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SCIENCE FOR A SUSTAINABLE DEVELOPMENT

AVIATION AND THE BELGIAN CLIMATE POLICY : INTEGRATION OPTIONS AND IMPACTS

«ABC-IMPACTS»

SD/CP/01A

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Climate

FINAL REPORT PHASE 1

AVIATION AND THE BELGIAN CLIMATE POLICY : INTEGRATION OPTIONS AND IMPACTS

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SD/CP/01A

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ACRONYMS, ABBREVIATIONS AND UNITS

AERO2k	European project on global aircraft emissions for climate impacts evaluation
AIC	Aviation Induced Cloudiness
BEST	Board of European Students in Technology
CCIEP	national Coordination Committee on International Environmental Policies
CLM	Climate version of the 'Lokal Modell', which is the operational weather forecasting model used by the 'Deutscher Wetterdienst' (DWD). (http://clm.gkss.de)
ECOSONOS	**E**missions of **CO_2**, **SO_2** and **NO_x** from **S**hips Research project financed by the Belgian Scientific Policy Office (Belspo)
ESRA	Eurocontrol Statistical Reference Area
EU-ETS	European Union's Emission Trading Scheme
GHG(s)	Greenhouse gas(ses)
GTP	Global Temperature Potential
GWP	Global Warming Potential
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
JCM5	Java Climate Model, fifth version
LTO	Landing and Take-Off
MAMCA	Multi Actor and Multi Criteria Analysis
MOPSEA	**Mo**nitoring **P**rogramme on air pollution from **sea**-going vessels Research project financed by the Belgian Scientific Policy Office (Belspo)
NECTAR	Network on European Communication and Transportation Activities Research
RCM	Regional Climate Model
RFI	Radiative Forcing Index
SRAGA	IPCC Special Report on Aviation and the Global Atmosphere
SRES	IPCC Special Report on Emissions Scenarios
TAR / AR4	Third / Fourth Assessment Report of IPCC
TRADEOFF	European project on aviation and climate (from the 5th framework program)
TREMOVE	*"TREMOVE is a policy assessment model, designed to study the effects of different transport and environment policies on the emissions of the transport sector."* (http://www.tremove.org/index.htm)
UNFCCC	United Nations Framework Convention on Climate Change
WP	Work Package

For more acronyms, abbreviations and units, see the glossary and synthesis documents on the website of the project: http://dev.ulb.ac.be/ceese/ABC_Impacts/open_section_in_brief.php.

A pdf version of the glossary is also available on the ABC Impacts website (http://dev.ulb.ac.be/ceese/ABC_Impacts/open_section_references.php#project).

All the words of the text appearing in blue are explained in the glossary.

EXECUTIVE SUMMARY

1. Introduction

Since the publication of the Intergovernmental Panel on Climate Change (IPCC) special report on aviation (1999), the international scientific community has become aware of the importance of the impacts of emissions from the aviation sector on global warming. The report indeed shows that not only CO_2, but also NO_x, condensation trails (contrails) and enhanced cirrus cloud formation, have a significant impact on climate change. Yet, emissions from international air transport are not targeted by the Kyoto Protocol commitments, and are not integrated in any international climate policy, despite considerable growth in aviation since more than 10 years.

The possibility of integrating this sector is increasingly considered both at the European level and in the context of the United Nations Framework Convention on Climate Change (UNFCCC). The European Union is planning on including aviation in its emission trading scheme in 2011-2012, and it is very likely that part of the post-Kyoto international negotiations will be dedicated to accounting for emissions from international air transport.

On the 20th of December 2006, the European Commission has officially published its proposal to include the aviation sector in the EU-ETS. Adding the current negotiations on the review of the existing EU-ETS at the European level and on the post-2012 scheme and commitments at the UNFCCC level to the picture provides an overview of how climate impacts of the aviation sector have become an important "hot" topic but also how tricky and interdependent policy options to include aviation in climate policy are.

Concerning scientific progress related to climate impacts of non-CO_2 emissions from the aviation sector, major scientific advances have been included in the IPCC AR4 report (as well as projects such as TRADEOFF), compared to the TAR and SRAGA. These include that the estimated impact of NO_x and contrails has been reduced but the impact of cirrus cloud formation seems to be greater than expected although there is still a large uncertainty. This implies that the total impact of aviation is dominated by the non-CO_2 impacts, particularly as far as Belgium is concerned.

In this context, the *ABC impacts* project intends to analyse these different climate policy options (as well as their consequences) and to provide an in-depth study of the technical, economic and environmental characteristics of the aviation sector.

2. Climate, climate policy and the aviation sector

The influence of human activities on climate has been demonstrated by the IPCC and it is well known that the main anthropogenic greenhouse gasses are generated by combustion processes, such as those related to the transport sector.

Climate policy aims at limiting climate impacts either by adapting ecosystems and human societies to those climate changes (adaptation) or by trying to reduce emissions causing climate change (mitigation).

The transport sector is not only responsible for an important share of the total GHG emissions, especially in industrialised countries (more than 20% of the total GHG emissions of those countries are due to transport), but it grows strongly and continuously while other sectors succeed in stabilising, or even in reducing, the total quantity of their GHG emissions. Among the different transport segments, aviation plays a particular role for two main reasons:

1. aviation induces greater climate impacts than those due to Kyoto greenhouse gasses emitted by aircrafts (e.g. perturbation of the high cloud cover, which induces a strong regional forcing) ;
2. aviation registers one of the highest growth rates within the transport sector during the last years, and market forecasts seem to confirm this trend for the following years.

Different policy instruments are available for the climate policy to mitigate climate impacts from the transport sector:

1. instruments with a direct link on the global warming issue (raising public awareness, voluntary/negotiated agreements or actions, financial and economic tools such as taxes / fees / subsidies / market mechanisms, R&D, command-and-control regulation) ;
2. instruments not aiming specifically at global warming but having an indirect influence on it (planning, financial and economic tools to set up a level playing field between all transport modes such as VAT or duty free sales, infrastructure management such as slot allocation at airports, the environmental legislation focusing on other air pollutants than GHGs or related annoyances such as noise, R&D to support more environmentally friendly transport solutions or alternatives to transport).

The analysis of those instruments results in the realization that the environmental effectiveness of a policy mix is often better than the environmental effectiveness of a sole instrument. No isolated instrument offers simultaneously a real limitation on the total climate impact and a satisfactory level of flexibility to minimize the related costs as much as possible. In other respects, raising public awareness seems to be a basic element for a good comprehension and acceptance of other climate policy instruments. Moreover, ensuring a level playing field between all transport modes by applying a harmonized rate of VAT on the tickets and fuel tax is necessary to avoid competition distortion, as well as harmonizing the duty free practices.

Moreover, the adoption of any policy measure should be done with the assessment of all its global consequences, seeing that even measures not focused on tackling climate change could have a substantial indirect influence on the efficacy and efficiency of other climate policy instruments.

The world-wide extent of global warming and transports such as aviation generally implies that international agreements could have a better environmental efficiency and a lower risk of market distortion than measures adopted at the local level (e.g. tax on kerosene or on CO_2 emissions; emission standards; airport taxes or fees; etc.). On the other hand, this kind of agreements may take a long time to be implemented and are often limited to the adoption of the lowest common denominator between the parties.

The adoption of the Montreal Protocol, the UNFCCC, the Kyoto Protocol and the EU-ETS falls within this scope. The two last ones are aiming at increasing the flexibility of the policy measure and at reducing the compliance costs by combining a strict emission ceiling with market mechanisms.

In this framework, the European Commission has officially launched in December 2006 a directive proposal to include the aviation in the EU-ETS. Diverging views between the European Parliament and the European Council Environment require a procedure of second reading that is expected to begin in May 2008.

3. Emissions from aircraft

Due to the continuous growth of transport, related CO_2 emissions have continuously increased during the last years, and are expected to reach 25% of world-wide CO_2 emissions by 2030.

Aviation is one of prime drivers of this growth, and yet its total climate impact is by far more important than only its CO_2 emission climate impact. The concerned atmospheric pollutants are generated through kerosene combustion in aircraft engines and their respective total quantity of emissions depends either on the fuel composition (NO_x, SO_x), or on combustion conditions. These last ones vary according to the flight phase, so that more CO, NO_x and unburnt hydrocarbons (HC) are emitted during the LTO phase than during the cruise phase and that the energy efficiency per kilometre flown is lower for short-distance flights than for long-distance flights. LTO emissions are more worrying for health and ecosystems (air quality), while cruise emissions are particularly more sensible for climate change.

