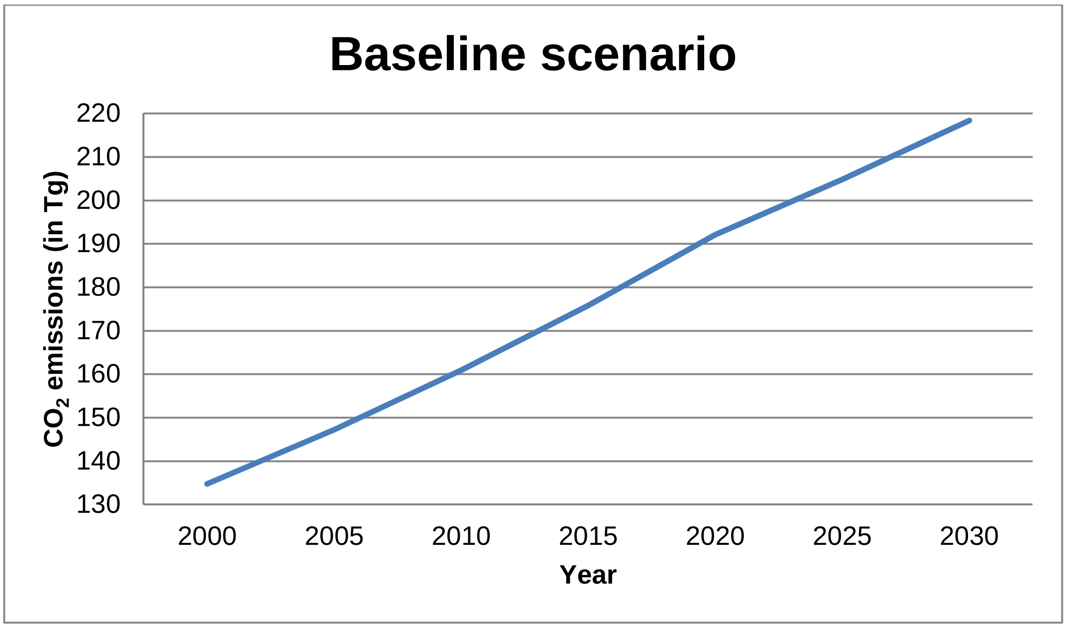


Figure 6.12: Baseline scenario of development in CO_2 emissions from aviation in EU-27

It is seen that this line is more fluent than the development in Figure 6.12, which can be explained by the fixed annual growth factor of the baseline scenario. This baseline scenario can be used for determining the impact of SES in chapter eight. From this figure can be seen that CO_2 emissions are growing rapidly, especially from 2010 to 2020.

6.5 Concluding remarks

The environmental impact of air transport is determined via the amount of CO_2 emissions, because CO_2 emissions are the most detrimental since they emit by far the most (99.3%) of all greenhouse gasses in air transport. Fuel burn increased from 193,922 TJ fuel in 1990 to 239,167 TJ fuel in 2010 in Europe, causing rapid growth in CO_2 emissions from both civil and international aviation. The total CO_2 emissions increased from 83 Tg CO_2 in 1990 to 149 Tg CO_2 in 2010 in Europe, where the emissions from international aviation almost doubled. Continuing the line of past developments to the future, with no drastic changes, gives the baseline scenario which is used to determine the impact of SES in chapter eight. The baseline scenario is given for the period 2000 to 2030, where older studies regarding forecasts of CO_2 development are examined. These studies shows different forecasts due to different assumptions on the indicators GDP, population development, energy intensity and travel activity. Based on averaged indicators from this studies, the baseline scenario is determined with 135 Tg CO_2 emissions in 2000 growing to 218 Tg CO_2 emissions from aviation in 2030 in Europe.

7 Single European Sky

7.1 Introduction

Through the rapid growth in the aviation sector, it is essential for the sector to make adjustments to the changing sector. Pressure is put on air traffic management and on the available infrastructure and airspace. Fragmentation and inefficiencies in air transport are becoming a bigger issue. This is also due to the high number of air navigation service providers, which all have their own air traffic management system, their own procedures and their own training capabilities.

In order to improve the performance of European aviation and to become more sustainable, the Single European Sky (SES) is introduced in 2000 by the European Commission (European Commission, 1999). The idea is to create a single sky in Europe, through which the design, management and regulation is coordinated by the European Union. Through having common rules, standards and procedures in Europe, there will be standardization and harmonization of air navigation services. A greater level of collaboration and improved relationships between ANSPs are essential to improve current operations. National boundaries will become less dominant in air traffic management with the implementation of Single European Sky. This leads to less cross-border inefficiencies, less fragmentation and increased capacity (Desart et al., 2009, p.81-82). Consequence is less congestion and less delays, which is beneficial for the environment because there is a reduction in fuel burn and greenhouse gas emissions.

Within SES there are four key performance areas: safety, capacity, environment and cost-efficiency. Improving performance in these areas is the key objective. The following five pillars form the context within the Single European Sky framework:

- The legislative pillar, performance-based regulatory framework
- The airport pillar, optimization of the airport infrastructure
- The safety pillar
- The technological pillar
- The human factor (European Commission, 2008a)

7.2 Targets

With the implementation of Single European Sky, several targets are set in order to speed up the deployment, to improve current functioning and to achieve goals. Specific goals per key performance area are set. The following goals are set by the European Commission in 2005, with full implementation of SES:

- Safety: safety improvement by a factor of ten from 2005 to 2020, with regard to ATM induced accidents
- Capacity: tripling airspace capacity from 2005 to 2020, with reducing delays on the ground and in the air
- Environment: lowering the environmental impact of aviation by 10% from 2005 to 2020, compared to the baseline scenario

- Cost-efficiency: reduction of cost of air traffic management by 50% from 2005 to 2020 (SESAR, 2012, p.17)

The context of the environmental target will be further elaborated in the next chapter, where the environmental impact of full implementation of SES is being determined. The aim is to reduce the greenhouse gas emissions.

7.3 SES I

Several regulations and legislations concerning SES are adopted. In 2004 the SES I legislative package was adopted and in 2009 the SES II package. The first package, SES I, includes technical standards with specific rules and community specifications. The SES I package includes regulation on the following aspects:

- A framework for the creation of Single European Sky
- The organization and use of the airspace
- Provision of air navigation services
- Interoperability of the European air traffic management network

This is the main focus of SES I, together with the initiative of the functional airspace blocks (FABs), the initiative of flexible use of airspace (FUA), establishment of the performance scheme, the charging scheme, air traffic control officer licensing and the management and operation of the network (European Commission, 2004a).

7.4 SES II

Due to slow development from 2004 to 2009, a new package, SES II, was introduced in 2009 in order to accelerate the development. The main focus of this package is improving the performance of air traffic management, with taking care of the key objectives safety, capacity, environment and cost-efficiency. The SES II package focuses on the following four key initiatives:

- The performance scheme
- The functional airspace blocks (FABs)
- The network manager
- The charging regulation (European Commission, 2008a)

For this research, these pillars are interesting in terms of consequences for the environmental impact. Further elaboration and explanation on the context of these initiatives is given in the following section (7.5).

7.5 Key initiatives

7.5.1 Introduction

Improvements in the aviation sector are crucial in order to cope with the growing demand and also to address climate change and to diminish the environmental impact of aviation. Solutions can be found in the following aspects:

- Technology, through alternative fuels
- Operational efficiency, through improving operations and saving fuel
- Infrastructure improvements, reducing emissions through addressing air traffic management inefficiencies
- Economic measures, through charge regulation

There is an initiative in place for improving energy efficiency, reducing emissions and reducing aircraft noise, which is called the Atlantic Interoperability Initiative to Reduce Emissions (AIRE). This is in cooperation with the FAA, where ATM stakeholders work together to improve performance and integrate flight trials (SESAR, 2010a, p.10).

The environmental target of SES, lowering the environmental impact of aviation by 10% from 2005 to 2020, aims at finding solutions to reduce greenhouse gas emissions from aviation. The possible effects of SES are related to air traffic management. Possible solutions to reduce air traffic management related emissions with SES are:

- Improving flight efficiency, by designing more optimal and direct routes
- Reducing congestion and delays, by reducing cross-border inefficiencies and avoiding to keep aircrafts in a holding
- Improving air traffic management systems and procedures (technology)

SES aims at improving the flight profile, routes, procedures and operations in air traffic management. This means that a part of the 7-11%, due to ATM and airport inefficiencies (from chapter 4.4), of the total fuel burn in aviation can be saved with SES, which results in reduction of CO_2 emissions. Major improvements can be made through shorter routes and better approach procedures (IEA, 2009, p.327).

In order to make these solutions concrete and to enforce improvements, five key initiatives within SES are initiated, which can have an effect on the environmental performance of the air transport sector. The initiatives are technological, operational, infrastructural and economical related. Each initiative is further explained in the following sections. Moreover, the initiative of Flexible Use of Airspace (FUA) is also explained. The five key initiatives are listed below, of which four are already mentioned before in the SES II package.

- The performance scheme = operational solution
- Functional Airspace Blocks (FABs) = infrastructural solution
- The network manager = operational solution
- Charging regulation = economic solution
- Single European Sky ATM Research (SESAR) = infrastructural solution (Eurocontrol & European Commission, 2012)

7.5.2 The performance scheme

The performance scheme is introduced in order to accomplish punctual, greener and more cost-efficient air transport. This is initiated through setting and implementing binding performance targets for EU Member States. Consistent performance plans and incentive mechanisms are included. Only from January 2012 the performance scheme has been operational. The aim of the performance scheme is to reduce fragmentation of the airspace and to improve the cooperation between air navigation service providers (ANSPs) and the national supervisory authorities (NSAs). Efficiency improvements can be achieved through better communication, common procurement, training and improving resources of air traffic controllers (ATCs). Increased capacity and shorter flight paths results in less delays, less costs and a lower environmental impact (Eurocontrol & European Commission, 2010, p.2-11).

The four performance areas safety, capacity, environment and cost-efficiency are incorporated in the performance scheme. Performance targets are set for reference period 1, which is 2012-2014, for the whole EU. These targets include the performance areas, except for safety:

- Capacity: target of 0.5 minute en-route ATFM delay per flight in 2014
- Environment: a reduction of 0.75% of the route extension between 2009 and 2014
- Cost-efficiency: target of unit rates per service unit of €57.88 in 2012, €55.87 in 2013 and €53.92 in 2014 (in €2009) (Eurocontrol & European Commission, 2010, p.35)

7.5.3 Functional Airspace Blocks

As seen before, an important problem of the European airspace is that it is fragmented and that ANSP units become sub-optimal. About 70% of all flights in Europe are concentrated into 14% of the available airspace (ATAG, 2010, p.17). Flight routes are not optimal and are often longer than the direct route, which can be due to several factors, such as weather issues, avoiding expensive airspace, dense traffic (congested airspace), restricted airspace and military zones (Reynolds et al., 2009). Figure 7.1 represents the influence of possible issues while determining the flight route.

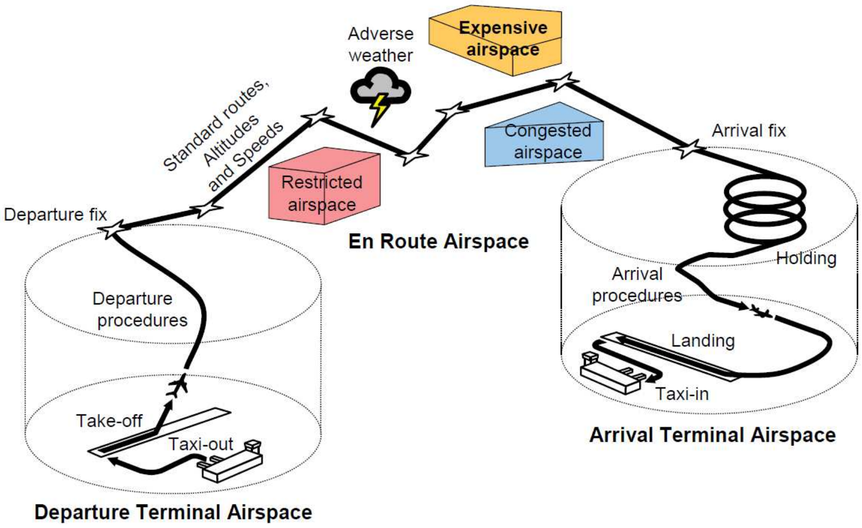


Figure 7.1: Aircraft optimal trajectory constraints (Reynolds et al., 2009)

These circumstance result in sub-optimal use of the airspace, also through the fact that routes are determined within a national context and the network is not approached as a whole (European Commission, 2008b, p.16). The distance of flights in Europe is on average about 9% longer than the direct route from departure to destination. This evolves in time loss and 9.6% additional fuel burn (Eurocontrol, 2003a, p.14-18). An example of the actual route with respect to the shortest distance is displayed in Figure 7.2 below.

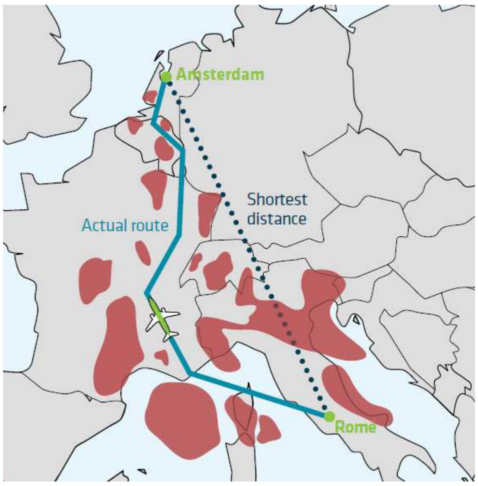


Figure 7.2: Example of a flight route with avoiding military airspace and national borders

In order to tackle this problem of fragmentation of airspace in Europe, the initiative of Functional Airspace Blocks (FABs) is introduced. Air traffic control is regrouped in so called Functional Airspace Blocks, where the European airspace is divided into a smaller number of airspace blocks, regardless of State boundaries. This means that there will be less air traffic control centers and the sub-optimal airspace design will be addressed on a much larger scale. The European airspace was divided in 27 blocks and this will be brought back to only 9 FABs. Operational management, training, procurement and support functions will be more centralized, which leads to optimized airspace, human and technical resources. Current work practices of air traffic controllers will change and common standards and procedures are developed. Collaboration between providers is essential, because this will improve operations and reduce service fragmentation (IATA et al., 2013, p.13-15).