In order to realise an aviation emission inventory for Belgium based on the calculation of aircraft emissions and related energy consumption, the following parameters have to be taken into account:

- activity data of Belgian airports, as well as of overflights ;
- aircraft types (and as far as possible the used engine technologies) ;
- distances flown ;
- the different flight phases.

CO_2 emissions and energy consumption related to flights departing from or arriving at a Belgian airport almost reach the same level as in 2001, before the SABENA bankruptcy and the New York attacks, while those related to overflights have steadily increased period to attain practically twice the emission level of Belgian airport activities. A similar trend exists for NO_x emissions, as opposite to CO and HC emissions that are typically generated in higher quantities during the LTO phases (in this case, on Belgian airports) rather than during the cruise phase of overflights.

There are different solutions to mitigate aviation emissions on a short to middle term either at the aircraft level (engine technology improvement, higher load factor, small modifications of the aircraft design, etc.), or at the level of the global aviation sector (alternative fuels, improvement of the navigation system, better emission management at airports, etc.). However, reduction potentials face many obstacles to be really efficient (time delay for the adoption and market penetration of new R&D solutions, huge increase of the total forecasted emission volume due to the market growth compared to the emission reduction potential, etc.).

4. Aviation sector prospect and Belgian characteristics

After 2001, the aviation sector almost recovered its former activity level partly thanks to the strong growth in the freight segment. Another general trend in the passenger transport consists in the use of larger aircrafts which increase the number of available seats.

In contrast, the number of flights at the European level has risen sharply since 1985 (with a little drop in 2001-2002) but overflights represent a minor part of the total flights contrarily to the Belgian situation.

Considering air traffic forecasts, passenger flights are expected to grow by 4% per year, leading to a doubling of the current frequencies by 2023, and cargo flights could reach an even stronger growth level between 4,4% and 5,9% per year.

More specifically, European air traffic is expected to increase on average by 3,3% annually in the mid term and from 2,3% to 3,4% in the longer term (until 2023), while Belgian/Luxembourgian air traffic should grow annually by 2,8% on average in the mid term, with an increased proportion of overflights in the total, and by 2,3%-3,4% in the longer term.

As regards the characteristics of the Belgian aviation sector, 15 companies registered their licence in Belgium in 2007, from which 2 helicopter businesses. At the airports level, Brussels National Airport still registers the most important activity but suffered the Sabena bankruptcy in 2001, while passenger numbers have grown substantially at regional airports, especially Brussels South Charleroi Airport. Concerning cargo flights, which grew faster than passenger flights in Belgium, Brussels Airport is still the major Belgian cargo airport but the market share of regional airports, mainly Liège Airport, has increased sharply these last years with a stronger trend than for passenger transport.

Since Belgium is situated in the middle of the main European air knots, overflights above the Belgian territory are especially important (more than 750.000 in 2006 compared to more or less 200.000 LTO cycles at Belgian airports).

From the financial point of view, the situation of the Belgian aviation sector has improved since 2001 and the staff number hired and paid in Belgium has strongly declined (decrease in the sector employment + growth in staff hired following another country rules), but the Belgian aviation sector has never been profitable as a whole during the last ten years.

5. Interactions between the climate and the aviation sector

As mentioned earlier, aviation has a greater climate impact than that only induced by CO_2 emissions.

Emissions at high altitude play an important role:

- in the interactions with the atmospheric chemistry (methane destruction, ozone formation, aerosols formation), modifying the radiative forcing balance of the atmosphere,
- and in clouds induction (contrails, cirrus), which is mainly a local phenomenon along the main air corridors.

Therefore, the total climate impact of an aircraft at 12 km, taking into account global and regional impacts, is on average twice as large as its impact at 8 km.

On global average, the total climate impact from the aviation sector ranges from 2,5 (IPCC, 1999) times to more 5 times (TRADEOFF, 2003) the climate impact from aviation CO_2 emissions only.

Whereas in Europe as a whole, overflights (without landing or taking off in any European airport) represent only a tiny portion of all flights (less than 1%), they represent the majority of the flights over the Belgian territory (~70%). This is reflected in the radiative forcing of contrails and aircraft induced cloudiness (AIC) produced by these flights.

Seeing that Belgium is right in the middle of the main European air knots, it will suffer from one of the most important contrail covers.

In Belgium the impact of LTO flights represent only ~4% of RF due to contrails or AIC as most of the flights taking off or landing in Belgium do not reach an altitude where contrails can be produced before leaving the Belgian airspace.

Belgium is thus submitted to important climate impacts (imbalance in radiative forcings inducing local temperature changes, enhanced cloudiness) from these flights that do not or barely contribute to the economy of the country (It is important to note that although the RF from AIC in Belgium is of the same order of magnitude than that of all anthropogenic CO_2, this does not imply that the temperature increase generated by these radiative forcing imbalances will be the same, as the climate system will be able to disperse the impact of such a strong local forcing).

One implication of this result is that it would be in the interest of Belgian policymakers to propose a strong mechanism to include the non-CO_2 gases, either within the Emissions Trading System or some parallel process.

In order to assess climate impacts from the aviation sector, two new modules have been added to the interactive Java Climate Model JCM5. This version of JCM5 is already available online, and can be launched easily with one click from a web browser, assuming that Java 5+ is installed. {see point 5.2}

To make it easier to find the new plots and parameters, a system has recently been developed to automatically set up the model settings and layout to illustrate a specific topic such as aviation. The aviation setup includes a documentation page linking to other examples, illustrating the changing mixture of radiative forcing from different aviation gases and also a variety of scenarios, both unmitigated within the context of the EU 2°C limit.

During the second phase of the ABC Impacts project, further work will be done on the assessment of regional climate impacts generated by the aviation sector. First tests to model regional climate changes have already been carried out with the CCLM model.

6. The MAMCA analysis

Among several evaluation methods on transport related projects, the multi stakeholders multi criteria analysis (MAMCA) has been chosen by the ABC Impacts project.

The methodology consists of seven steps.

The first step is the definition of the problem and the identification of the alternatives (step 1). Secondly, the various relevant stakeholders are identified as well as their key objectives (step 2). Then, these objectives are translated into criteria and then given a relative importance (weights) (step 3). For each criterion, one or more indicators are constructed (e.g., direct quantitative indicators such as money spent, number of lives saved, reductions in CO_2 emissions achieved, etc. or scores on an ordinal indicator such as high/medium/low for criteria with values that are difficult to express in quantitative terms, etc.) (step 4). The measurement method for each indicator is also made explicit (e.g. willingness to pay, quantitative scores based on macroscopic computer simulation, etc.). This enables the measurement of each alternative performance in terms of its contribution to the objectives of specific stakeholder groups.

Steps 1 to 4 can be considered as mainly analytical, and they precede the "overall analysis", which takes into account the objectives of all stakeholder groups simultaneously and is more "synthetic" in nature. Here, an evaluation matrix is constructed aggregating each alternative contribution to the objectives of all stakeholders (step 5). The MCDA yields a ranking of the various alternatives and gives the strong and weak points of the proposed alternatives (step 6). The stability of this ranking can be assessed through a sensitivity analysis. The last stage of the methodology (step 7) includes the actual implementation.

7. Main conclusions and recommendations

Based on the former chapters, the following conclusions and intermediary recommendations have been drawn by the ABC Impacts project:

7.1 Through important innovative adaptations the aviation sector succeeded in implementing an important reduction of the emissions (CO_2, H_2O, Soot, CO, SO_x, NO_x, etc.) and fuel consumption of individual aircraft. However, the **reductions of the emissions (fuel consumption decreases by 0,5% - 2% per year) are less than the high growth rate of the sector** (average of 6,4% per year between 1991 to 2005, European Commission).

In the future several improvements are to be expected. In the long term some radical changes (like the use of hydrogen as a fuel for aircraft) might occur. In the meantime some other technological evolutions are to be expected (implementation of synthetic fuels, biofuels, etc.) all of which present some specific strengths and weaknesses. Some other innovative concepts have recently been presented (adapted rear turboprop mounting, adapted empennage and air frame, improved aerodynamics...) and form promising options for the future.

7.2 On the other hand, some **sector management changes** (improved ATM, implementation of the Single European Sky, Reduced Vertical Separation Minimum (which is already largely implemented), Continuous Descent Approach…) might reduce the impact of aviation on climate by more than 10% without the need for new technologies to be implemented onboard and without the delay that is necessary for fleet renewal when new technologies are implemented.

7.3 The Belgian aviation market has a very specific position within Europe due to its geographical situation; in the middle of the so-called FLAP area which is demarcated by the four main airports of Europe: Frankfurt, London, Amsterdam and Paris. This also implies that the **number of overflights is already considerable through Belgian airspace and could become even more important due to the sectoral growth and potential route adaptations** (according to Statfor-Eurocontrol, the adoption of shorter routes could increase overflights above the Belgian territory by 10%).

7.4 The **role of ozone and cirrus clouds**, especially for regional climate, is fundamental and so operational measures to reduce them should be considered, despite remaining uncertainties. This is especially important as tradeoffs are to be found between the different impacts. In general a reduction of CO_2 emissions for an engine induces an increase in NO_x emissions, thus producing more ozone. Also it is a general trend that more fuel efficient engines produce more contrails at higher temperature (i.e lower altitudes).

7.5 It is important to note that on the one hand the impacts of the Belgian aviation sector on global climate change is relatively small compared to other sectors or other countries (Belgium's contribution to aviation **emissions** is not particularly remarkable), but that on the other hand regional climate impacts due to contrails, cirrus formation and change in the ozone concentration could have a large influence on the country because of the concentration of flights over the Belgian territory. **One focus for Belgian policy makers could be to reduce the impacts from transit aviation**, especially via operational measures targeting non-CO_2 gases, as well as shift to other transport modes.

1. INTRODUCTION

1.1. Context

Since the publication of the Intergovernmental Panel on Climate Change (IPCC) special report on aviation (1999), the international scientific community has become aware of the importance of the impacts of emissions from the aviation sector on global warming. Such report indeed shows that not only CO_2, but also condensation trails (contrails), NO_x emissions and cirrus cloud formation have a significant impact on climate change. Yet, emissions from international air transport are not targeted by the Kyoto Protocol commitments, and are not integrated in any international climate policy, despite considerable growth in aviation since more than 10 years.

The possibility of integrating this sector is increasingly considered both at the European level and in the context of the United Nations Framework Convention on Climate Change (UNFCCC). The European Union is planning on including aviation in its emission trading scheme in 2011-2012, and it is very likely that part of the post-Kyoto international negotiations will be dedicated to accounting for emissions from international air transport.

On the 20th of December 2006, the European Commission has officially published its proposal to include the aviation sector in the EU-ETS. On the one hand, ICAO had already expressed its support to voluntary agreements and to the integration of the aviation sector in existing emission markets, but on the other hand ICAO seems to be reluctant to accept the application of the EU proposal to non-EU carriers without bilateral agreements (cf. General Assembly of ICAO in September 2007).

Adding the current negotiations on the review of the existing EU-ETS at the European level and on the post-2012 scheme and commitments at the UNFCCC level to the picture provides an overview of how climate impacts of the aviation sector have become an important "hot" topic but also how tricky and interdependent policy options to include aviation in climate policy are.

Concerning scientific progress related to climate impacts of non-CO_2 emissions from the aviation sector, major scientific advances have been included in IPCC AR4 report (as well as projects such as TRADEOFF), compared to the TAR and SRAGA. These include that the impact of NO_x and contrails has been reduced but the impact of cirrus cloud formation seems to be greater although there is still a large uncertainty. This implies that the total impact of aviation is dominated by the non-CO_2 impacts, particularly as far as Belgium is concerned.

Different options may thus be considered for the inclusion of aviation into climate policy. The analysis of these options is of particular interest for Belgium, given the importance of this sector in its economy and the intensity of greenhouse gas emissions from air traffic over the Belgian territory.

1.2. Objectives

In this context, the *ABC impacts* project intends to analyse these different climate policy options (as well as their consequences) and to provide an in-depth study of the technical, economic and environmental characteristics of the aviation sector. When relevant, the project will also draw a comparison with the case of international maritime transport, using as a basis the results of previous research projects such as MOPSEA and ECOSONOS.

This research project serves two main objectives:

1- to inform political decision-makers about the environmental, political and socio-economic implications for Belgium of integrating (or not) the international aviation and maritime transport sectors into climate policy;

2- to present itself as a tool for the preparation and assessment of Belgian climate policy, on the eve of the negotiations concerning the expansion of the European Emission Trading Scheme (EU-ETS) and the post-2012 phase of the Kyoto Protocol.

The ABC Impacts project has been split into two phases:

- first phase (2006-2007): this starting phase focuses on the state-of-the-art about the problematic of the climate change and the aviation sector through the identification of the different policy options to include aviation in the climate policy, the analysis of aircraft emissions and the creation of an emission database, the integration of an "aviation module" in the JCM5 climate model in order to assess climate impacts from aviation, and the identification of stakeholders and their characteristics for the MAMCA.

  This report summarises the work already carried out by the research team in connection with this first phase.

- second phase (2008-2009): this phase aims at consolidating the work undertook in the first phase through the introduction of systematic analyses of a set of policy options according to different scenarios, and at refining analyses and results based on data already gathered during the first phase and updated if necessary.

1.3. Methodology

To achieve these objectives, a multidisciplinary approach has been adopted.

On the basis of a **literature review**, a preliminary "**state-of-the-art**" has been carried out on the evolution of the climate policy, the emissions from aircrafts, the evolution of the transport sector and specifically the aviation and maritime transport sectors, the scenarios and assumptions as regards climate modelling.

Concerning the climate policy, work has been completed by the **follow-up** of the current negotiations on the post-2012 UNFCCC-Kyoto scheme and the proposal to include the aviation in the EU-ETS. Different **analyses** have been carried out in order to assess the consequences and stakes related to the different options discussed or proposed by stakeholders about this proposal, as well as the potential interaction of this inclusion with other policies (e.g. post-2012 negotiations, EU-ETS review, etc.). The work carried out on this thematic is summarized in Chapter II.

As regards the emission of the aviation sector, data have been collected from airports, Belgocontrol and Eurocontrol in order to build an **emission inventory** of aircrafts landing on or taking-off from a Belgian airport, as well as of overflights above the national territory. The work carried out on this thematic is summarized in Chapter III.

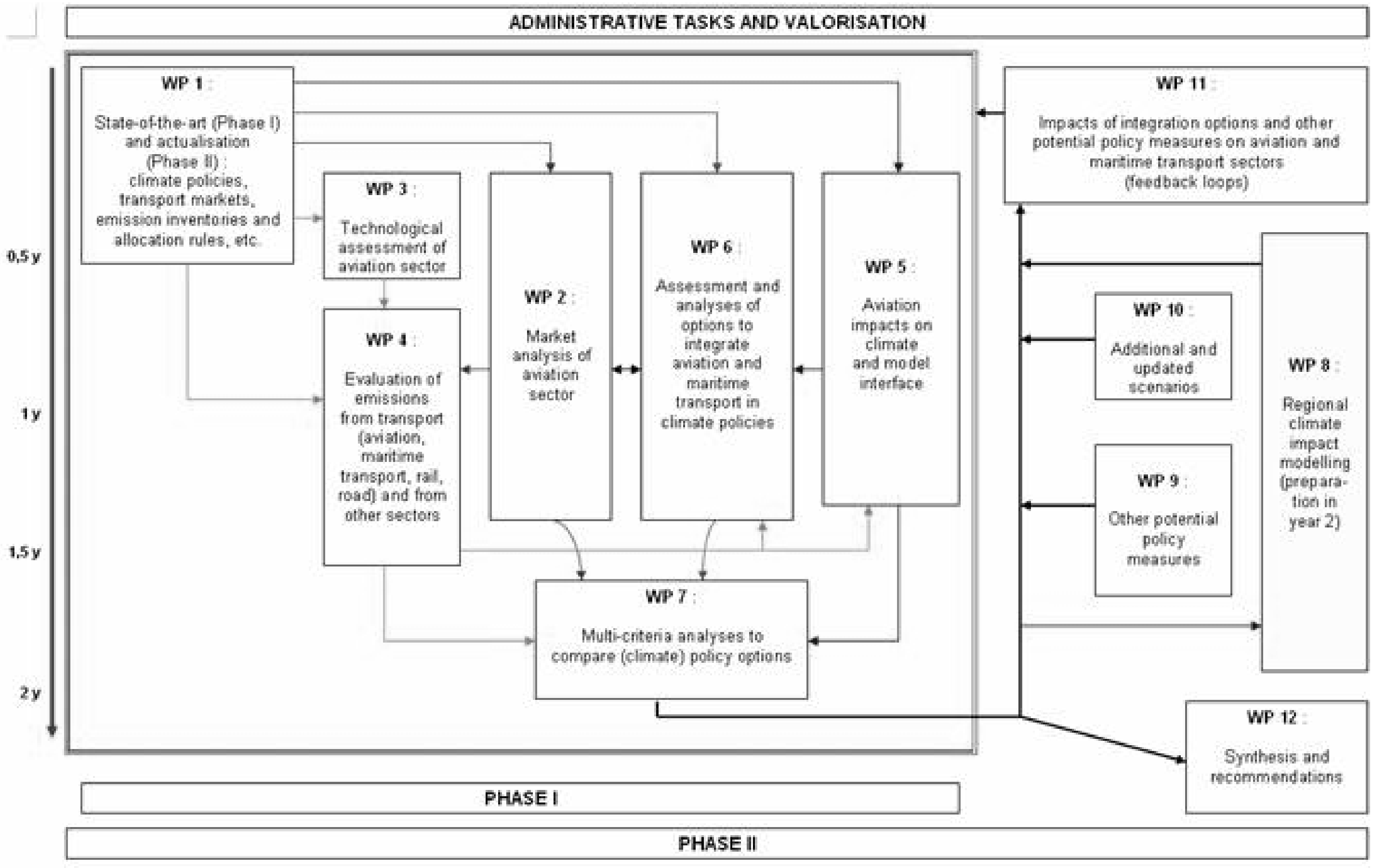
In order to assess the evolution of aviation in the following years and to identify the characteristics of the different market segments (for the EU and for Belgium in particular), a **market analysis** has been carried out. This will be used to forecast the related aircraft emissions more in detail, as well as to assess the consequences of the integration of the aviation sector in climate policies on the environment, the aviation sector, etc. The work carried out on this thematic is summarized in Chapter IV.