The European airspace will be divided into the following nine FABs within the FAB initiative, which can be seen back in Figure 7.3:

- UK-Ireland FAB: United Kingdom & Ireland
- Danish-Swedish FAB: Denmark & Sweden
- Baltic FAB: Lithuania & Poland
- BLUE MED FAB: Cyprus, Greece, Italy & Malta
- Danube FAB: Bulgaria & Romania
- FAB CE (FAB Central Europe): Austria, Bosnia & Herzegovina, Croatia, Czech Republic, Hungary, Slovak Republic & Slovenia
- FABEC: Belgium, France, Germany, Luxembourg, the Netherlands & Switzerland
- NEFAB (North European FAB): Estonia, Finland, Latvia & Norway
- SW FAB (South West FAB): Portugal & Spain (European Commission, 2007a)

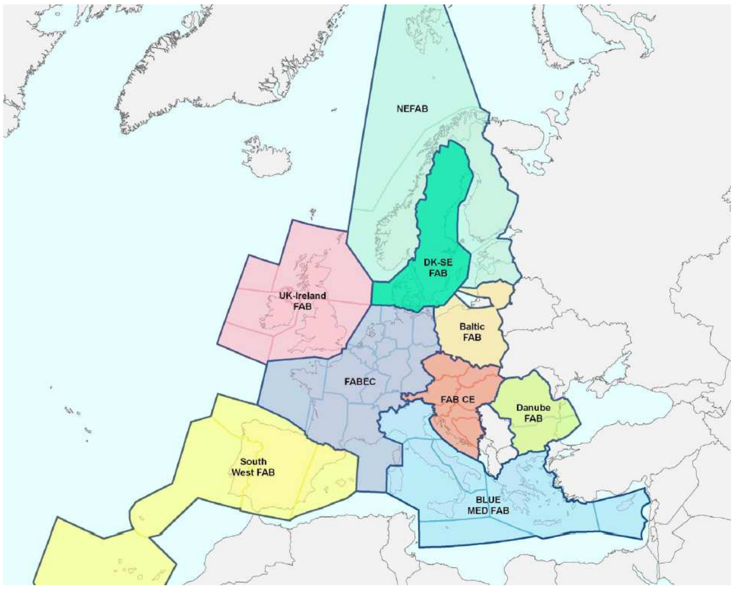


Figure 7.3: Division of European airspace into nine FABs

Currently the implementation and deployment of these FABs is in process. The intended development of air traffic control areas is given in Figure 7.4 below, through which also the level of fragmentation becomes clear.

Figure 7.4: Division flight control zones

Over time, a shift from picture 1 to 2 to 3 is desirable, whereby there will be less blocks, functions will be more centralized and the European airspace will be approached as a single sky. This will ensure maximum capacity and improve operations and efficiency in air traffic management. Essential thereby is:

- Cooperation between ANSPs and the national supervisory authorities (NSAs)
- Integration of common procurement
- Developing joint operations with neighboring States
- Optimization of air traffic controllers (ATCs) resources
- Industry-wide standards
- Training (European Commission, 2008a)

In order to steer the implementation and development of FABs further, a combination of enhanced cooperation and integration across borders. Thereby sufficient regulation needs to be present.

7.5.4 The network manager

The network manager provides the management of the network functions of air traffic management (ATM), which are airspace design and flow management. Moreover, it provides management of resources that are scarce, such as transponder code allocations and radio frequencies. The network manager is established in the beginning of 2012 and aims at improving the performance of the whole aviation network, and especially air navigation services (ANS). The main tasks of the network manager are:

- Providing traffic forecasts
- Coordinating and working with ANSPs
- Slot coordination and allocation
- Coordination of technologies and their procurement
- Informing the performance review body (PRB) (Eurocontrol, 2012d)

Developing and implementing common procedures for designing, planning and managing the European ATM network are hereby essential to achieve improved performance over the whole network (European Commission, 2008b, p.27). Regulation and empowered responsibilities and functions need to be in place to enable the network manager to enforce coordinated action by the air navigation service providers and to create improved service quality. The network manager is able to set time lines for implementations and can apply penalties to FAB Member States if they do not meet deadlines (IATA et al., 2013, p. 15).

7.5.5 Charging regulation

Since congestion and delays have negative effects on costs, time and fuel burn, it is desirable to diminish congestion. A tool that can be used for that is a mandatory modulation of (air navigation) charges depending on the level of network congestion. The objective is to encourage airlines to change flight plans in terms of using less congested routes. This would lead to more diffused air transport and more efficient use of the available airspace. It will reduce the environmental impact, because congested routes will be avoided through which there is a lower flight time, less fuel burn and less greenhouse gas emissions (Cambridge Economic, 2007, p.1). Moreover, it encourages predictability of flight plans. This process succeeds if there is an effective charging regulation in place with the right incentives and height of costs, which will actually make airlines change their plans. Consistency, transparency and uniformity are essential in the process of charging regulation. It is the question if it would be beneficial to implement congestion charging at all States or to only implement it at the five most congested ACCs (European Commission, 2012a, p.7).

Current charging

The current charging mechanisms in aviation are reflected here in order to give an overview of the existing incentives. Since 2004 it is possible by regulation to apply modulation of charges in aviation, but it is only very limited applied. The current permission of modulation charges is included in the Common Charges Scheme for Air Navigation Services (EC No. 1794/2006 as amended by EC No. 1191/2010) of the European Commission (Eurocontrol, 2012e, p.4). The Central Route Charges Office (CRCO) of Eurocontrol is responsible for the calculation, billing and collection of route charges for the Contracting States. The following States agreed on route charges: Belgium, Luxembourg, Germany, France, United Kingdom, the Netherlands, Ireland, Switzerland, Portugal, Austria, Spain, Greece, Turkey, Malta, Cyprus, Hungary, Norway, Denmark, Slovenia, Czech Republic, Sweden, Italy, Romania, Slovakia, Croatia, Bulgaria, Monaco, FYROM, Moldova, Finland, Albania, Bosnia and Herzegovina, Serbia, Montenegro, Poland, Lithuania, Armenia and Latvia. Further specifics about these charging zones are given in Figure 7.5 (Eurocontrol, 2012f, p.1).

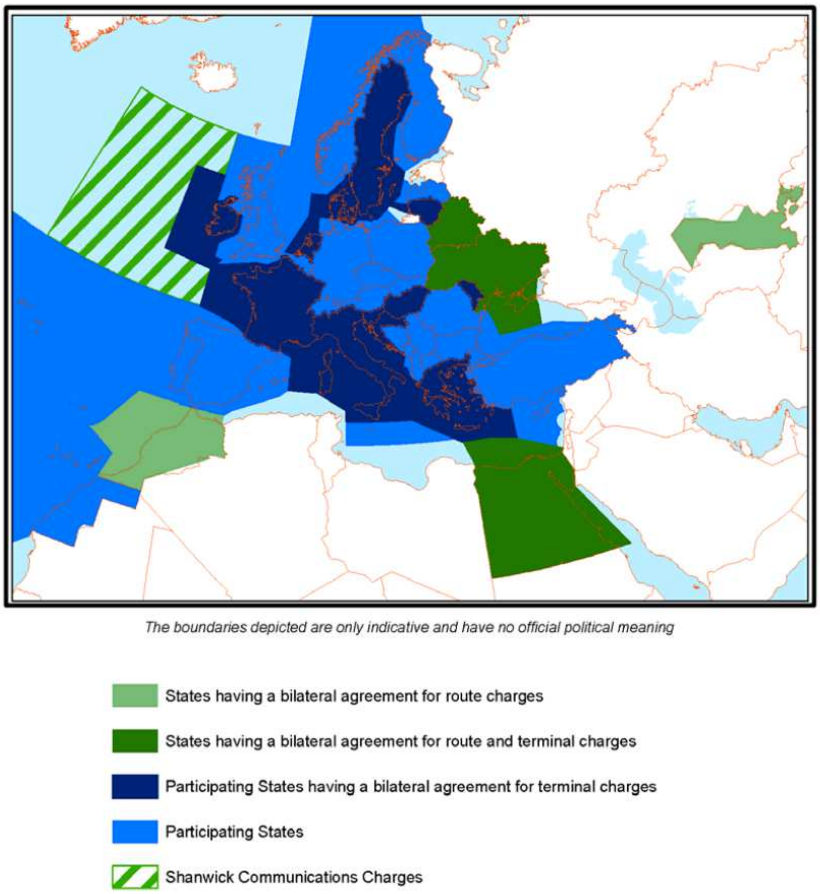


Figure 7.5: Eurocontrol charging zones in 2011 (Eurocontrol, 2012f)

There are several kind of charges in place, known as en-route charges, slot allocation, charges for terminal Air Navigation Services, navigation charges and communication charges (Eurocontrol, 2012g). The modulation of these charges is included in the Common Charges Scheme for Air Navigation Services (EC No. 1794/2006 as amended by EC No. 1191/2010) (Eurocontrol, 2012d, p.4). The weight of aircrafts is an important parameter for the current charging system in Europe (Janic & Stough, 2003). In 2011 the Central Route Charges Office billed €7.0 billion for route charges for flights (CRCO, 2012, p.5).

Belgian terminal charge modulation

A study of Zhang & Czerny (2012) points out that airlines are mainly focused on reducing travel times. Carriers will only have the incentive to adjust flight plans if it is profitable or if it is limiting its peak flights (Zhang & Czerny, 2012, p.18). This can also be seen back in the case of the Belgian airspace, where there is a charging modulation in place with specific charging zones, having high fees (charges) at peak hours and lower fees in off-peak periods (Brueckner, 2008, p.681). The height of charge in Belgium is dependent on several factors, such as the period of day of the flight and the noise class of the aircraft. The charge is calculated by the following formula:

$Charge = U \times W_i \times E_i \times D_i \times \alpha$

Where U = the unit rate, W_i = the air navigation service units, E_i = the environmental factor, D_i = the factor for day or night and α = the compensation coefficient for cost recovery of the factors E and D. The environmental factor E will range from 0.85 to 1.7 and the factor for day or night (D) will range from 0.9 to 3.0, depended on take off or landing (Belgisch Staatsblad, 2011, pp.60842-60843).

The idea of this modulation is that environmental unfriendly aircrafts pay for their damage to the environment and that certain peak times are more expensive than others, in order to reduce congestion. Airlines are through this modulation forced to rethink their performance and flight plans, because costs will be higher and the economic situation of airlines is essential. Making adaptations in the flight plan can reduce costs if the total amount of charges is lower due to other routes or time.

7.5.6 Single European Sky ATM Research (SESAR)

Introduction

Full implementation of Single European Sky is only possible if the whole system and the operations improve, whereby improving the air traffic management system is most important. The current ATM system is based on procedures and technologies from 1950, which is becoming less efficient and will probably not cope with the increasing demand in the future. Moreover, different centers use different software for air traffic management, which is displayed in Figure 7.6 below (Eurocontrol, 2006a, p.31). The lack of common systems and system interoperability leads to increased inefficiencies.

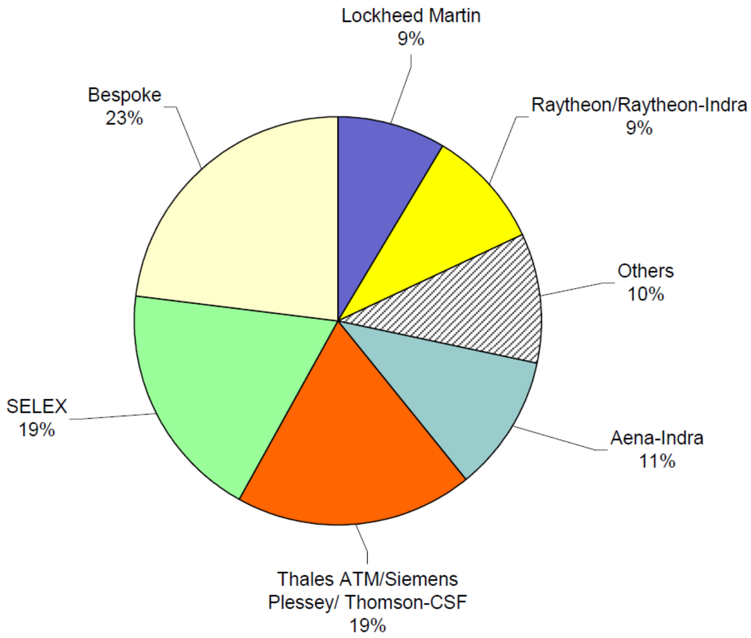


Figure 7.6: Air traffic management systems in Europe (Eurocontrol, 2006a)

Right now, due to these inefficiencies, each flight is on average 50 kilometers longer than necessary and thereby consumes more (unnecessary) fuel and emits about 5 million tonnes CO_2 extra per year (SESAR, 2011, p.3). With the expected growth of air travel for the coming years, it is essential to develop new technologies for the information systems, such as innovations in automated data-links for communications, navigation and surveillance (ATAG, 2010, p.15). Therefore the initiative of Single European Sky ATM Research (SESAR) has been created to take care of the technological dimension (of ATM systems).

The Single European Sky ATM Research is part of SES and focuses on innovative technologies that need to come in place to enable restructuring of the European airspace and to create additional capacity. In the current situation, the workload in the cockpit and for air traffic controllers increases when an aircraft crosses a national boundary. With the new interoperable ATM system the workload of the pilot and air traffic controller will be reduced, because several tasks can be automated through standardization in systems and procedures (ATAG, 2010, p.16).