This data collection is of most importance for the **climate modelling**, mainly as regards the development of a specific model aiming at assessing the regional climate impacts caused by aircrafts. In the first phase, a former climate model (JCM5) has been updated and completed with a specific module dedicated to the aviation sector. During the second phase of the project, a specific climate model on regional climate impacts will be developed in order to assess the climate effects of several aircraft emissions having more localized impacts (e.g. change in the ozone concentration due to NO_x interactions, induced cloudiness due to particles, aerosols and water vapour, etc.). The work carried out on this thematic is summarized in Chapter V.

The **Multi Actor and Multi Criteria Analysis** (MAMCA) will be used to synthesize the results of the comparison between the different policy options to tackle the climate impacts from aircraft and to range them according to different stakeholder positions or criteria. The methodology of the MAMCA is summarized in Chapter VI.

Figure 1 presents an overview of the different work packages (WPs) of the project and their interactions.

Figure 1 : Task scheme and interconnections between the different WPs of the ABC Impacts project



A project website has been set up (**http://www.climate.be/abci**) with :

- a detailed description of the tasks (http://dev.ulb.ac.be/ceese/ABC_Impacts/abc_home.php) and of the partners (http://dev.ulb.ac.be/ceese/ABC_Impacts/open_section_about_us.php),
- different interesting references (http://dev.ulb.ac.be/ceese/ABC_Impacts/open_section_references.php) and links (http://dev.ulb.ac.be/ceese/ABC_Impacts/open_section_related_links.php) on the topic of aviation and climate change
- an extended glossary and various synthesis documents (http://dev.ulb.ac.be/ceese/ABC_Impacts/open_section_in_brief.php),
- the climate model developed by ASTR with a specific module dedicated to the aviation global climate impact (http://www.climate.be/jcm/jcm5/wsjcm5_aviation.jnlp).

2. CLIMATE, CLIMATE POLICY AND THE AVIATION SECTOR

This chapter presents an overview of the origins of the climate policy, the interaction between the climate change and the transport sectors, the description of different climate policy tools and a brief history of the international climate policy agreements and their interactions with transport sectors.

2.1. Climate stake and climate policy

Since several decades, and mainly around the 70s, governments and the private sector begun to be conscious of the negative impacts of human activities on different environmental compartments (such as the air, the soil, water systems, ecosystems, etc.). In order to reduce the pollution, the depletion in biodiversity or natural resources, and to tackle waste management, they set up different instruments like laws, regulations for the public sector and self-regulation and rule-making for the private sector.

All those instruments and other policy mechanisms related to environmental issues and sustainability are part of the **environmental policy**. Since the environment is considered as a transversal approach through the traditional policy pillars, environmental policy may cover other policy sectors such as energy, transport, economy, etc.

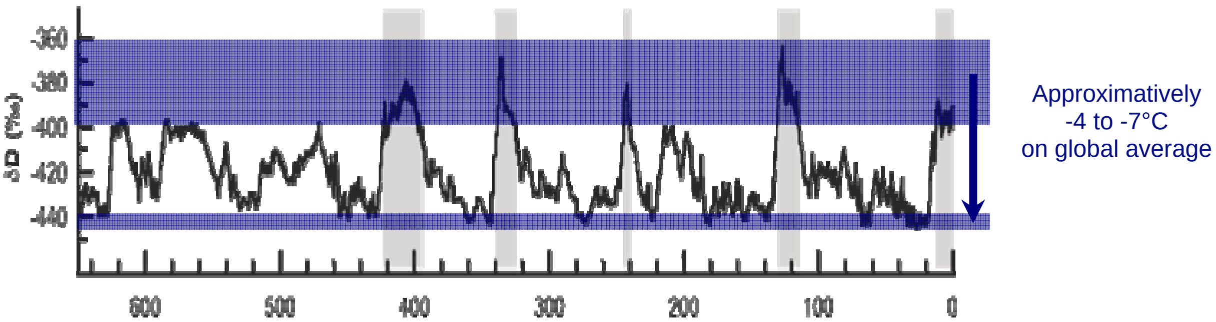
The first great international event to focus on the environment and to consider the water problematic was the United Nations conference of Stockholm in **1972**, where the **United Nations Environment Programme** (UNEP) was created.

2.1.1. Climate stake

Concern about climate change is relatively a recent topic in the environmental policy, compared to other environmental themes with more local consequences such as health impacts of pollutants for example. In fact, scientific evidence about the influence of anthropogenic activities, the potential impacts and the necessity of an international approach of the climate issue was quite difficult to identify.

Generally speaking, climate change refers to any change in climate over time, due to natural variability (see Figure 2). Since some time past, scholars have shown that this change can also be a result of human activity (anthropogenic emissions of greenhouse gases).

Figure 2 : Variations of deuterium (δ D), a proxy for local temperature derived from ice cores from Antarctica. The blue bands give an indication of global temperature variations and the gray shading indicates the last interglacial warm periods



Source: IPCC, 2007

Indeed, the average temperature at the Earth surface has fluctuated quite a lot (see Figure 2). These **temperature variations have several natural causes**, such as the plate tectonics, volcanic eruptions, solar radiation variability and the orbital variability of our planet. In addition, without **natural**

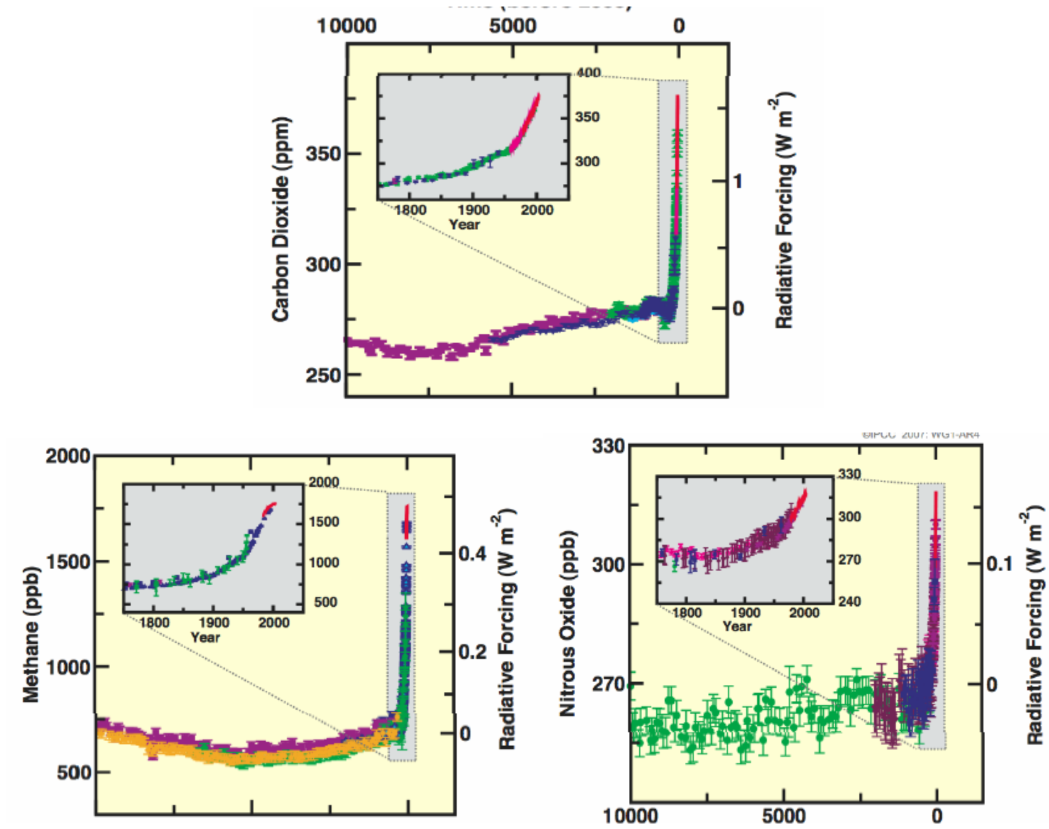
emissions of greenhouse gases (like water vapour[1], carbon dioxide and methane emitted by living species or by evaporation), the average temperature on Earth would be 30°C colder than it is today.[2]

2.1.1.1. Anthropogenic influence

However, scientists have taken note that starting from the **industrial revolution** in the 19th century, concentrations of different greenhouse gases in the atmosphere (see Figure 3) have gradually increased in parallel with the growth of human activities, such as burning fossil fuels, deforestation, agriculture[3] and stock farming[4], the use of refrigerants[5] and some other chemical components[6].

These activities have in fact an important impact on the emission of GHGs (carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, etc.) and the carbon cycle balance.

Figure 3 : Evolution of selected GHG concentrations in the atmosphere before 2005 (year 2005 = 0)



Source: IPCC, AR4, WG1, 2007

2.1.1.2. Climate impacts

The increased concentrations of those different **anthropogenic greenhouse gases** have induced a global warming phenomenon due to the fact that less infrared radiation is re-emitted by the

[1] Water vapour is the most important natural greenhouse gas.
[2] UNEP/WMO, http://unfccc.int/resource/beginner.html, 12 March 2007.
[3] Modern agriculture methods involve increasing amounts of fossil fuels and of fertilizers resulting in nitrous oxide emissions.
[4] Livestock is a great emitter of methane due to fermentation occurring in the stomach and gut of animals. The food given to the animals and the production of this food play a role in the amount of greenhouse gases emitted.
[5] Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), etc.
[6] E.g.: halons.

atmosphere towards space (cf. greenhouse gases absorb those kinds of radiation and influence the radiative forcing of the atmosphere). This is called the **greenhouse effect**[7].

This results in **global warming which is expected to have different impacts** on: the sea level, biodiversity, rain and drought patterns, etc.[8] and that this phenomenon will be more or less serious and rapid depending on the accumulation of GHGs in the atmosphere, hence according to human beings capability to slow down the increase of their emissions or, even better, stabilise and decrease them.

2.1.2. Answer to the climate issue: the climate policy

Climate policy covers all plans, measures and instruments implemented in order to tackle climate change and its impacts. One major characteristic of climate policies is the direct and strong link existing between the measure adopted and the causes or impacts of the climate change.

Knowing those stakes, climate policy can be split into two main categories: adaptation and mitigation.

2.1.2.1. Adaptation

Adaptation involves all decisions or activities aiming at **"*adjusting natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*"**[9]. These decisions/activities can then be classified according to binary characteristics: anticipatory / reactive, autonomous / planned, private / public.[10]

From a climate policy point of view, adaptation includes among other things R&D funding, technology transfer, monitoring and estimations of future climate impacts, financial means to help countries that will most probably be victims of future climate impacts, etc. However, according to the IPCC definition of adaptation, measures aiming at covering damages from unavoided climate impacts (e.g.: relief, rehabilitation, reconstruction, etc.) or indirect effects ("impacts of response measures") are not taken into account.[11]

Some multilateral funds have been set up to financially support adaptation measures (cf. the Special Climate Change Fund of the UNFCCC created by the CoP7 in 2001 ; the Least Developed Countries Fund financed by voluntary contributions of industrialized countries ; the Adaptation Fund established under the Kyoto Protocol in favour of developing countries that are Parties to the protocol[12] ; the Strategic Priority on Adaptation fund of the GEF Trust Fund[13]) but bilateral agreements are the most common funding solution.

The greatest challenge related to this topic consists in estimating the cost of adaptation measures at the present time and in the future for developed as well as for developing countries.

Seeing that the underlying philosophy of this category of climate policies consists of tackling the potential impacts of climate change and not acting on the causes of this change, adaptation measures will not further be studied in this project.

2.1.2.2. Mitigation

In the context of climate change, mitigation means "*a human intervention to reduce the sources or enhance the sinks of greenhouse gases. Examples include using fossil fuels more efficiently for*

[7] For more details, see http://maps.grida.no/go/graphic/greenhouse_effect
[8] See http://unfccc.int/resource/docs/publications/caring2005_en.pdf for more details
[9] UNFCCC glossary, http://unfccc.int/essential_background/glossary/items/3666.php, 8 March 2007.
[10] Müller B. & Hepburn C. (2006), IATAL - An outline proposal for an international air travel adaptation levy, Oxford Institute for Energy Studies, EV 36, October 2006, 40 p., http://www.oxfordenergy.org/pdfs/EV36.pdf
[11] idem.
[12] This fund will be financed through a 2% tax on Clean Development Mechanism credits.
[13] GEF : Global Environment Facility

industrial processes or electricity generation, switching to solar energy or wind power, improving the insulation of buildings, and expanding forests and other 'sinks' to remove greater amounts of carbon dioxide from the atmosphere"[14].

2.2. Climate change and transport

Most important sources of anthropogenic GHG emissions are related to the combustion of fossil fuels and it is well known that transport activities have one the most important fossil fuel consumption among human activities.

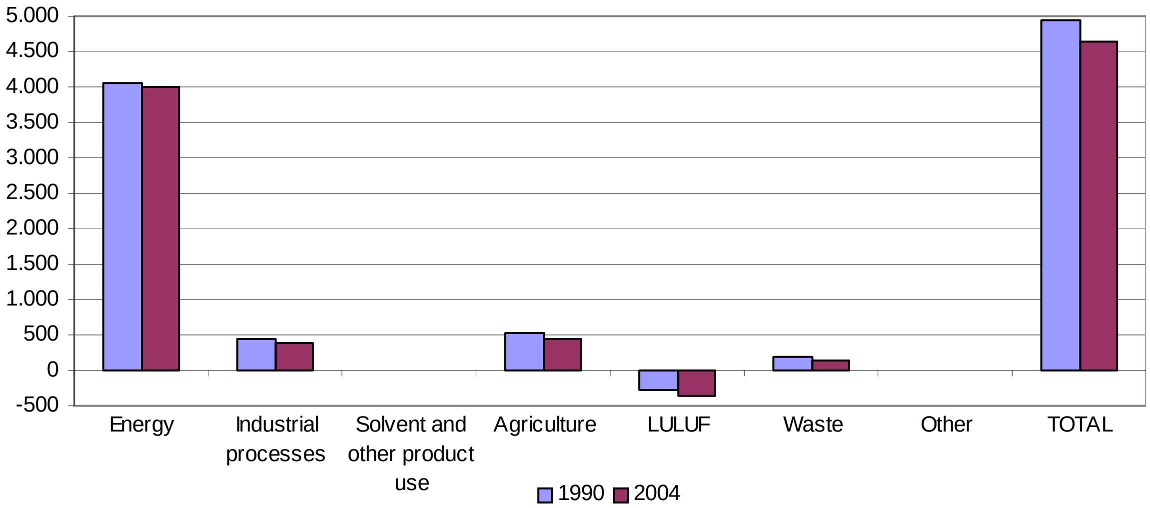
2.2.1. Repartition of anthropogenic GHG emissions

Human activities can be shared out into **7 main categories** when analysing GHG emissions:

- energy,
- industrial processes,
- solvent and other product use,
- agriculture,
- land-use/land-use change/forestry (LULUCF),
- waste
- others.[15]

Energy is by far the greatest source of GHG emissions (see Figure 4). These emissions are mainly due to the combustion of fossil fuels.