SESAR aims at providing a sufficient new generation air traffic management system that ensures safety and reliability in air transport. The SESAR Programme contains three phases for the implementation of the new system and infrastructure:

- The definition phase (2004-2008): in this phase the ATM Master Plan is delivered, containing the development and deployment plans for future ATM systems. It includes roadmaps per stakeholder group to ensure the deployment plans. This plan is constructed by a collaboration of Eurocontrol and the European Commission
- The development phase (2008-2013): in this period the new generation of technological systems and components will be developed. Public and private funding is needed here
- The deployment phase (2014-2020): in this timeframe the new infrastructure will be built in order to secure full implementation of SES. High performance air transport activities is the expected outcome (SESAR, 2012)

Contribution to improved performance

The deployment of SESAR is crucial, because the coupled performance improvements will generate economic, environmental and strategic value for whole Europe (European Commission, 2012c, p.7). The implementation of SESAR will have a positive impact on creating employment, improving European R&D and reducing the impact of climate change. SESAR has the following objectives:

- Reduce costs
- Reduce flight times
- Reduce delays
- Reduce CO_2 emissions
- Create employment
- Improve services
- Increase safety
- Increase fuel efficiency

- Increase energy efficiency
- Increase economic growth/GDP (SESAR, 2011, p.4-6)

The specific 'green' objectives of SESAR are:

- Achieve emission reduction, a 10% reduction of CO_2 emissions per flight
- Improve the management of noise and reduce the impact of noise, through better flight paths
- Improve the role of air traffic management in enforcing local environmental rules, such as restrictions and quotas
- Improve the role of air traffic management in developing new environmental rules, finding the best solutions in terms of sustainability

These improvements can be made through optimizing flight profiles and air traffic management through better coordination between the airport, air traffic controllers and the pilot (SESAR, 2010a, p.9).

The 'European ATM Master Plan for 2020' states that SES could achieve the following (specific) targets by 2020 with SESAR's contribution:

- Increase in capacity of 73%, compared to 2004
- Improvements in safety, with no increase in ATM-induced accidents and incidents (despite the traffic growth)
- Reduction of environmental impact by 10% per flight, compared to 2005
- Reduction in costs by 50% per flight, compared to 2004 (SESAR, 2012, p.17)

SESAR in charge modulation

In order for SESAR to succeed, it is of importance that both airlines and ANSPs invest in SESAR, because both are depended on each other for making optimal use of the possibilities of the new ATM system. Thereby it is important that airlines do not only look at the high investment of SESAR, but also keep the significant (long-term) benefits in mind. There will be cost reduction (in the long-term), because due to the new technology operations will be more efficient and there will be less fragmentation. This evolves in less delays, less fuel burn, less noise and increased capacity. This is an advantage for the passenger since the ticket price will be lower (due to less costs for delay) and the supply of air transport will increase (SESAR, 2010b, p.3). A delay of investment in SESAR will therefore have negative effects on GDP and energy efficiency. Besides bridging the gap of costs, the following governance attributes need to be present for SESAR to deploy: independence, accountability, representation & participation, decision recognition, timing for set up and the link with R&D (European Commission, 2012c, p.7).

Due to the high investment costs of SESAR deployment, which exceed €30 billion, it is essential to bridge these costs. This is important, because there are no direct (short-term) benefits due to the fact that the equipage of both aircrafts and ANSPs need to be present (European Commission, 2012c, p.4). An option to stimulate the uptake of SESAR compliant equipage is to apply benefits for SESAR equipped aircrafts. Benefits can be included in the charge modulation, via reducing the charges for aircrafts that are equipped with SESAR or giving these aircrafts certain priorities or privileges.

7.5.7 Other initiative emission reduction

An option for making more efficient use of the European airspace and increasing the efficiency is the concept of Free Route Airspace initiative. Shorter routes will be possible, because airspace users can freely plan their routes with this initiative. This will have a positive effect on reducing fuel burn and reducing emissions, whereby the environment will benefit from it (Eurocontrol, 2012a, p.57). Regulation concerning the flexible use of airspace (FUA) is implemented in order to make efficient use of the available airspace. Cooperation and coordination is essential for improving the efficiency and for SES to succeed. The outcome of the report on the SES legislation implementation is that 13 of the 29 States do not coordinate with their neighbors. Improvement of the coordination is needed since it is desirable to coordinate airspace management policies with neighboring States in order to make efficient use of cross-border airspace structures (Eurocontrol, 2012a, p.58).

7.6 Concluding remarks

Single European Sky (SES) is introduced in 2000 with the aim to create a single sky in Europe, whereby the design, management and regulation is coordinated by the European Union. It is the objective that through the implementation of SES, there will be a shift from the current fragmented situation, with fragmented area control centers and diverse ATM systems, to a defragmented situation, with consolidated area control centers and common ATM systems in air transport. Common rules, standard and procedures are thereby essential. The environmental goal of SES is to lower the environmental impact of aviation from 2005 to 2020 by 10%, compared to the baseline scenario, through improving efficiency, reducing route extension and reducing delays. Improving performance in air traffic management leads to less cross-border inefficiencies, less fragmentation, increased capacity and less congestion and delays. A reduction in fuel burn and greenhouse gas emissions is the environmental benefit. The five environmental initiatives that aim at improved performance and reduced emissions are the performance scheme, functional airspace blocks, the network manager, the charging regulation and Single European Sky ATM Research.

8 Environmental impact with full implementation of Single European Sky

8.1 Introduction

Determining the environmental impact with full implementation of Single European Sky is the key objective of this research. The gathered information and data from previous chapters are useful for determining the environmental impact. Mainly chapter four to seven are important, especially with regard to delay and the performance comparison with the US. The baseline scenario and underlying assumptions from chapter six are used, as well as the key initiatives of SES from chapter seven. The following key initiatives have positive consequences for the environmental impact of aviation:

- The performance scheme
- Functional Airspace Blocks (FABs)
- The network manager
- Charging regulation
- Single European Sky ATM Research (SESAR)

These initiatives of SES focus on the environmental goal of SES, which is to reduce the environmental impact of aviation by 10% from 2005 to 2020, compared to the baseline scenario. This means that it is aiming at diminishing 10% of the projected CO_2 emissions in 2020 (where SES is not implemented), with an increasing annual reduction from 2005 to 2020, leading up to 10% in 2020. With establishing the future scenario with SES implementation in this chapter, the feasibility of this goal can be determined. Statements can then be made on the reliability of the set goals by SES and if the expectations are in the same range of what is actually feasible. SES can reduce the environmental impact and climate change impact through improving network structure, more efficient route planning and new procedures. SES is putting forward the following solutions for reducing emissions from aviation:

- Reduce waiting time for take off
- Using more optimal flight patterns
- Minimize circling in holding patterns (waiting area) before landing at congested airports (European Commission, 2007b, p.7)

The environmental impact of SES will be determined via the development of CO_2 emissions with full implementation of SES. This will be done for the period 2000-2030, because major effect are expected to obtain after 2020 when SES is fully developed and deployed. The outcomes from chapter six on the CO_2 emission development in the period 2000-2012 will be used to determine this period first, with an outlook to SES I and SES II and the possible impact of this on the development of CO_2 emissions. Based on assumptions and estimations, the environmental future impact (2013-2030) will be determined through computing the potential of emission reduction per key initiative of SES. Subsequent the effect of SES on improving flight efficiency and congestion reduction is explained. The performance of ATM in Europe is compared with the performance of ATM in the US in order to assess what is possible with improved operations. In the end, the definite future scenario is given for the development of CO_2 emissions with a comparison between no implementation of SES and full implementation of SES.

8.2 Environmental past impact (2000-2012)

The impact of SES on the environment over the past period 2000 to 2012 is determined here in order to give an overview of the achievements. Moreover, the past impact can be used to say something about the future development. The period 2000-2012 is divided in the following sub-periods of SES:

- Period 2000-2004: determining SES approach and packages
- Period 2004-2008: SES I package
- Period 2009-2012: SES II package

In order to determine the impact of SES on the CO_2 emissions from aviation, studies on the impact of SES are assessed and forecasts dating from 2000 (with no incorporation of SES) are compared with the actual development of CO_2 emissions, where SES could have had an impact. The impact per sub-period is described below and in the end there is an overview of all reported results.

8.2.1 Period 2000-2004

For the period 2000-2004, Single European Sky was at its early stage and no hard adaptions were done in this period. The approach of SES is discussed in this period, recommendations are given and no concrete legislation was implemented. Consultation on the possibilities to develop a single sky resulted in the first legislative package in 2004, under the name SES I.

Macintosh & Wallace (2008) elaborated on the improvements in aviation emissions from 1990 to 2005. It is stated that emission intensity of international aviation declined from 191 kg CO_2/100 RTK in 1990 to 113 kg CO_2/100 RTK in 2005, which is an improvement of 40 percent. The reduction in emission intensity is due to improvements in air traffic management and in aircraft and engine design and due to an increase in load factors. The biggest improvement has been made between 1990 and 1995. From 2000 to 2005 the emission intensity reduced only from 122 to 113 kg CO_2/100 RTK (Macintosh & Wallace, 2008, p.266). This is only a small improvement, also compared to the period 1990-1995.

Since the improvements have different causes, it can be stated that only a small part of the reduction in emission intensity can be assigned to improvements in air traffic management due to SES. The small reduction in emission intensity can be explained by the fact that SES is at its early stage in the period 2000-2004 and that there were only little improvements. Moreover, it is seen that that this reduction in emission intensity is not much higher than the 1.03% annual decline of energy intensity, assumed in the baseline scenario. This means that SES did not lead to additional improvement. Therefore, the impact of SES on the CO_2 emissions may be waived and it is thus assumed that the environmental impact of SES in this period is not present or limited, due to no or small change. For this period, the same trend as in the baseline scenario is therefore used.

Referring to the actual overall CO_2 emissions in aviation, it is seen that the CO_2 emissions from 2000 to 2005 increased with 10.3% while air traffic grew with 9.5% in Europe in that period (Eurocontrol, 2012a).

8.2.2 Period 2004-2008: SES I

In 2004 the first legislative package of SES is introduced under the name SES I, containing plans and roadmaps for the development and deployment of SES. The initiative of Functional Airspace Blocks and Single European Sky ATM Research is also introduced in this period. A report from the European Commission called 'First report on the implementation of the Single Sky Legislation: achievements and the way forward' from 2007 elaborated on the impact of SES. It is stated here that 'expected results are not delivered', which can be explained by the fact that the FABs are not enough deployed and that no major issues are effectively addressed. This evolves in a delay in delivery of efficiency and capacity improvements. The conclusion from this report is that the improvement, in terms of less CO_2 emissions due to the implementation of SES, is neglectible (European Commission, 2007b).

In 2008 an impact assessment on European aviation was provided by the European Commission. Here it is stated that due to the lack of good network coordination and a network approach, SES did not achieve much in terms of environmental impact. This is also due to the fact that the SES I package is not environmentally oriented. Furthermore, not all FABs were established in 2008, which means that certain countries did not set up arrangements, because they were still waiting for the establishment of FABs. However, SES achieved in this short period already increased collaboration and improved cooperation between service providers and it ensured separation between national service provision and oversight (European Commission, 2008b). This is of importance for the future development of FABs and SES in general (Eurocontrol, 2006b, p.ii).

Overall, in this period SES does not cause much performance improvements, because it does not really tackle current issues in ATM through which there is no efficiency improvement. Eurocontrol states that States should provide a common playing ground and should take care of inconsistencies. Improvements can be ensured by non-regulatory actions, such as guidance material, supporting NSAs, information provision and facilitate cooperation between stakeholders (Eurocontrol, 2006b, p.iii).

Referring to the actual overall CO_2 emissions in aviation, it is seen that the CO_2 emissions from 2005 to 2010 increased with 9.4% while air traffic grew with 3.26% in Europe in that period, with an outlier in 2008 where air traffic grew with 9.8% from 2005-2008 (Eurocontrol, 2012a).

8.2.3 Period 2008-2012: SES II

SES II is introduced in order to adapt to the changing aviation sector and its infrastructure, but mainly to speed up the development of Single European Sky. This package is introduced to strengthen the existing SES I package and to focus more on performance improvements, mainly related to the environment. This makes this package more interesting, in terms of achieving environmental benefits. Those environmental benefits are expected to be achieved through the five key initiatives that are the core of this package and are mentioned already in section 8.1.

The legislative package around the performance scheme, network manager and charge regulation is being initiated and developed in these years. In these years, the objectives around FABs and SESAR are further developed and establishments are made. The FAB and SESAR initiative is thereby at a further stage than the other three initiatives, which are at their consultation phase. This means that in the period 2008-2012 mostly regulations are made for the start up of the initiatives, which results in no or little operability in this short period. The performance scheme and network manager are only operational from January 2012 and FABs, charging modulation and SESAR are still under development in this period. The environmental benefits can only possibly be gathered from the FAB and SESAR initiative. As seen also in the first period, for 2004-2008, mainly qualitative data and few quantitative data is available regarding the environmental impact of the initiatives of SES.

Charging regulation

The 'Report on SES Legislation Implementation' from 2011 reviews the status of current initiatives. Regarding the charging regulation, it is stated that improvements were modest until 2011 due to the fact that there are no or insufficient effective measures in place. An important remark here is that this modulation is voluntary and not mandatory (Eurocontrol & European Commission, 2011, p.3)

FABs

The establishment of FABs is still under construction, since some FABs are not yet established. This causes delay in setting up arrangements, which evolves in existing FABs not having implemented a cooperation mechanism with neighboring FABs. Therefore the current initiatives on FABs are not providing the expected improvements in efficiency (Eurocontrol & European Commission, 2011, p.4-11).

The International Air Transport Association (IATA), the Association of European Airlines (AEA) and the European Regions Airline Association (ERA) published a report under the name 'A Blueprint for the Single European Sky' that reviews upon the achievements and current state of SES. This report concludes that 'progress has been painfully slow and the inefficiencies of the European Air Traffic Management are still generating 8.1 million tonnes of additional CO_2 emissions every year'. On the performance scheme and FABs, they conclude that the development has been 'unacceptably slow and passive'. This is due to slow establishment of FABs and no sufficient regulation in place. Current FABs have not optimized airspace along air traffic flows or optimized human and technical resources, but it is seen that there is a small increase in operational efficiency. However, there is still a lot to do and challenges need to be addressed, where integrated management can play an important role. The integration of airspace is a process that needs time to deploy, which means that environmental benefits can be expected on the long term (IATA et al., 2013, p.3-6).

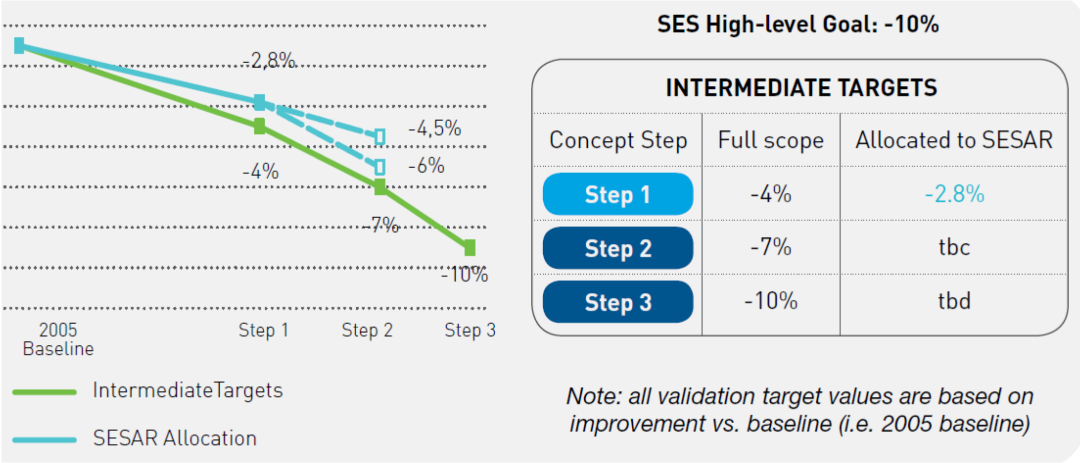
In the report of the SES legislation implementation the performance of FABs is also discussed, with mainly qualitative operational improvements per FAB. Important quantitative data was published for the Danube FAB with actual savings in route time, fuel and CO_2 until November 2011. Due to improved route network, 1,214 minutes, 55,274 kg fuel and 173,561 kg CO_2 is saved per day, based on 2,402 flights. This is equivalent to savings of 0.5 minutes per flight, 23 kg fuel per flight and 72.2 kg CO_2 per flight (Eurocontrol & European Commission, 2011, p.101). Extracting this to whole Europe, with about 10 million flights per year, results in 0.72 Tg CO_2 savings per year. This is about 0.48% of the total CO_2 emissions in aviation per year in Europe.

SESAR

Edition 2 of the ATM Master Plan (2012) presented results with regard to the set targets, with the influence of SESAR. The performance of 2005 is compared to the performance of 2012 (step 1). The contribution of SESAR with regard to the performance improvements is given for the period 2005-2012:

- Increase in airspace capacity of 27%
- No increase in ATM-induced accidents and incidents
- Reduction of environmental impact by 2.8% per flight
- Reduction in costs by 6% per flight (SESAR, 2012, p.17)

The following figure gives a reflection of the reduction of the environmental impact from 2005 (baseline) to 2012 (step 1). It is seen that with the help of SESAR fuel efficiency improved with 2.8% from 2005 to 2012, while the target for that period was 4% (SESAR, 2012, p.24).



SES High-level Goal: -10%

INTERMEDIATE TARGETS

Concept Step	Full scope	Allocated to SESAR
Step 1	-4%	-2.8%
Step 2	-7%	tbc
Step 3	-10%	tbd

Note: all validation target values are based on improvement vs. baseline (i.e. 2005 baseline)

Figure 8.1: Fuel efficiency (SESAR, 2012)

Conclusion

The conclusion that can be drawn for the period 2008-2012 is that due to the consultation, establishment and early stage of the initiatives the performance scheme, the network manager and charging regulation, the impact of SES on the environment is small. These initiatives are in their starting phase and do not generate major improvements on the short term. The FAB and SESAR initiative are at a somewhat later phase, but are still not fully operational in Europe. Therefore the major improvements remain out and are expected on the long term, because it needs time to become effective.

8.2.4 Overview of achieved environmental results

In order to make clear what the achieved results are, the table below gives an overview of the results per period which are described in the previous section.

Table 8.1: Overview environmental results per period for 2000-2012

Period	Source	Initiative	Result	Remark
2000-2004	Macintosh & Wallace (2008)	SES in total	Emission intensity reduction from 122 to 113 kg CO_2/100 RTK from 2000-2005 (decrease of 7.38%)	Also due to improvement in aircraft and engine design and due to an increase in load factors
	Multiple sources	SES in total	No or little environmental impact, due to early stage of SES	-
2004-2008	European Commission (2007b)	SES in total	Expected results are not delivered due to insufficient deployment of initiative (FABs)	-
	European Commission (2008b)	SES in total	No environmental impact due to lack of good network coordination and network approach and due to lagging development of FABs	Increase in collaboration between service providers and ensured separation between national service provision and oversight is established
	Eurocontrol (2006b)	SES in total	No or little efficiency improvement	-
2008-2012	Eurocontrol & European Commission (2011)	Charging regulation	Improvements were modest until 2011 due to no or inefficient effective measures in place	-
	Eurocontrol & European Commission (2011)	FAB	No significant efficiency improvement with the FAB initiative	Establishment in FABs is still in process
	IATA et al. (2013)	Performance Scheme and FAB	Progress on the performance scheme and FABs has been unacceptably slow and passive, inefficiencies of ATM are still there	Environmental benefits will be there in the long term, because the integration of airspace is a process that needs time to deploy

Period	Source	Initiative	Result	Remark
	Eurocontrol & European Commission (2011)	FAB	Danube FAB generated 72.2 kg CO_2 savings per flight until 2011	For whole Europe this would mean 0.72 Tg CO_2 savings per year, which is about 0.48% of the total CO_2 emissions from aviation
	SESAR (2012)	SESAR	Increase in airspace capacity of 27% and a reduction in environmental impact by 2.8% per flight	This result is mainly provided by the SESAR initiative, but also other initiatives contributed

As can be seen in this overview, the environmental benefits of SES from the period 2000 to 2012 are very small. Therefore it is assumed that in this period there is no quantitative impact of SES on the environment, thus the impact will not be taken into account in the scenario. The development of CO_2 emissions from the scenario without SES (baseline scenario) is assumed to be the same as the scenario with the implementation of SES I and SES II (desired future scenario). However, the 0.48% CO_2 savings per year due to FABs and the 2.8% reduction in the environmental impact per flight due to the SESAR initiative are important parameters to keep in mind and to use this for assessing the future impact.

8.3 Environmental future impact

Having determined the past impact of Single European Sky, the next step is to forecast the environmental impact of Single European Sky over the period 2013 to 2030. There will be an assessment for each initiative on what the expected impact is on the CO_2 emissions in aviation. This is done through looking at the percentage improvement, reduced en-route delay, the avoided fuel burn or reduced flight distance according to several reports and calculations. The benefits of SES are mainly improved flight efficiency, improved flight plans, improved network structure, more efficient route planning, reduced delay and reduced congestion. The environmental future impact will be operationalized via the avoided CO_2 emissions (in Tg or percentage) due to the implementation of SES. There will be a distinction between the period 2013 to 2020 and the period 2020 to 2030. From 2013 to 2020 there will be the largest increase in emission savings, because it is expected that SES will be fully implemented in 2020 with full operability of the initiatives. For the period 2020 to 2030 the annual emission reduction (compared to the baseline scenario) will be at a higher value, with fewer increase in savings per year.

8.3.1 The performance scheme

The performance scheme aims at improving performance. Environmental benefits are expected on the long term, because the performance scheme is implemented in 2012. IATA et al. (2013) states that improving operational performance has the potential to reduce flight time with 10 minutes per flight and save 3 million tonnes fuel per year (IATA et al., 2013, p.19). One tonne fuel saved is equivalent to 3.15 tonnes CO_2 emissions, meaning that reducing the flight time by 10 minutes per flight, the total reduction in CO_2 emissions will be 9.45 million tonnes CO_2 per year, assuming about 10 million flights per year (ATAG, 2010, p.5).

8.3.2 Functional Airspace Blocks (FABs)

As mentioned before, results will be achieved when all FABs are established and are operational. The European Commission mentioned that there is room for improvement and integration of resource management in the coming years (European Commission, 2007a, p.9). This will enable to obtain environmental benefits. FABs will mainly defragment the European airspace (along national borders), which is essential because fragmentation is a main issue in aviation. Currently fragmentation causes 1% additional flight inefficiency and in total about 5 million tonnes CO_2 per year (European Commission, 2007b, p.7).

FABs will improve operations, provide more direct routes and provide free routing. Through removing the constraints of national boundaries there will be improved sector design, which leads to improved routing and greater flight efficiency. With the right target setting and regulation within the FAB initiative, FABs will improve quality of ANS provision, promote mobility of the workforce, reduce cross-border inefficiencies, increase capacity and encourage innovation. It will reduce horizontal flight inefficiency, which currently results in 3.7% additional fuel burn (Eurocontrol, 2012a). Due to these improvements, the route extension will reduce with approximately 50%, from about 63 kilometer to 32 kilometer route extension. This leads to cost savings and about 3 million tonnes CO_2 savings (IATA et al., 2013, p.16).

It is expected that FABs can improve flight efficiency with about 0.3%, equivalent to about 15,000 flight hour savings per year (Eurocontrol, 2012a). The average fuel burn per minute per flight is 49 kg fuel, which means that 44,100 Mg fuel will be avoided in total per year. Multiplying this by 3.15 tonnes CO_2 per tonne fuel, gives about 1.4 million tonnes CO_2 savings per year for FABs (ICAO, 2010, p.41). This calculation from 15,000 flight hour savings leading to 1.4 million tonnes CO_2 savings, will also be used later on (in the congestion/delay part). One hour flight savings is therefore equal to 92.61 tonnes CO_2 emission savings.

As seen before, the environmental impact of FABs for SES II was assessed for the Danube FAB in quantitative terms. It is seen that 0.72 million tonne CO_2 is currently saved per year, when extracting the results of the Danube FAB to whole Europe. There will be enhanced improvements in the future and the CO_2 savings will incur due to improvements in the route network. Therefore the savings from 2020 onwards will be about threefold of current savings, resulting in 2.2 million tonnes CO_2 savings per year from 2020 (Eurocontrol & European Commission, 2011, p.101).

8.3.3 The network manager

Through improved management of the network functions of air traffic management there are considerable benefits to achieve, mainly on the long term. The European Commission stated that through optimizing route planning, there is the potential to reduce CO_2 emissions from aviation with 6 to 12%, equivalent to 9 to 18 Tg CO_2 savings (European Commission, 2007b, p.8-9).

The 5 million tonnes extra CO_2 emissions per year due to fragmentation, can be approached through the right network approach in place. This means that the network manager can also bring about benefits here.

8.3.4 Charging regulation

The environmental impact of the charging regulation initiative (congestion charging) is hard to determine, because it can affect the aviation sector in different ways. Thereby it is difficult to predict what the reaction of airline and air traffic control will be and how they will change their way of operating. The limited research on the impact of charging regulation makes it even more inconvenient to determine the potential of emission savings. In order to determine what the potential effects can be and what behavior changes will occur and to what extent, other price mechanisms in the aviation sector are elaborated and also congestion charging is investigated in other transport modes. An overview of these case studies is given in ‘Appendix 1: Charging regulation case studies’.

Potential of applying congestion charging in aviation

The impact and the potential of congestion charging depends on the behavior of airlines and the adjustment in its flight plans, where the sensitivity of airlines to price incentives plays an important role. In the en-route environment it would propose lower charges for more circuitous routes, allocated to aircraft required to operate them due to congestion on the aircrafts preferred routing. Any discount would need to reflect the cost of additional fuel and inconvenience. It would reduce the randomness of current congestion-based re-routings.

Having looked at the effects from other price mechanisms in the aviation sector and congestion charging in other transport modes (in Appendix 1), it can be concluded that congestion charging may lead to airlines adjusting their schedule to take advantage of differential charges depending on time of operation. This will be the expectation since profit margins of airlines can be low sometimes and a rise in costs will therefore have a high impact on the profit. The extent of adjustment per airline differs, because airlines have different objectives, costs and profit margins. There will be differences between major, regional and low-cost companies, with a larger impact of charging on low-cost carriers (Eurocontrol, 2003b, p.4-7). However, compared to fuel costs, charging costs are not that high and will not account for a large share of the total costs (Eurocontrol, 2003b, p.9). Small changes in route charges will therefore not influence behavior of airlines (Eurocontrol, 2003b).

In order to determine the potential of congestion charging, the effects of slot allocation, air navigation charges, the Belgian airspace and congestion charging and kilometer charging on the road on behavior of stakeholders will be taken into account. The conclusion can be drawn that the introduction of a modulation of charges will affect the behavior of stakeholders. An advisor from airport and airport management in Belgium stated that the introduction of a charging modulation in Belgium has led to less flights during the night (Clippel, 2013). Therefore it is the expectation that the implementation of a mandatory modulation of congestion charges will evolve in adaptations of airlines, in terms of adjusting flight plans.

Hereby the magnitude of the impact depends on the height of charges, because it is seen that with low charges there will be less behavioral changes and a limited potential. Airlines are sensitive to these changes, but only from a certain height of charges. Different routes (rerouting), different timing and different destinations belong to the possibilities of adjustment in the flight plan. Rerouting will thereby only be beneficial for the environment if the alternative route is avoiding congestion with maintaining the total flown distance. If the alternative route becomes much longer, there are no savings in terms of avoided fuel burn while avoiding congestion.

An important difference between air navigation charges and congestion charging is that flying alternative (longer) routes due to congestion charging has the benefit of both cost savings and avoiding congestion. This will reduce the flight time and improve schedule reliability, through which the potential will be higher. Airspace users should be encouraged enough in order to shift demand from congested to less congested areas or times of day, through offering preferential rates in areas with spare capacity. The alternative route need to have benefits, in terms of less costs or time savings, through avoided congestion and avoided delays. Moreover, it is essential that the modulation of charges is mandatory.

Congestion charging on the road in London has led to a reduction of 36% cars in the center of the city during peak hours, because people choose other routes, other destinations or other transport modes. This will possibly also happen in the air transport sector, but with a different order of magnitude because it are two different sectors. The structure and accessibility differs in these sectors. In road transport the passenger/driver is often the decider upon routes, whereas in air transport the passengers do not decide upon the route and flight plan. This will lead to different effects, because the behavior of airlines differs from the behavior of car drivers.