Figure 4 : Kyoto GHG emissions from the different human activities within the EEA area[16]
(Mt GHG emissions)



Source: EEA, 2007

Within the EU, the "Energy" sector was responsible in 2004 for 80% of total[17] EU(25) GHG emissions (emissions from international aviation and marine bunker fuels not included). More than 85% of these emissions were due to EU(15) countries.

2.2.2. Responsibility of the transport sectors in the GHG emissions

[14] UNFCCC glossary, http://unfccc.int/essential_background/glossary/items/3666.php, 8 March 2007.
[15] Human activities classification used within the UNFCCC.
[16] European Environment Agency area = EU(27) + Iceland + Lichtenstein + Norway + Switzerland + Turkey.
[17] Only GHGs covered by the Kyoto Protocol are taken into account.

Within the classification of human activities, transport is integrated in the **global "Energy" class** covering:

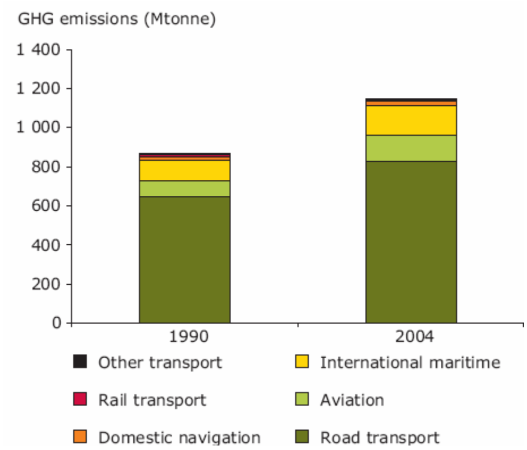
- energy production (electricity, fuels, etc.),
- transport,
- manufacturing industries and construction,
- the real estate sector (heating of buildings).

GHG emissions from transport cover emissions from the combustion and evaporation of fuel for all transport activity, regardless of the sector. Concerning non-CO_2 Kyoto GHG emissions from transport, the main contribution comes from the use of F-gases in air-conditioning and refrigeratory appliances.

Transport amounts for a huge, and increasing, part of the energy-related GHG emissions.

While the general "Energy" category has slightly reduced its GHG emissions between 1990 and 2004 within the EEA area, the sub-category "Transport", taking into account all international transport, has increased its emissions by more than one third (see Figure 5) to reach roughly 26% of the energy-related GHG emissions.[18]

Figure 5 : Evolution of Kyoto GHG emissions from transport in the EEA area



Source: EEA, 2007

Remarks: the EEA area covers 32 countries ; data include all international transport ; GHGs specific to the aviation sector not included[19]

Again, the EU(15) countries are by far the biggest emitters in this sub-category, and register the highest growth in GHG transport emissions: +26% between 1990 and 2004 (excluding international aviation and maritime transport).[20] Without international aviation and shipping, transport generated 22% of all GHG emissions related to EU(15) in 2004, compared to 17% in 1990. The main source of emissions is road transport. Inside the "Energy" category, transport represented 25% of the emissions in 2004 compared to 21% in 1990.

Emissions from the international aviation (+86%) and maritime transport are growing even much faster than emissions from other transport modes in the same period. Major growth has been registered in EU(15) countries. A detailed analysis of the aviation trends is available at point 4.1 in chapter 4.

As regards market segmentation, both passenger and freight transports have continuously increased in volume within the EEA area, but growth was more significant for freight transport (respectively +27% between 1990 and 2004 and +51% between 1990 and 2003).

[18] On a worldwide level, transport accounted for 23% of the energy-related GHG emissions in 2004, for instance 6,3 Gt of CO_2 emissions. As regards the energy use, transport consumed around 77 EJ in 2000 with 11,6% for the aviation sector and 9,5% for shipping. (IPCC 2007: AR4, WGIII)

[19] See point 2.2.3 and point 5.1 in chapter 5 for more details on this topic.

[20] EEA, 2006.

This trend in the transport sector is expected to continue in the following decades. The International Energy Agency[21] forecasts a global progression of energy consumption by +2% a year for transport with a more marked increase (+3,6% / year) in emerging economies, mainly due to light-duty vehicles, freight trucks and air travel[22].

Aviation has already grown at an average rate of +3,8% per year between 2001 and 2005, and is currently growing at 5,9% per year (with a particularly pronounced increase of +12,2% in the Europe/Asia-Pacific traffic). As regards the future, passenger traffic is expected to double within 15 years (~ 5% / year) and freight traffic to follow an even stronger trend.

Those forecasts are however based on the working hypothesis that world oil supply would be sufficient and affordable, that world economies would continue to grow without significant disruption[23], and that extreme climate events related to the raising global temperature would have no major impacts on economies and on the aviation sector itself.

2.2.3. Aviation specificities related to GHGs

Beside the GHG emissions mentioned in the former paragraphs, dominated essentially by CO_2 emissions, and covered by the Kyoto Protocol, it is important to note that the aviation sector generates specific emissions having an impact on the climate change.

This particularity is caused by the fact that a great part of aviation emissions occur at **high altitude** and interfere with the chemical balance between substances in the atmosphere:

- **NO_x** emissions play a role in the natural balances of atmospheric chemistry. At cruising altitudes they lead to a reduction of methane concentrations and a local increase of ozone concentrations,
- **particles**, **sulphurs** and **aerosols** modify locally the radiation energy budget,
- **water vapour**, which is generally considered as a natural GHG, is responsible together with aerosols and NO_x for the formation of contrails and cirrus clouds under specific meteorological conditions, which influence the local radiation energy budget.[24]

As a consequence, the total climate impact of aviation is more important than the climate impact related to "traditional GHG" emissions only. Experts have evaluated that the total warming effect of aviation could reach 2 to 5 times the effect generated by aviation's CO_2 emissions only.[25]

This phenomenon is explained in more detail in chapter 5, point 5.1.

2.3. Climate policy instruments and transport

Different policy instruments exist to tackle climate change.

In this point, a kind of inventory of main instruments having a direct and an indirect link with this global problematic are presented. Instruments are classified (see Table 1) according to their characteristics (economic instrument, regulation, planning, etc.), described briefly and analysed from the point of view

[21] IEA, World Energy Outlook, 2006

[22] **Air travel is expected to generate 23% of the growth in energy consumption for transport by 2030**. (WBCSD, Mobility 2030 in IPCC 2007 AR4 chIII)

[23] IPCC 2007, AR4, chIII.

[24]

O_3 production from NO_x	: positive radiative forcing of	+ 21,9 mW/m²
CH_4 reduction from NO_x	: negative radiative forcing of	- 10,4 mW/m²
Sulphate particles	: negative radiative forcing of	- 3,5 mW/m²
Soot particles	: positive radiative forcing of	+ 2,5 mW/m²
H_2O	: positive radiative forcing of	+ 2,0 mW/m²
Contrails	: positive radiative forcing of	+ 10,0 mW/m²
Cirrus formation	: positive radiative forcing of	+ 10,0 - 80,0 mW/m²

(IPCC 2007: AR4, chIII)

[25] IPCC, 1999 ; Sausen, 2005

of the suitable competency level to implement them, and their relative environmental efficiency. Some examples of existing climate policy instruments in the transport sector are also mentioned.

2.3.1. Policy tools having a direct link with climate change

In this part of the work, all instruments described and analysed have a strong link with the aim of mitigating climate impacts from human activities (it is the main reason to adopt and implement them).

The inventory starts with instruments aiming at raising public awareness, and then goes successively to voluntary/negotiated agreements or actions, financial and economic instruments, Research & Development and command-and-control regulations.