Since it is seen that congestion charging will lead to different and longer routes in some cases, it is assumed that congestion charging will not have that much environmental benefits on its own, because the avoided emissions in avoiding congestion are coming back in the longer distance flown. However, the charging regulation will have positive effects on the whole system of Single European Sky and contribute to sustainability in the sense that it prevents airlines to fly on congested routes and shift to a different time period during the day or month of the year.

8.3.5 Single European Sky ATM Research (SESAR)

Savings with SESAR

The effects of SESAR on the environment are important to assess, because lowering the impact on climate change and becoming sustainable is beneficial. Minimizing the environmental impact is one of the targets of SESAR, with the focus on noise and local air quality at and around airports as well as climate change, which is driven by greenhouse gas emissions from fuel burn of aircrafts.

The SESAR Joint Undertaking (SESAR JU) is a public-private partnership that manages the development phase of SESAR, which states that SESAR will have a positive effect on mobility. The flight time will approximately be 10% shorter per flight. Predictability and punctuality of flights will improve. It is expected that SESAR contributes to carbon neutral growth and that it will mitigate about 50 million tonnes of CO_2 emissions in the period 2013-2020 (ICAO, 2010, p.109). Despite of the additional capacity and demand, SESAR will still have a positive net effect on the total CO_2 emissions in the period 2013-2020 (SESAR, 2011, p.7).

The report ‘Revolutionising air traffic management: practical steps to accelerating airspace efficiency in your region’ states that the CO_2 saving due to SESAR will incur to 12.2 million tonnes per year until 2020 and 17.7 million tonnes per year until 2030 (ATAG, 2010, p.17).

Implementing SESAR in the charge regulation will result in even more CO_2 savings. For the possibilities of introducing SESAR in the charging modulation, it is of importance to look at other similar initiatives. Firstly the effects of high fuel prices on the type of aircraft will be determined in order to determine the potential for including SESAR in the charge modulation.

Charging - effects fuel price

If the fuel price become higher, it affects the behavior of airlines and the type of equipment. This is seen in the past when fuel prices rose and airlines chose for more efficient and less consuming aircrafts. A study of Toru (2009) concerning the effects of increased fuel prices on air traffic, concluded that the fuel price is of importance for the performance of aviation. The height of fuel price is becoming more important, because fuel costs represent 20-30% of total operating costs, where it was 10-15% in the past. Jet fuel prices increased sharply, with a tripling of price from 2004 to 2008. It is seen that a rise in fuel price causes an increase in air fares, through which air travel demand will become more price sensitive. With higher air fares, passengers choose to travel less, use a different mode of transport or reduce the length of flight. This has the consequence that air traffic declines and CO_2 emissions decrease (Toru, 2009).

Moreover, due to higher fuel prices airlines are reviewing new strategies such as cutting capacity, decreasing flight frequency, options for mergers, improving efficiency and achieving efficiency gains in non-fuel cost items. One of the options is replacing the fleet through more efficient aircraft. There is a notable relation between the height of fuel prices and the purchase of other, more efficient, aircrafts (Toru, 2009). Due to high fuel prices there is a decrease in value of less fuel efficient aircrafts and an increase in the value of more fuel efficient aircrafts (European Commission, 2009, p.23-24).

Potential for SESAR equipage in charging regulation

There is currently a gap between short-term investments required for SESAR and the benefits to users in the longer term, which prevents users to invest. Modulating charges is therefore an incentive to encourage airlines to equip aircrafts with SESAR. It is a possibility to punish operators if they are not yet equipped, which will help to overcome the current situation. This is important, because bringing forward full deployment of the SESAR technologies will improve the ATM performance and it will be beneficial for both airspace users and passengers, in terms of costs, time and environmental impact (European Commission, 2012b, p.7).

The experiences in the fuel price section, indicate that airlines are influenced by the price mechanism in their fleet strategy. High fuel prices stimulated airlines to acquire more fuel efficient aircraft and the Belgian terminal ANS charge experience showed that a more noise-efficient fleet was deployed. Changes in costs will cause changes in the behavior of airlines and their operations. This is also seen in the cases of road transport, where travelers avoid high costs. Based on these experiences, it is concluded that modulating ANS charges for SESAR uptake is a valuable incentive to stimulate early installation of SESAR equipage. Early installation of SESAR equipage is beneficial, because it will reduce costs, increase job creation and have more CO_2 savings.

In the report 'Assessing the macroeconomic impact of SESAR' of SESAR JU it is examined that a 10 year delay of implementing SESAR will have a loss of benefits of about € 268 billion of GDP (direct and indirect), a reduction in the 189,000 jobs created and the emission savings will be less than 55 million tonnes of CO_2 (SESAR, 2011, p.20). Airlines can avoid high costs and generate discount through equipping their aircrafts with SESAR. However, it is expected that the potential for SESAR will be lower than the potential for fuel prices, because the investment costs of SESAR equipage are at a high rate and because the costs of charges are not that crucial for airlines as fuel prices are.

ANSPs may support the charges modulation if it is financially doable, by having lower operating costs in order to justify the investment. Thereby the threshold will be lowered for airlines to equip aircraft with SESAR equipment and the deployment of SESAR ATM capabilities will accelerate. Other options to promote SESAR equipment are restricting flight levels to equipped traffic and enabling ANSPs to charge penalties or penalize operationally for non-compliance of equipage mandates (European Commission, 2012b, p.17).

The task force for supporting the European Commission in air transport and the airports and airspace management in Belgium expect that including SESAR in congestion charges modulation will have an effect on the SESAR deployment and SESAR equipment, but that more action is needed to ensure SESAR deployment and implementation (European Commission, 2012c, p.7). It is the question if introducing SESAR in the charging modulation is sufficient for the uptake of SESAR equipage.

8.3.6 Overall forecasts SES

Having observed the expected impact per SES initiative, there are also forecasts for Single European Sky as a whole. The objective of SES is to reduce the environmental impact with 10% from 2005 to 2020, compared to the baseline scenario. As seen before, in chapter 7.5.1, SES can have environmental benefits, which are mainly reducing ATM congestion/delay and improving flight efficiency. The impact of SES on these objectives will be described below, concluded with the important comparison with performance in the US.

Congestion/delay

As seen before in chapter four, 18% of all flights in Europe are delayed by more than 15 minutes over the year 2011 due to congestion and delay, with a total ATFM delay of 17.9 million minutes. These delays were mainly due to air traffic control capacity and staffing problems. Out of the total ATFM delay 47% is en-route ATFM delay, equivalent to 8.4 million minutes en-route ATFM delay. The en-route ATFM delay causes longer flight time and this is where SES can have an impact. Completely diminishing the en-route ATFM delay in 2020 results in 140,000 reduced flight hours and savings of about 13 million tonnes CO_2 per year from 2020 onwards. This is calculated by the formula that 1 flight hour is equal to 92.61 tonnes CO_2 emissions, which is also used before in the FAB section (ICAO, 2010, p.41). Multiplying the 140,000 reduced flight hours by the 92.61 tonnes CO_2 emission savings per flight hour gives 13 million tonnes CO_2 savings. However, it is not expected that all en-route ATFM delays can be avoided in the future, because this is depending on so many factors.

Flight efficiency

Besides the impact on congestion/delay, SES is aiming at improving flight efficiency. The Association of European Airlines published a report in 2012 regarding sustainable European aviation, with possible improvements in the sector. This report concludes that full implementation of SES (in 2020) can result in a significant increase in operational efficiency, whereby 16 million tonnes CO_2 can be saved in total per year, which is about 10% of the total CO_2 emissions in aviation. Unnecessary fuel burn is hereby avoided through improved efficiency (AEA, 2012, p.14). This corresponds to the extra fuel burn due to ATM inefficiencies, which is 7-11% of total fuel burn (as seen in chapter four).

Comparison with the US

In order to complete the overview of expected environmental impact of Single European Sky, there will be a comparison again between the European airspace and the airspace of the US. Because the US operates with one air navigation service provider and Europe is working towards this, the impact can be assessed through expected performance improvements.

In the US there are 14,600 air traffic controllers against 16,700 in Europe, while the US controls about 15.9 million flight against 9.5 million flights in Europe. This means that the air traffic control officer productivity in Europe is much lower than in the US, caused by inefficiencies in air traffic management in Europe. This can be explained by the inter-centre coordination which leads to high workload for hand-over in European centres. This can be improved by having a limited number of equipment types and by operating in a single sky (Eurocontrol, 2006a, p.ix).

Moreover, it was seen before in chapter five that the US is performs more optimal, based on the delay/capacity and environment/flight efficiency indicators. It was seen that 82% of all US flights are on time against 75.5% in Europe. For 2010, 5.7% of the European flights are delayed by more than 15 minutes due to en-route ATFM constraints, against 0.1% in the US. As already explained, this is mainly due to greater (ATM) efficiency in the US with less ANSPs. The implementation of SES, with FABs and SESAR, is aiming at improving ATM efficiency, where congestion, delays and route extension will decrease. Thereby the US is a role model and an example of how a system with a single sky performs. Therefore the performance of the US will be used to say something about the potential (environmental) impact of SES, with special focus to the indicators. The situation and performance in the US is thereby the ‘desired’ scenario.

Comparing the 5.7% delay in Europe against the 0.1% delay in the US, means that ATFM delays in Europe can be reduced by 98% if Europe will perform as efficient as the US in the future. This will lead to a decrease of the current 8.4 million minutes en-route ATFM delay (see chapter four) to 0.2 million minutes delay per year in the future (2020) with full implementation of SES. The CO_2 emission savings will then result 12.7 million tonnes CO_2 per year from 2020, because 8.2 million minutes saved is equivalent to 136,667 flight hour savings. Multiplying this by the 92.61 tonnes CO_2 per flight hour, gives the 12.7 million tonnes CO_2 savings. A remark here is that the 98% reduction in ATFM delay is a bit optimistic, because there are also other differences between the European aviation sector and the sector in the US and also some which are not approached through SES. However, overall the airspace of the US and Europe is comparable, due to similar volume of airspace, similar operations and similar density. With the implementation of SES, the European aviation sector will be more comparable with the US, due to a single sky with one service provider, common procedures and operations and a common air traffic management system. Therefore it is expected that Europe can achieve similar performance in the future as the US, with drastically lower ATFM delay.

The horizontal en-route flight efficiency indicator also performs better in the US than in Europe, with a third less route extension in the US (Eurocontrol & FAA, 2012). This means that if Europe would have similar operations as the US, there can be 1% fuel savings due to shorter routes, equivalent to about 1.8 million tonnes CO_2 savings per year from 2020.

Overall, when comparing Europe to the US, it is seen that 12.7 million tonnes CO_2 can be saved by reducing ATFM delay and 1.8 million tonnes CO_2 can be saved though reducing the route extension. This is a total potential of environmental benefits of SES of about 14.5 million tonnes CO_2 from 2020.

8.3.7 Overview environmental future impact

In order to make clear what the expected impact on the environment is, the table below gives an overview of the forecast per initiative per source which were elaborated in the previous section. The environmental impact is determined with full implementation of SES and therefore reflects the final impact in year 2020. The benefits will incur from 2020 to 2030. The impacts in the table are compared to a baseline scenario where SES is not implemented.

Table 8.2: Overview future impact per initiative in 2020, compared to a baseline scenario

Initiative	Impact	Remark	Source
The performance scheme	Saving 9.45 million tonnes CO_2 emissions per year, through contributing to improved operational performance	This is due to a combination of several initiatives, which strengthen the performance scheme	IATA et al. (2013)
Functional airspace blocks	Saving 5 million tonnes CO_2 emissions per year through defragmentation	Only possible through diminishing all inefficiencies and defragment the airspace	European Commission (2007b)

Initiative	Impact	Remark	Source
	Saving 3 million tonnes CO_2 emissions per year through more direct routes and free routing	-	IATA et al. (2013)
	Saving 1.4 million tonnes CO_2 emissions per year through improved flight efficiency	-	Eurocontrol (2012a)
	Saving 2.2 million tonnes CO_2 emissions per year from 2020 onwards	Based on the Danube FAB results	Eurocontrol & European Commission (2011)
The network manager	Saving 9 to 18 million tonnes CO_2 emissions per year through optimized route planning	This is due to a combination of several initiatives, which strengthen the network manager	European Commission (2007b)
Charging regulation	No or little environmental benefits expected, because congestion will reduce but the total distance flown will increase	However, it is contributing to sustainability since it contributes to reducing congestion and it strengthens and compliments other initiatives	Reynolds et al. (2009) & Jovanović et al (2011)
SESAR	Saving 50 million tonnes CO_2 emissions in total for the period 2013-2020	There will also be additional capacity and demand, which results in extra emissions	ICAO (2010)
	Saving 12.2 million tonnes CO_2 per year in 2020 to 17.7 million tonnes CO_2 per year in 2030	-	ATAG (2010)
SES in total	Saving 16 million tonnes CO_2 emissions per year through improved efficiency and taking away all the ATM inefficiencies	This is with full efficacy	AEA (2012) & IEA (2009)
	Saving 13 million tonnes CO_2 emissions per year from 2020 onwards, through avoiding all en-route ATFM delay	This is with full efficacy	Eurocontrol (2012a)
	Saving 12.7 million tonnes CO_2 emissions per year from 2020 onwards, through reducing en-route ATFM delay	With similar performance as the US	Eurocontrol & FAA (2012)
	Saving 1.8 million tonnes CO_2 emissions per year through reducing route extension	With similar performance as the US	Eurocontrol & FAA (2012)

From this table can be concluded that there are different approaches in determining the environmental impact of SES and the initiatives, which leads to forecasts from different ranges. This also has to do with different baseline scenarios in each report, with different assumptions. Some reports do not even explain or reflect upon their baseline scenario, but the baseline scenario from most studies is comparable with the baseline scenario used in this research. This has to do with the fact that most reports incorporate the assumptions and forecasts of the European Commission (2010).

Moreover, it is seen that certain outcomes cannot be allocated to one specific initiative. Such as improved operational performance or increased flight efficiency is due to a combination of several initiatives and their workability. An example is that initiatives, such as the performance scheme, have a larger impact in combination with other initiatives, such as the implementation of a new air traffic management system with SESAR. In this way, the initiatives strengthen each other and lead to greater benefits.

The overview from Table 8.2 is used as a comparison (or indication) with the calculated future impact with performance such as the US and the results for SES in total. Therefore the conclusion can be drawn that the results from calculations with regard to the performance comparison of Europe and the US of 12.7 million tonnes CO_2 savings due to ATFM delay reduction and the 1.8 million tonnes CO_2 savings due to route extension reduction (in total 14.5 million tonnes CO_2 savings), give a reliable indication of the possible impact. The other estimations from several studies are namely in a similar range.

8.4 Future scenario with full implementation of Single European Sky

8.4.1 Introduction

The future scenario will be developed here for the period 2000 to 2030 for Single European Sky as a total package, including all initiatives. Since all initiatives are depended on each other and are interrelated, it is the best to determine the impact as a whole for SES.

8.4.2 Traffic forecast

In 2011 there were 9.8 million flights per year and the expectation is that air traffic will grow with 2.8% per year (Eurocontrol, 2010, p.1). The development of air traffic is given in the table below.

Table 8.3: Air traffic development from 2011-2030

	2011	2015	2020	2025	2030
Flights (in M)	9.8	10.9	12.6	14.4	16.6

8.4.3 Forecast emission reduction

As seen in Table 8.2 it is expected that SES will have a positive effect on the environment, with different orders of magnitude. In order to determine the future scenario, with full implementation of SES, the calculations from Table 8.2 are reflected with the objective to come to reliable CO_2 savings per year that can be used to determine the future development of CO_2 emissions. Especially the data for ‘SES in total’ from Table 8.2 is important.

Reflection other studies

ATM inefficiencies cause additional fuel burn and additional CO_2 emissions per year. Through shorter routes, improved operations and less delay, this additional CO_2 can be lowered, but it is the expectation that not the total 16 million tonnes CO_2 emissions or the 13 million tonnes CO_2 emissions (both from Table 8.2, with full efficacy) can be avoided. These two scenarios are somewhat optimistic, because it reason from completely taking away all ATFM inefficiencies and avoiding all ATFM delay by 2020. It is expected that this will not work out, because this is a too optimistic scenario, where all kind of factors are of influence.

The calculations from Table 8.2 are given in Figure 8.2 below, in order to give a good overview of all forecasts. The avoided CO_2 emissions per year from Table 8.2 are expected to be reached in 2020 and thereafter increase further per year. In Figure 8.2 below, the two left columns are for specific SES initiatives, where the other four blue columns reflect forecasts for SES as a whole. The most right one is the projection based on the comparison between Europe and the US, which is important for the 'desired future' scenario.

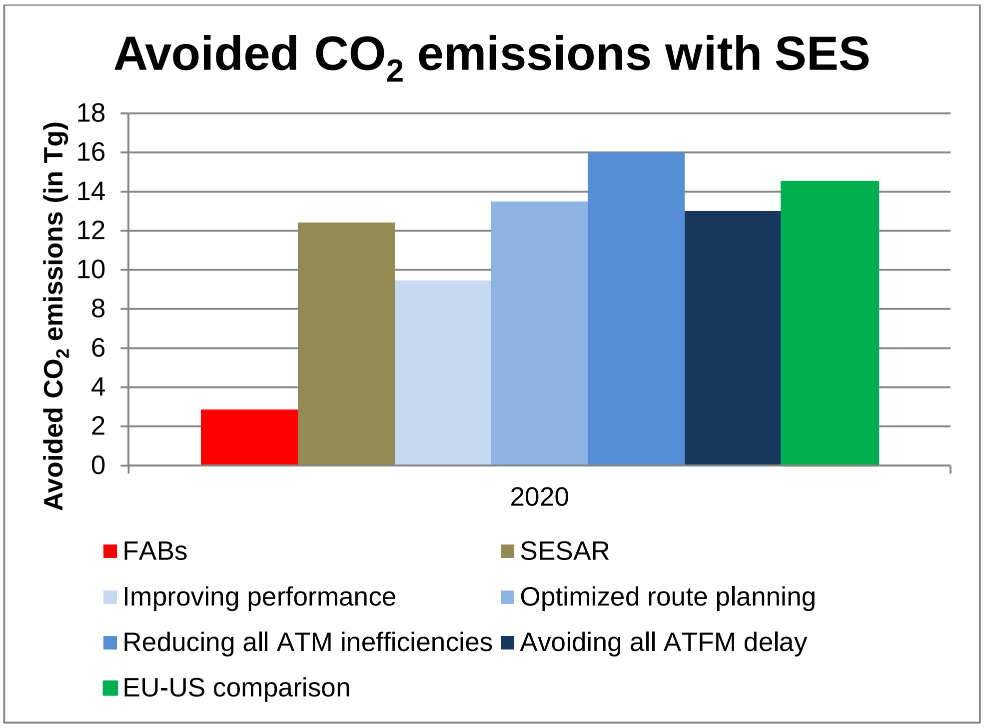


Figure 8.2: Avoided CO_2 emissions with implementation of SES, according to several sources

From this figure can be derived that the right green column with possible improvements due to better performance, such as in the US, falls in the range of other estimations. If the European airspace will become as efficient as the US airspace, it is expected that SES will reduce emissions with about 14.5 million tonnes CO_2 per year from 2020 onwards, the sum of 12.7 million tonnes savings and 1.8 million tonnes savings. Optimized operational performance, optimized route planning, defragmentation and improving ATM efficiency is incorporated here. The 14.5 million tonnes CO_2 savings per year from 2020 is being built up in the period 2013-2020, where SES is being further developed. There will be a slight emission reduction in the beginning, which will become greater in the long term.

Determining future scenario

Since it is assessed that the calculations from the EU/US performance are reliable, these outcomes are used to determine the future scenario. Knowing the final future impact of SES in 2020 (14.5 million tonnes CO_2 savings), the savings per year from 2013 to 2020 still need to be determined. Firstly, the CO_2 emission savings for the year 2013 are determined using the quantitative evaluation on the Danube FAB. In section 8.2.3 it was calculated that improvements such as in the Danube FAB could lead to 0.72 Tg avoided CO_2 emissions in 2013 for whole Europe with the FAB initiative. In combination with other initiatives of SES, the CO_2 reduction for 2013 will be even higher than the 0.72 Tg CO_2. Therefore the choice has been made to set the avoided CO_2 emissions for 2013 at 1 Tg CO_2.

The development in CO_2 emission savings in the desired future scenario is given with the starting year 2013, where CO_2 savings are determined at 1 Tg CO_2, and will eventually run up to 14.5 Tg CO_2 emission savings in 2020. It is assumed that the CO_2 savings will increase exponentially from 1 Tg in 2013 to 14.5 Tg in 2020, because every year there will be additional savings due to increased operability of the initiatives (Jonsson, 2007). Moreover, these initiatives strengthen each other further every year, leading to increased CO_2 emission savings (Al-Ghandoor, 2012). The closer to 2020, the better the initiatives perform and the greater benefits are achieved. This exponential growth in emission savings from 2013 to 2020 is given in Figure 8.3 below.

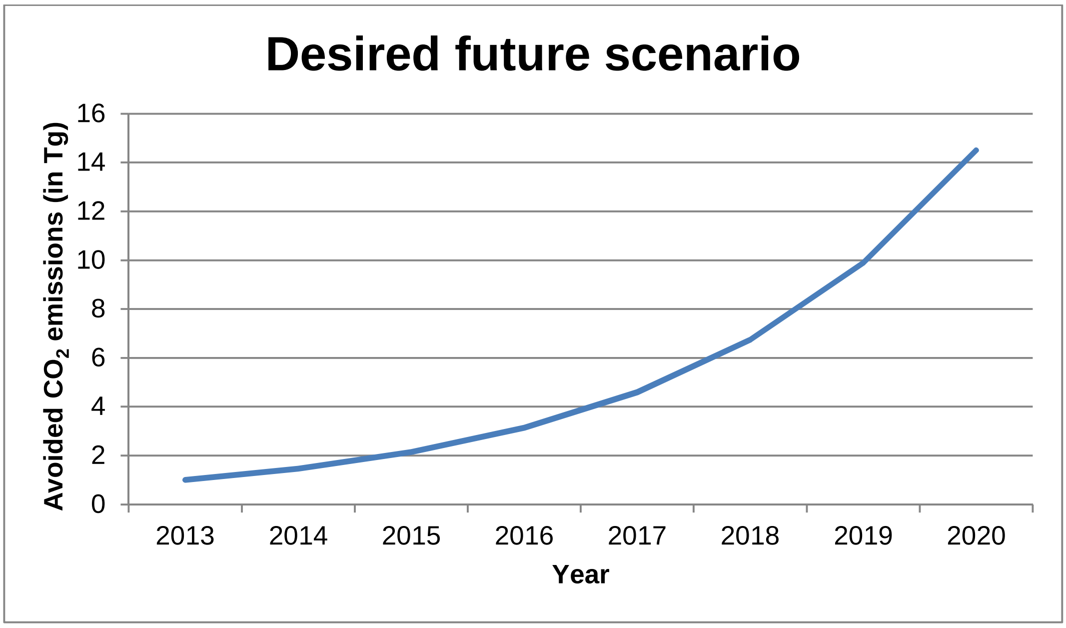


Figure 8.3: Avoided CO_2 emissions for desired future scenario for 2013-2020

From this exponential development can be seen that the savings increase by a factor of 14.5 in a time period of 7 years. This means that there is an annual growth of 47% in avoided CO_2 emissions per year, using the equation $14.5^{1/7}$, which means that the CO_2 savings increase almost by half every year. The following formula can be used to determine the exact CO_2 emission savings in a specific year (from 2013-2020):

CO_2 *emission savings*$_{2013+x}$ = CO_2 *emissions savings*$_{2013}$ * *annual growth factor* CO_2 *emission savings*^{x}

Taking into account the annual growth factor of 1.47 (extracted from the exponential growth in Figure 8.3) and the CO_2 savings of 1 Tg CO_2 in 2013, gives the following formula for the period 2013 to 2020:

CO_2 *emission savings*$_{2013+x}$ = *1 Tg * 1.47*^{x}

This leads to the exact development in CO_2 emissions in the following table:

Table 8.4: Development in CO_2 savings from 2013-2020 in EU-27

	2013	2014	2015	2016	2017	2018	2019	2020
CO_2 emission savings (in Tg)	1.0	1.47	2.15	3.14	4.60	6.75	9.89	14.5

It is seen that the further the development of SES is, the more CO_2 emissions are avoided per year, which is logic because air traffic management will improve further with further implementation of SES. Air traffic management operations, procedures and routes are improved and further in time there will be more benefits. In 2020 there are 14.5 Tg CO_2 emission savings, which is 7.55% savings compared to the baseline scenario with a total of CO_2 emissions of 192 Tg CO_2 in 2020.

After full implementation of SES and its initiatives in 2020, the emission savings will increase further, but with lower annual growth in emission savings. For the period 2020 to 2030 the savings are calculated through determining the annual growth in CO_2 emission savings, using the annual growth rate in air traffic, the annual autonomous energy intensity decrease and the annual growth in SES related savings. The annual growth of CO_2 emission savings for the period 2020 to 2030 can be calculated as follows:

Annual growth CO_2 *emission savings = annual air traffic growth + annual SES related* CO_2 *emission savings – annual energy intensity decrease*

Air traffic grows with 2.8% per year and the energy intensity decreases with 1.5% in the period 2020 to 2030 (see baseline scenario in chapter six). It is calculated that in 2020 there are 7.55% CO_2 emission savings, leading to an annual saving rate of 1.3%, using the formula $7.55^{1/7}$. Filling in the above formula gives the following annual growth in CO_2 emission savings:

Annual growth CO_2 *emission savings = 2.8% + 1.3% – 1.5 = 2.6%*

This means that there will be 2.6% additional CO_2 emission savings per year from 2020 to 2030, on top of the 14.5 million tonnes CO_2 emissions in 2020. The CO_2 emission savings for a certain year in the period 2020 to 2030 can be calculated with the following formula:

CO_2 *emission savings*$_{2020+x}$ = *14.5 Tg * 1.026*^{x}

The following table gives an overview of the development of CO_2 emission savings from 2020 to 2030 in EU-27.

Table 8.5: Future scenario with development in CO_2 savings from 2020-2030 in EU-27

	2020	2025	2030
CO_2 emission savings (in Tg)	14.5	16.5	18.7

These CO_2 emission savings are being deducted from the baseline scenario from chapter six, where there was no impact of SES incorporated. Table 8.6 gives the development of CO_2 emissions with full implementation of SES for the period 2000 to 2030, which is the desired future scenario.

Table 8.6: Future scenario of development in CO_2 emissions from aviation in EU-27

Future scenario	2000	2005	2010	2013	2015	2020	2025	2030
CO_2 emissions (in Tg)	135	147	161	169	174	178	189	199

8.4.4 Baseline scenario versus desired future scenario

In order to determine if the 10% target is feasible or not, the baseline scenario is compared with the desired future scenario. The exact data is given in the table below.

Table 8.7: Development in CO_2 emissions from 2013-2030 in aviation in EU-27

	2000	2005	2010	2013	2015	2020	2025	2030
Baseline scenario (in Tg)	135	147	161	170	176	192	205	218
Desired future scenario (in Tg)	135	147	161	169	174	178	189	199

The development in CO_2 emissions from the desired future scenario, with full implementation of SES, contains lower values than the baseline scenario, with no implementation of SES. The two scenarios are given in Figure 8.4 for the period 2000 to 2030 in order to give an overview of the impact of SES, deposited against the environmental target of 10% emission reduction from 2005 to 2020.