Table 1 : Classification of policy instruments

Type of instrument		
FIN	Financial / economic	All instruments aiming to encourage the target groups to take action by means of a positive or negative financial incentive (with the exception of R&D programmes)
REG	Regulations	All instruments of a restrictive nature, i.e. encouraging the target groups to modify their behaviour through legal, regulatory or administrative constraints
R&D	Research and development	All instruments promoting research and development in the sectors concerned
INF	Infrastructure	All modifications of infrastructure
PLA	Planning	Policy planning procedures
ORG	Organisation	(Re)organisation of the structures of public authorities or their mode of action
EDU	Information, education, training	All measures to raise awareness in the target groups by information campaigns and training
VOL	Voluntary / negotiated agreements	All initiatives by the political authorities to obtain the voluntary engagement of target groups with the objectives of the policy being pursued
MIX	Mixed	Integrated implementation of a whole series of instruments belonging to different categories

Source: from Belgian federal state (2006),
Fourth national communication on climate change under the UNFCCC

2.3.1.1. Raising public awareness

A. Description

This type of policy measure corresponds to the category "Information, education, training" (EDU) listed in the former table (see Table 1).

This is probably the first measure needed before trying to implement anything else. Several sociological studies[26] have indicated that raising public awareness was a key element in the environmental policy. Without raising public awareness, how would it be possible to implement specific tools to tackle an environmental problem if people, public authorities, managers of enterprises, etc. ignore the stakes related to that problem and/or do not understand the link between potential measures, their activities and the possible solutions to adopt?

Raising public awareness helps concerned actors to accept adopted measures more easily on the one hand and to act voluntarily by implementing on their own some potential solutions (see voluntary/negotiated agreements/actions) on the other hand.

[26] e.g. Cairns S. & Newson C., 2006

B. Tools

Main tools to implement this measure consist of information campaigns (e.g.: press, radio, television, posters and leaflets, website, etc.) and trainings (classes or lectures, specific courses, support tools for autodidacts, etc.).

The efficiency of such kind of measure depends not only on the confidence in and the credibility of the source and arguments put forward, but also on the clarity and simplicity of the message transmitted.

As regards the effectiveness of the tool, the major challenge is to target the right groups and to induce a change in their mentality and/or behaviour.

C. Action / competency levels

This kind of measure can be implemented at all levels:

- from scientists who ring the alarm bell and give the scientific background on the issue,
- to NGOs / sector-based federations / other pressure groups that initiate (public) debates and direct it generally according to their sensitivity,
- to public authorities that try to make allowances between all diverging interests and to protect "public goods" and citizens.

D. Environmental efficiency

The environmental efficiency of this measure is difficult to determine as no real quantitative objectives are defined and as the measure tries to induce changes in behaviours, acceptance of other practical measures, etc. which are not easily quantifiable (cf. interdependence and correlation factors between different parameters).

Moreover, the message carried by the information campaign or the training has generally to face the prevailing reluctance of human beings to change their usual patterns. Raising public awareness as such is generally not sufficient to induce significant changes.

E. Example in the transport sectors

Many actions have already been implemented, towards private persons but also towards companies and administrations, to raise public awareness about the negative impacts (health, environment, depletion of energy sources) of road transport. Up to now, results are not really significant because the message clashes with habits, with the comfort and social prestige granted to one's own private vehicle, the lack of suitable alternatives (e.g.: public transport is thought to be not flexible enough by a large part of the population and is less available or less competitive outside urban areas), problems related to the very high fixed costs for the ownership of a vehicle, etc.

2.3.1.2. Voluntary/negotiated agreements or actions

A. Description

In the private sector, as well as in the public one or amongst citizens, some rules or types of behaviour can be adopted voluntarily, without any regulation behind them, in order to be in phase with one's image (e.g.: marketing or social purposes, own convictions) or to avoid a strict regulation imposed by the authorities. In the last case, it is generally a matter of negotiated agreement between authorities and the private sector.

Next to agreements adopted through the intermediary of public authorities, some initiatives can come into being independently such as "good practices guides", internal charters or even participation in a voluntary programme (e.g.: voluntary compensation programmes for CO_2 emissions related to a flight).

The OECD has published two detailed reports on these approaches where more details can be found:

- OECD (1999), Voluntary approaches for environmental policy: effectiveness, efficiency and usage in policy mixes, Paris[27] ;
- OECD (2003), Voluntary approaches for environment policy: an assessment, Paris[28].

B. Tools

This kind of measures offers great flexibility and can be implemented through a lot of instruments. In the environmental policy, those can take the simple form of a negotiated agreement (with public authorities, an NGO[29], etc.) on a target to reach within a certain delay, a good practices guide, a charter, a commitment to take part in an action programme (cf. compensation programme) or a more complex framework like an eco-labelling process of products/services/companies[30].

In the above mentioned OECD reports, it is shown that, in practice, voluntary agreements are generally combined with other policy measures playing the role of incentives.

C. Action / competency levels

As the action is voluntary, it can be adopted at all levels: public authorities, private sector, citizens, NGOs, etc. (associations, administrations and companies are supposed to mostly adopt agreements while citizens are supposed to adopt actions).

However, NGOs and public authorities could play a significant role by offering a harmonised framework, regulation or criteria to satisfy in order to ensure a minimum level of control, confidence and credibility toward the agreement (e.g.: role of the independent controller, setting a level playing field, requirement of information in order to be able to evaluate the compliance with the agreement, etc.).

Regarding negotiated agreements, public authorities are completely involved in the procedure. Such kind of agreement is actually a more flexible solution suggested by public authorities to companies, instead of a strict regulation or standard, only on one condition – companies will have to commit to reaching a negotiated target within a given period of time.

D. Environmental efficiency

As the nature of the measure rely only on a voluntary base with no penalty if the target negotiated or fixed is not reached, its environmental efficiency depends on the good will and the implication of the concerned people or organizations. Even if the target itself is generally set at a low level (no company will voluntarily and drastically impede its economic development for environmental reasons even less if competing actors do not enter the system), the risk of not reaching the target is consequently rather high. Moreover, in such a framework, no control on the global volume of emissions is set: it is usually a way to reduce specific emissions (for a specific service or product, for example: emissions per km or per produced kg of a product) compared to a business-as-usual scenario without any strict emission ceiling.

Conclusions from the OECD's reports on the topic (see point A) underline indeed that voluntary initiatives have in general both low environmental effectiveness and economic efficiency.

[27] http://www.oecd.org/LongAbstract/0,2546,fr_2649_201185_2790075_1_1_1_1,00.html
[28] http://www.foundationpartnership.org/pdf/oecd.PDF
[29] For example, the WWF proposes different kinds of partnership to enterprises having choose to involve themselves in environmental subjects (e.g.: information campaigns towards clients and workers, selection of "environmental-friendly" equipment, financial support of specific action or conservation programmes, etc.)
[30] See for example the ISO14001 and the EMAS labelling, eco-labelling developed by local authorities, etc.

However, such tools could be useful in a framework aiming at raising public/companies awareness and at implementing initiatives to build a "learning-by-doing" (e.g.: improvement in data accuracy, improvement of energy management information, etc.) or "institutional capacity" process.

With regard to negotiated agreements, public authorities may well impose stricter or less flexible measures as a sanction but the threat is not always sufficient to ensure that signatories meet their commitments.

Concerning voluntary carbon offset programmes, the main environmental disadvantages are that generally no target of emission reduction over a specific period is predetermined and that the environmental effectiveness depends largely on the kinds of investment chosen (e.g. : the emission reduction would be more effective and can be more easily checked if the money of the offset programme is used to buy real certified emission credits such as AAUs than if it is invested in JI or CDM projects).

E. Examples in the transport sectors

a. Negotiated agreement between the EU and the automotive sector

Up to now, the European policy to reduce CO_2 emissions from road transport is based on three pillars, one being voluntary agreements with carmakers to reach an average of 140 g of CO_2 per km by 2008 for European ones or 2009 for the Japanese and Korean ones, for all new cars sold on the European market. These agreements have been concluded in the general framework of the European Commission objective to reduce the average CO_2 emissions from new cars to 120 g of CO_2/km by 2012.

For several reasons, these voluntary agreements are not fully satisfactory[31] (not all carmakers take part in the effort, it is only the base-line model that is taken into account without any options which are more energy consuming, it does not consider the leak problem of refrigerant used in air conditioning, etc.), so that European authorities work now on new approaches with among other things a proposal on a strict CO_2 emissions regulation by 2012 for new light vehicles put on the European market.

b. Voluntary compensation programmes for air passengers

In the aviation sector, some airlines offer their customers to offset voluntarily the CO_2 emissions related to their flights.