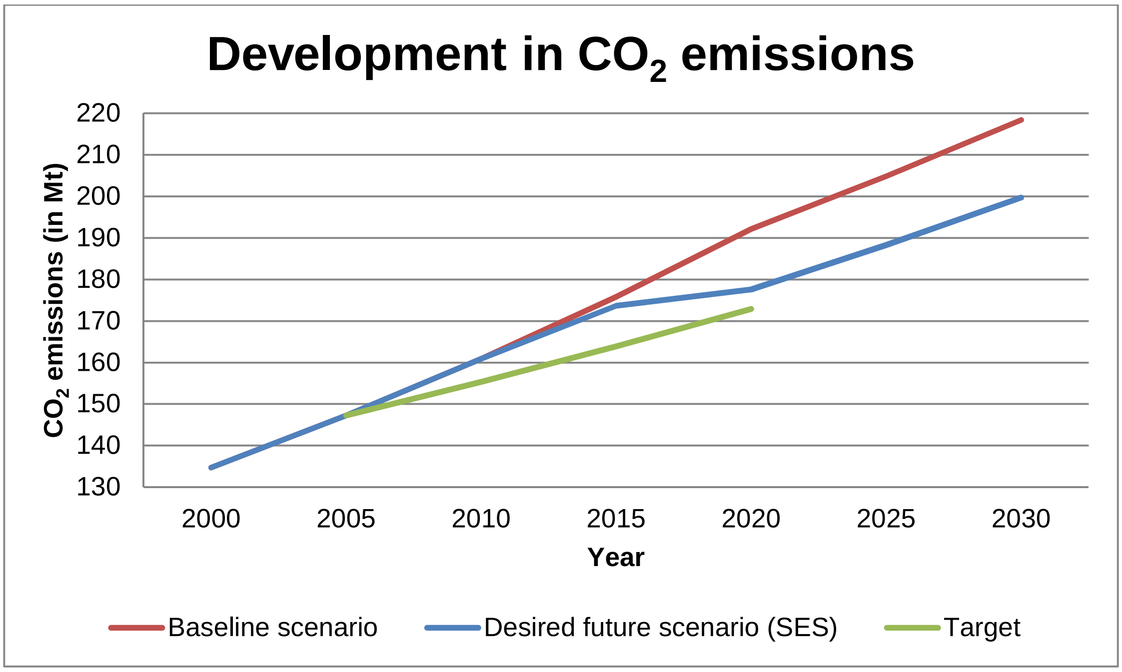


Figure 8.4: Development in CO_2 emissions for the baseline and desired future scenario for the period 2000-2030 in EU-27

The CO_2 emissions being lower in the future scenario is a positive outcome, because SES aims at reducing the environmental impact and contributing to sustainable air transport. However, it is seen that the line of the desired future scenario lies above the target line. This means that it is the forecast that SES will not meet the target of 10% emissions reduction from 2005 to 2020, compared to the baseline scenario. In order to assess the impact of SES on the development in CO_2 emissions in percentages, the percentage CO_2 emission savings per year is given in the following table through comparing the two scenarios for the years 2013 to 2030.

Table 8.8: CO_2 reduction with full implementation of SES for the period 2013-2030, compared to the baseline scenario

	2013	2015	2020	2025	2030
CO_2 reduction (in %)	0.59%	1.22%	7.55%	8.06%	8.56%

From this table can be concluded that SES contributes in reducing the environmental impact of air transport. However, the 10% target for 2020 is not reached in this scenario, because the CO_2 reduction with SES amounts about 7.55% from 2005 to 2020, compared to the baseline scenario. It is seen that there are major improvements from 2015 to 2020, which can be explained by the fact that a lot is changed and implemented in this deployment phase and SES will become more operational. From 2020 to 2030 it is seen that the CO_2 reduction due to SES is even higher, because the changes made in 2010 to 2020 are providing long-term benefits and operability increases. In 2030 the future scenario comes closer to the 10% target of 2020, because the CO_2 reduction will then be about 8.56%. The expectation is thus that the environmental goal will not be reached in 2020, but it performs better on the long term (in 2030). This can be explained by the fact that the goals set by the European Commission were ambitious and that operability was expected sooner. However, it takes time to change and adapt the air traffic management operations and system, which evolves in benefits on a somewhat longer term.

8.5 Concluding remarks

Since SES aims at reducing the environmental impact and ambitious goals are set, such as the environmental goal of 10% emission reduction from 2005 to 2020, it is essential to examine the feasibility of the effects with full implementation of SES. Through reducing the constraints of national boundaries via SES, air traffic management can operate more efficiently. The desired future scenario is determined, containing SES and its five environmental initiatives, whereby the development of CO_2 emissions is given for the period 2000 to 2030. Concerning the past environmental impact of SES over the period 2000 to 2012, there were only small (qualitative) improvements due to FABs and SESAR. The environmental impact of SES in quantitative terms in neglectible in this period and is therefore not taken into account in the desired future scenario.

For the future scenario, containing the years 2013 to 2030, several forecasts are done for the impact of SES regarding improving flight efficiency and reducing congestion. Also the situation in Europe is compared to the situation in the US, through looking at the several performance indicators. This evolves in the overall forecast that there will be an emission reduction of 14.5 Tg CO_2 in 2020 and a reduction of 18.7 Tg CO_2 in 2030 in Europe. The total CO_2 emissions from aviation will therefore amount to about 178 Tg CO_2 in 2020 and 199 Tg CO_2 in 2030. The environmental impact of SES will then be 7.55% CO_2 reduction in 2020 and 8.56% CO_2 reduction in 2030, compared to the baseline scenario. This means that SES contributes in reducing the environmental impact of air transport. However, the 10% target for 2020 will not be reached, which can be explained by the fact that implementation and operations are lacking behind and that it takes time to adapt the air traffic management system, whereby environmental benefits will be generated on the long term.

9 Discussion

9.1 Starting phase

During this research, some points of discussion have come up, regarding problems and assumptions. First of all, in the starting phase of the research the scope of research was determined in order to define the area of investigation and to deepen intro a specific topic, which makes the literature study more specific and focused. Regardless the fact that Single European Sky can also have an impact on air transport outside Europe, there is chosen to only determine the impact for EU27+2, because here will be the main changes and here is where SES will be implemented. Military aviation is left aside, because this is just a small part of the total aviation and there are different rules and operations applied there. Since SES focuses on air traffic management, the performance and organization of airports is not taken into account. Moreover, the focus of this study goes to the effect of SES on the environment, but SES also provides improvements in capacity, safety and costs. These effects are not described in this study, but it is possible to assess those in a future study.

9.2 Data collection

A main issue during the literature study was the difficulty of data gathering, because finding the right data did not always succeed or the desired data did not always exist. Determining the environmental impact of the implementation of SES has been an issue, both for the past (2000-2012) and the future (2013-2030). There is little evaluation on the past impact of SES, where mostly qualitative data is given while quantitative data is desired. Due to several sources mentioning that SES did not force much, there is chosen to give a similar development of CO_2 emissions over the period 2000-2012 for the scenario with and without the implementation of SES. For the future there are forecasts for the impact of SES on CO_2 emissions, but these forecasts differ from each other. This is due to different assumptions and different (or unknown) baseline scenarios. In order to determine the reliability of the different sources, the choice has been made to make own calculations, based on improving efficiency (reducing route-extension) and reducing en-route ATFM delay. This is based on possible improvements in Europe, compared to operations in the US. For assessing the future development it would have been desirable if more quantitative data is published by the European Commission or Eurocontrol, so this would be a recommendation for these organizations.

9.3 Exceptional events

What need to be kept in mind, while looking at the performance of air transport and air traffic management in Europe, is that there have been some exceptional events influencing the air traffic. The year 2009 was an exceptional year in air transport, because in this year weak economic growth is observed in Europe. This caused a decline in air traffic and greenhouse gas emissions. Furthermore, 2010 was also an unusual year due to exceptional events, such as the volcanic ash cloud and unusual weather. This resulted in 111,000 cancelled flights in April and May 2010, which can be an explanation for the actual greenhouse gas emissions being lower in this period than initially estimated in previous (2000) studies (Eurocontrol & FAA, 2012, p.9).

9.4 Tripling airspace capacity

Besides the focus of Single European Sky on sustainability and environmental benefits, there are also other aims of this initiative that do not cope with becoming more sustainable and reducing the climate change impact of aviation. The most important issue is that SES is also aiming at tripling airspace capacity from 2005 to 2020, whereby air traffic will increase even further in the coming period. This leads to increased fuel burn and increased CO_2 emissions and is therefore not contributing to sustainable air transport. On the other hand, increasing capacity is also needed in order to meet demand. Therefore it is essential for SES to have more environmental benefits per flight than the increase in air traffic, through which greenhouse gas emissions will not rise high. The goal of increasing capacity is not specifically taken into account while determining the baseline and desired future scenario of CO_2 emissions. However, the assumption of 2.8% air traffic growth per year already incorporates increased capacity, because this traffic growth is only possible if sufficient capacity is available. A remark is that it is seen that airports are lacking capacity, which will be an even bigger problem in the future, also in terms of achieving the capacity goal (Eurocontrol, 2013). This issue is not discussed in this report, because the focus is on airspace and air traffic management and not on airports.

10 Conclusion

10.1 Introduction

Through data gathering throughout this research, the research question and sub questions can be answered. The defined research question in the beginning of this research is: *What is the performance of current air transport in Europe and how can Single European Sky contribute to more efficient and sustainable air transport, in terms of reducing delay and greenhouse gas emissions?* This question will be answered in the end of this conclusion, after giving answer to each of the sub questions.

10.2 Sub question regarding current situation

The first sub question in this research is: *How is current air transport and air traffic management organized in Europe?* This question has been answered in chapter three by giving an overall explanation of the current structure. In Europe there is 11.5 million km^2 airspace, where currently 9.8 million flights are handled by 16,700 air traffic controllers. Air transport is a fast growing sector with an expected average growth rate of 2.8% in air traffic per year, which will result in about 16.9 million flights per year in 2030. Therefore it is essential to function properly in this sector and become more sustainable, also because the airspace is becoming more fragmented and air traffic management is becoming more inefficient. This is due to the 38 ANSPs in Europe that operate within their national boundaries and all have their own operations and characteristics. Combined with the lack of communication between the ANSPs and the lack of a common, up-to-date ATM system, the procedures in Europe are becoming more inefficient, which leads to increased greenhouse gas emissions. Currently about 70% of all flights in Europe are concentrated into 14% of the available airspace. In order to do something about the increasing environmental impact, the aviation sector is incorporated in the European Union's Emissions Trading Scheme (EU ETS) since 2012. To strengthen and support the emission scheme and increase ATM operability, the initiative of Single European Sky is introduced.

10.3 Sub question regarding current performance

Subsequently the second sub question is: *What is the current performance of air transport and air traffic management in Europe?* Using the indicators safety, delay/congestion, environment/flight efficiency and cost-efficiency, the performance of ATM in Europe is determined. It is seen that Europe, with its 38 ANSPs, is not performing at an optimal level. The indicator safety performed properly, because there were no ATM accidents in 2011. It is seen that aviation is currently contributing for 3.5% to the total CO_2 emissions in Europe and this percentage is expected to grow in the future. In 2010 there was an ATCO-hour productivity of 0.77 composite flight hours per ATCO-hour and total costs of €419 per composite flight hour. The indicator delay/congestion and flight efficiency is explained in the next question.

10.4 Sub question regarding ATM inefficiencies and delay/congestion

An important part of the performance is the air traffic management performance, for which the following sub question can be answered: *What are the air traffic management inefficiencies and cross-border delay/congestion where Single European Sky could have an effect on?* In Europe, 18% of all flights are delayed by more than 15 minutes and the total ATFM delay amounted to 17.9 million minutes in 2011. 47% of this delay is en-route ATFM delay, equivalent to 8.4 million minutes, where en-route ATC capacity and staffing problems is the main contributor. Noteworthy is that 17 of the 67 ACCs are responsible for 90% of the total en-route ATFM delay in 2010, with Madrid, Nicosia, Barcelona, Langen and Athinai + Makedonia being the five most congested ACCs. It is seen that ATM inefficiencies cause 7 to 11% additional fuel burn. This makes these indicators interesting in terms of improving performance in the future.

10.5 Sub question regarding comparison Europe with the US

In chapter five the following sub question is answered: *How does European air transport and air traffic management perform in comparison to the US?* Through comparing the European performance with the US, it is seen that European ATM performs less efficient. The US handles 67% more flights with less air traffic controllers than in Europe and the US performs better on the indicators delay/congestion, environment/flight efficiency and cost-efficiency. In the US 82% of the flights are on time against 75.5% in Europe, which is due to the fact that there is 57 times more en-route ATFM delay in Europe (5.7%) than in the US (0.1%). Moreover, the horizontal en-route flight efficiency is lower in Europe, because there is 50% more en-route extension. Furthermore, it is seen that Europe is less cost-efficient compared to the US, Canada and New Zealand.

10.6 Sub question regarding current environmental impact

Through determination of the emissions, the following sub question can be answered: *What is the environmental impact of current air transport?* The environmental impact of air transport is determined via the amount of CO_2 emissions, because CO_2 emissions emit by far the most (99.3%) of all greenhouse gasses in air transport. Rapid growth in CO_2 emissions, from both civil and international aviation, is observed over the past. The total CO_2 emissions increased from 83 Tg CO_2 in 1990 to 149 Tg CO_2 in 2010 in Europe. Continuing the line of past developments to the future, with no drastic changes, gives the baseline scenario. Assumptions for GDP, population development, energy intensity and travel activity are done, based on other studies on forecasts for the CO_2 development. The baseline scenario is given for the period 2000 to 2030, where CO_2 emissions increase from 135 Tg CO_2 in 2000 to 218 Tg CO_2 in 2030 in Europe.

10.7 Sub question regarding Single European Sky

In order to understand the Single European Sky initiative, the following sub question is answered: *How will the airspace and air traffic management in Europe be organized with full implementation of Single European Sky?* Single European Sky (SES) is introduced in 2000 with the aim to create a single sky in

Europe, whereby the design, management and regulation is coordinated by the European Union. It is the objective that through the implementation of SES there will be a shift from the current fragmented situation, with fragmented area control centers and diverse ATM systems, to a defragmented situation, with consolidated area control centers and common ATM systems in air transport. Common rules, standard and procedures are thereby essential. The environmental goal of SES is to lower the environmental impact of aviation from 2005 to 2020 by 10% compared to the baseline scenario, through improving efficiency, reducing route extension and reducing delays. Improving performance in air traffic management leads to less cross-border inefficiencies, less fragmentation, increased capacity and less congestion and delays. A reduction in fuel burn and greenhouse gas emissions is the environmental benefit.

10.8 Sub question regarding environmental initiatives of SES

The environmental aspect of SES will be explained via the following question: *What initiatives of Single European Sky focus on a reduced environmental impact?* The five environmental initiatives that aim at improved performance and reduced emissions are:

- Performance scheme (performance plans and targets)
- Functional airspace blocks (less control centers and common operations)
- Network manager (managing and improving network functions in ATM)
- Charging regulation (congestion charging to avoid delay)
- Single European Sky ATM Research (new ATM system)

10.9 Sub question regarding environmental impact of SES

In order to answer the research question, the following sub question is essential to answer: *What contribution to reducing the environmental impact in air transport will Single European Sky have with the key initiative?* Through reducing the constraints of national boundaries with SES, air traffic management can operate more efficiently, which is beneficial for the environment. The desired future scenario is determined, containing SES and its five environmental initiatives, whereby the development of CO_2 emissions is given for the period 2000 to 2030. Concerning the past environmental impact of SES over the period 2000 to 2012, there were only small (qualitative) improvements for FABs and SESAR. Therefore there is no quantitative environmental impact of SES taken into account in the past period in the desired future scenario. For the future scenario, from 2013 to 2030, it is the forecast that SES will cause an overall emission reduction of 14.5 Tg CO_2 in 2020 and a reduction of 18.7 Tg CO_2 in 2030 in Europe. This is based on several studies and a comparison with the US. The total CO_2 emissions from aviation will therefore amount to about 178 Tg CO_2 in 2020 and 199 Tg CO_2 in 2030 in the future scenario. The environmental impact of SES will be 7.55% CO_2 reduction in 2020 and 8.56% CO_2 reduction in 2030, compared to the baseline scenario.

10.10 Answering the research question

Having answered all sub questions, the research question can now be answered. The research question ‘*What is the performance of current air transport in Europe and how can Single European Sky contribute to more efficient and sustainable air* *transport, in terms of reducing delay and greenhouse gas emissions?'* consist of a performance part and a part on the contribution of Single European Sky to efficient and sustainable air transport. It is seen that the European airspace is fragmented, because about 70% of all flights in Europe are concentrated into 14% of the available airspace. Furthermore, air traffic management is becoming more inefficient which leads to increased delays, increased congestion, increased fuel burn and increased CO_2 emissions. This is due to the 38 ANSPs in Europe that operate within their national boundaries and all have their own operations and characteristics. The lack of communication between the ANSPs and the lack of a common up-to-date ATM system plays an important role here. Currently the en-route ATFM delay amounts to about 8.4 million minutes per year and ATM inefficiencies cause 7 to 11% additional fuel burn.

Single European Sky aims at improving ATM performance and reducing the environmental impact. The ambitious goal of 10% emission reduction from 2005 to 2020, compared to the baseline scenario, is set. Through reducing delays and improving efficiency, environmental benefits can be achieved. A desired future scenario with full implementation of SES is developed for the period 2000 to 2030, whereby an emission reduction of 14.5 Tg CO_2 in 2020 and a reduction of 18.7 Tg CO_2 in 2030 in Europe is achieved. The total CO_2 emissions from aviation will therefore amount about 178 Tg CO_2 in 2020 and 199 Tg CO_2 in 2030 in the future scenario. The environmental impact of SES will then be 7.55% CO_2 reduction in 2020 and 8.56% CO_2 reduction in 2030. This means that SES contributes in reducing the environmental impact of air transport. However, the 10% target for 2020 will not be reached, which can be explained by the fact that implementation and operations are lacking behind and that it takes time to adapt the air traffic management system, whereby environmental benefits will be generated on the long term.

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Appendices

Appendix 1: Charging regulation case studies

Slot allocation

In order to cope with the airport capacity and its increased traffic, airport slot allocation is implemented (Madas & Zografos, 2010, p.274). In 1993 the European Community adopted the Council Regulation (EEC) 95/93 on common rules for the allocation of slots at Community airports with the aim that airlines make the best use of the available capacity (European Commission, 2004b, p.2). Changes to this regulation have been accepted at the end of 2011 in the 'Better Airports Package', to allow for the introduction of market-based mechanisms across the EU. Slot allocation is defined under the UK and EU law as 'the scheduled time of arrival or departure available or allocated to an aircraft on a specific date at an airport' (Matthews & Menaz, 2003, p.1). The charging process that is coupled with it is slot sales, where the regulator or airport sells slots at a uniform price (Verhoef, 2010, p.327). By trading or auctioning of slots it is ensured that the slot is assigned to the airline that values it most (Basso & Zhang, 2010, p.381). In order to assess the effects of congestion charge modulation on congestion reduction, it is of importance to assess the impact of slot pricing on the behavior of airlines and their flight plans.

Several measures of combined regarding slot allocation and slot pricing will improve the efficient use of airport capacity, with an increase of about 1.6-2.0% passengers per year. Economic benefits and an increase in employment numbers will be coupled with this (European Commission, 2011c, p.5-6). In London it is seen that due to slot allocation airlines choose to avoid the airport London-Heathrow and move to London-Gatwick or another airport in London. Next to that, it is seen that the average aircraft size and the average distance flown increased. This means that airlines adjust their flight plans and fly longer routes in order to avoid high costs of slot allocation. Rerouting occurs, whereby there is a shift from congested primary airports to less convenient secondary airports (Mott MacDonald, 2006, p.8-4).

Belgian terminal charge modulation

In an interview with an advisor from the airports and airspace management in Belgium, he stated that the impact of the charging modulation is that the amount of flights during the night reduced and that there are more aircrafts with reduced noise production. Due to the high costs for movements in the Belgian airspace, it is seen that certain airlines avoid the Belgian airspace in order to reduce costs (Clippel, 2013).

Studies on air navigation charges

Several studies assessed the impact of air navigation charges. A study of Eurocontrol (2009b) proposed measures in order to overcome airport, airspace and environmental challenges, such as congestion. Overcoming congestion by shifting to alternative airports will reduce unaccommodated demand by about 30%. Therefore passengers and carriers need to be willing to relocate to other nearby and less congested airports, which in turn could save congestion charges

(Eurocontrol, 2009b). In the US there is a congestion charge modulation developed by Daniel and Harback (2008) that implies that implementing congestion pricing at 27 airports would reduce delays by 1000 aircraft-hours every day and it would save about 3-5 million dollars daily (Daniel & Harback, 2008, p.33). Studies of Reynolds et al. (2009) and Jovanović et al. (2011), regarding the expectations of charge modulation, are elaborated below.

Study on airline route choice and ANS charging

Reynolds et al. (2009) assessed the impact of charges for airlines for the US for usage of air navigation services. The charges differ per country, which influences the behavior of airlines. It is seen that airlines adapt their flight plans and fly longer routes if there are lower air navigation charges in other countries. This is only the case when there is a significantly lower charge, in comparison with higher fuel costs due to the longer routes, which is certainly not applicable for every flight plan. However, the expectation is that airspace charging will not have a major influence on the routing (Reynolds et al., 2009, p.2-7).

The most prominent example of charging and rerouting was the ‘TANGO route’ from Newcastle (UK) to Las Palmas, Gran Canaria (Spain). After an investigation, it is alleged that at least two UK-based charter airlines were deliberately flying longer routes on services from the UK to the Canary Islands (and back) to avoid flying through the more expensive airspace of Spain and Portugal. According to Reynolds’ calculations, the TANGO route is 123nm longer than the standard route and a Boeing 757-200 passenger aircraft would use an additional 990kg (7%) of fuel. This extra fuel burn results in 3100kg additional CO_2 emissions. However, even allowing for the additional fuel costs, the TANGO route would still save a B757-200 operator €471 per flight owing to the lower en-route charges. The conclusions of Reynolds concur with anecdotal evidence gathered during this study that airspace users tend to avoid Belgian airspace on East-West routes when possible, due to the relatively higher ANS route charges applied by Belgium compared to France and the Netherlands (Reynolds et al., 2009). A negative side effect is that when longer distances are flown, there will be increased CO_2 emissions. It is environmentally justified if the extra emissions come close to the extra emissions that are caused by congestion and delay.

Study on the impact of ANS charging

Jovanović et al. (2011) determined the effects of ANS charges through taking a small-scale real-world example. Implementing a charging regulation will be an efficient measure to put less pressure on a congested network and to move towards the equilibrium (of supply and demand). The charging modulation yields a fairly equitable, market-driven route assignment. This method seems more efficient compared to current practices, where there will be capacity improvements. Neutrality is important within the proposed method. Moreover, there are also some limitations of the method, which are due to uncertainties inherent to the air transport system (due to variety of disruptive factors) and the fact that the modulation is seen as a short-term solution for the demand-to-capacity imbalances (Jovanović et al., 2011, p.7-8).

Congestion charging other transport modes

Congestion charging is not a new issue in transport. Both in road transport and aviation, different varieties of congestion charging are applied. A description of some examples of congestion charging in road transport, which illustrate that transport users are sensitive to applied price mechanisms, are given below.

Congestion charging in London

In London, congestion charging has the objective to reduce the amount of traffic and congestion on the road in the center of the city. From 2003 there is a mandatory modulation of congestion charges in place in London, where less emitting vehicles pay fewer charges. From 2002 to 2006 the amount of passenger cars during peak times (from 7:00am till 6:30pm) reduced with 36% in the charging zone, which means that drivers choose to travel in another way. An increase in the amount of busses and bicycles is observed during that period. The conclusion is that the introduction of congestion charging in London changed the behavior of drivers and has led to less car traffic (SWOV, 2009). The introduction of congestion charging encouraged drivers to think about their trips and discourage them to travel during peak (charging) hours (Transport for London, 2008, p.113).

Kilometer charges in the Netherlands

Ecorys did some studies on kilometer charges on the road for the Netherlands. The outcome is that an increase of costs for a car owner leads to a decrease in car use (Ecorys, 2007a, p.19). Road users adapt their behavior in response to the charging, which means that it is possible that car users choose to not drive a certain route, adapt their route or destination (rerouting) or that they drive at another moment. So called ‘avoidance behavior’ will occur with the objective of car users to avoid as much costs, which evolves in less congestion and a more reliable travel time. Another possibility is that car users choose to buy a different (more efficient) car. The impact of kilometer charges is depending on the design, modulation and height of kilometer charges. As the height of charge increases, the observable effects will also increase (Ecorys, 2007b, p.7).

LKW-MAUT in Germany

Germany implemented in 2003 a toll for trucks using German highways, under the name LKW-MAUT. The charge is depended on the amount of axes per truck and the amount of emissions. The most important effects of this charging modulation are that the costs are charged to the customers, efficiency improvements occur and that there are changes in terms of routes, type of transport (water/rail), load, equipages and other vehicles. The LKW-MAUT system proved to be an incentive to promote the use of new vehicle technologies (Rijkswaterstaat Adviesdienst Verkeer en Vervoer, 2003, p.14).

Congestion charging Stockholm

In Stockholm there are congestion charges implemented in road transport in order to reduce congestion in the year 2006. The effects over the period 2006-2011 are examined and it is seen that there was a traffic decline in the inner city of 8-9% and about 22% of the car trips changed to ‘other things’ or transit. Moreover, there is an important effect on ‘clean car’ sales, where there was an increase of 27% (Centre for Transport Studies, 2011).

Future steps

Having observed the effects from other cases in air transport and road transport, conclusions can be drawn for the potential of congestion charging in aviation.

There are two possible scenarios with regard to air navigation charges, which will be described below:

1. Do nothing (business-as-usual scenario), with maintaining the current situation regarding ANS charges
2. Mandatory implementation of ANS charges modulation (desired future scenario) to reduce congestion (‘congestion charging’)

Scenario 1: Do nothing (business-as-usual scenario)

The first option is to leave the situation as it is and to do nothing in terms of modulation of congestion charges. Currently, there is no congestion pricing mechanism in place in the air transport management sector (Zhang & Czerny, 2012, p.16-17). Congestion in air traffic management will not be addressed via charges on a mandatory basis in this scenario, nor will SESAR uptake be influenced via charges. In this situation, the option of charging modulation remains open on voluntary basis, where an individual ANSP can take the initiative to introduce modulation.

In order for congestion charging to succeed, improvements and adjustments are needed. Charging regulation and market-based pricing in general is completely new to the ATM community. This evolves in the need for education, also because there is no background knowledge or experience on which the industry can draw. The development of white papers, briefing papers and trail balloons would be a very low cost means to educate the industry on what might be possible. Without this work, any attempt to address more complex options below is likely to be premature.

Scenario 2: Mandatory ANS charging (desired future scenario)

At some airports the demand exceeds capacity throughout the day, mainly at the airports London Heathrow, London Gatwick, Paris Orly, Milan Linate, Düsseldorf and Frankfurt (European Commission, 2011c, p.1). Congestion charging is aiming at influencing the behavior of involved stakeholders through financial advantages and disadvantages, with the objective to meet the established performance objectives that are set by the EU. This will put less pressure on the congested airports (Jovanović et al., 2011, p.1).

Mandatory ANS charging (congestion charging) could be an incentive to reduce congestion on certain routes and thereby increase efficiency and capacity. This is essential, because congestion and delay in air transport is becoming a larger problem. Part of congestion charging is peak/off-peak charging which depends on the time of day, the day of the week or on the time of year. Identifying these peak times is complex and difficult to implement since studies show considerable variations. Moreover, congestion charging will only have an effect with the right price elasticity, because there will be little or no impact in managing demand if the price elasticity is too low. Airspace users should be encouraged enough in order to shift demand from congested to less congested areas or times of day, by offering preferential rates in areas with spare capacity (Eurocontrol, 2012e, p.4).

Appendix 2: List of interviewees

The table below represents the interviewees with name, company and the date of the interview. Gathered information is incorporated in the study.

Name	Company	Date of interview
Laszlo Kiss	European Aviation Safety Agency (EASA)	January 21, 2013
Maurits de Clippel	Belgian Civil Aviation Authority	January 3, 2013
Patrick Ky	SESAR Joint Undertaking	January 16, 2013
Xavier Fron	Performance Review Unit	January 3, 2013