Offset programmes are already supported by the UNFCCC, the Kyoto Protocol and the EU-ETS to some extent and in a strictly controlled framework. A deeper analysis of the voluntarily offset programmes for air passengers[32] shows great disparities in the way CO_2/global GHG emissions are calculated, in the kind of programmes supported (e.g. investment in reforestation or in energy efficiency improvements, in industrialized countries or in developing countries), etc. This lack of harmonization which makes the control and the environmental efficiency of the programmes difficult to compare is often accompanied by a lack of transparency on the calculations, the administrative costs, etc.

Some public regulations could improve the confidence in and the efficiency of such programmes by offering a harmonized framework of comparison and control as it exists for CDM or JI projects.

Another problem related to offset programmes lies in the fact that it can only compensate for emissions having a global climate impact. Regional impacts such as induced cloudiness, change in the ozone concentration (see chapter 5, point 5.1 for more details), impacts on health and ecosystems from related emissions, etc. can not be compensated by emission reductions in other parts of the world.

[31] The average CO_2 emissions of new cars sold in the EU(15) reached 186 g/km in 1995 and 163 g/km in 2004. (http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/07/46&format=HTML&aged=0&language=EN&guiLanguage=fr)

[32] For more details, please refer to Heughebaert A., 2006 (http://dev.ulb.ac.be/ceese/ABC_Impacts/documents_abc/Heughebaert_report_compensation.pdf and http://www.iewonline.be/spip.php?article1441)

2.3.1.3. Financial / economic tools

A. Description

The main justification for public authorities to introduce financial and economic instruments to influence market mechanisms is the existence of established market bias in the way markets are functioning. The financial and economic instruments are one of the tools used to reduce or correct the bias such as negative externalities[33] that can be internalized in the market price.

The different potential instruments related to transport include: taxes and fees (fuel taxes for example), subsidies and other financial incentives and market mechanisms.

a. Tax / fee on GHG emissions / the use of GHG substances, carbon tax

The main distinction between a tax and a fee lays in the assignment of revenues levied by the tool. In the framework of a tax, revenues generated are deposited to the general public budget, while in the framework of a fee, revenues generated are allocated to a specific fund (e.g.: financial support to environmentally friendly actions or GHG mitigation projects). This specific fund may also be used to reinvest in the sector where the fee is levied in order to create a reward/sanction system.[34]

The mechanism of the tax/fee on a service or a product consists of increasing the market price of this service or product. By mean of elasticity[35] relations between demand and supply, the total quantity sold on the market can be more or less influenced downwards compared to the total quantity sold in the absence of the tax/fee. In addition, the tax/fee is a way to raise funds for the general budget or a specific policy. A tax/fee does not put any global emission ceiling, so that the environmental efficiency of the instrument depends mainly on the elasticity relation between demand and supply (a tax/fee will have no impact on demand in a inelastic market but a huge impact in a market characterized by a strong elasticity) and on the tax/fee amount.

Up to now, no carbon tax or fee on GHG emissions from transport has been set up. It is one of the economic instruments discussed at the European level to reduce climate impacts of transport but it is a touchy topic from the diplomatic point of view since it can be seen as a way to infringe world trade and protect domestic economies.

b. Fuel tax

Since decades, public authorities within the EU have levied taxes on fossil fuels used by road vehicles and on electricity among other things. International air and maritime transports have up to now always benefited from a tax exemption seeing that, at the end of World War II, it was a way to promote the new development of the aviation sector and to support growing international trade (cf. Convention of Chicago as regards aviation).

Even if a fuel tax exercises no strict demand restraint over demand for transportation, the different treatment between all transport modes creates a market distortion in favour of international air and maritime transport. Moreover, EU legislation lacks harmonisation as regards the different tax rates imposed on a same market segment (e.g. tax rate on diesel for cars), which creates another market distortion between Member States.

[33] From an economic point of view, an externality is a market imperfection caused by the fact that there are unpaid-for benefits (positive externalities) enjoyed by or uncompensated costs (negative externalities) borne by others in society as a consequence of a production process or a buyer/seller transaction (cf. social cost = private costs + externalities). In the environmental policy, this notion refers mainly to negative externalities such as pollution and damages to the environment and human health that are not taken into account in the market price of human activities. The existence of negative environmental externalities is the major "economic" justification for the intervention of the public sector to compensate for these market failures and is the basis for the adoption of the "polluter pays principle" (internalization of the environmental externalities).

[34] In such a system, the economic tool is combined with a regulation. All targeted actors performing better than the regulation are rewarded by a financial support from the fund, while actors not complying with the regulation are penalized by a fee to deposit to the fund.

[35] "*Elasticity is a measure of responsiveness. The responsiveness of behaviour measured by variable Z to a change in environment variable Y is the change in Z observed in response to a change in Y. Specifically, this approximation is common: elasticity = (percentage change in Z) / (percentage change in Y). The smaller the percentage change in Y is practical, the better the measure is and the closer it is to the intended theoretically perfect measure*." (http://economics.about.com/cs/economicsglossary/g/elasticity.htm)

Imposing a fuel tax on international flights is one of the main instruments suggested by European authorities to tackle the aviation climate impacts and, above all, to create a level playing field between all transport modes.[36]

However, to reach this aim, the EU will be forced by the Chicago Convention to progressively renegotiate bilateral accords with third countries, which will take quite a long time. Moreover, there is a true risk of market distortion if some third countries refuse to renegotiate the bilateral agreements and that only a part of the flights are imposed with a fuel tax (cf. tankering, evasion, etc.).

Concerning the environmental efficiency of a fuel tax, the same remarks as for a tax in general can be made. In addition, the amount of the fuel tax is directly proportional to the fuel consumption and its related CO_2 emissions but it does not take into account climate impacts induced by other aviation GHGs[37].

c. Subsidies and other financial incentives

Another kind of economic instruments are gathered under the generic term of "financial incentives", consisting of subsidies, tax exemption/reduction, accelerated provision for depreciation, lower interest rate, etc.

These instruments are mainly used to support R&D, demonstration projects or market introductions of new technologies.

Their environmental efficiency is difficult to measure because it depends on several quantitative (cost structure, market price compared to competing technologies, energy prices, available infrastructure, etc.) and qualitative (consumer behaviour, institutional obstacles, inertia against changes, etc.) factors. Moreover, the risk of "rebound effect"[38] may reduce the global efficiency of the instrument.

d. Market mechanisms

Description

Market mechanisms based on emissions are depending on:

- a strict environmental regulation setting standards/benchmarks or a cap on emissions complemented by allowing concerned actors to exchange reduction credits (when emissions are below the target) in order to minimise global costs of compliance,
- or targets decided in a voluntary agreement between different partners.

The price of the emission credit depends strongly on the baseline fixed by public authorities / partners (an emission target set too low induces rocketing prices, while a cap that is set too high makes emission credits lose most of their value). To limit the upward trend, a maximum price can be introduced in the system by setting a penalty "in full discharge".

An official register and an independent control are generally needed to implement such a measure to make it transparent and reliable. Moreover, exchanges can be facilitated by intermediaries or market places.

The amount of emission credits available depends on the number of installations covered by the environmental regulation, their profile and characteristics, their marginal abatement costs, the baseline set on emissions and the possibility to rely on flexible mechanisms.

It is worth noticing that a market mechanism is generally a more interesting instrument for large emitters rather than small ones because of administrative burden, transaction costs, the complexity of the scheme, etc. Moreover, the price volatility, new abatement technologies available on the market at low costs, design modifications in the system (e.g. looser target, discontinuity), etc. introduce a risk

[36] See EC Communication outlining plans to reduce the impact of aviation on climate change, the European Council conclusions on this communication and the European Parliament resolution in response to the EC communication.

[37] See point 2.2.3 and point 5.1 in chapter 5 for more details on this topic.

[38] In economy, the rebound effect appears when a better process efficiency lowers the production cost per unit of a product and therefore increases demand for this product. A similar phenomenon occurs with energy consumption which means that a part of the energy economies forecasted by the implementation of an incentive is offset by the increase of demand.

that the investor will not be rewarded at the level expected when the investment decision took place because price has fallen.

Action / competency levels

As the cost-efficiency and stability of an emission market is related to the number of participants and the amount of credits traded, the best level of action is international, or at least at the national level for big countries (e.g. emission market between different states of the USA).

However, different green certificates for renewable energy sources aiming at producing electricity or for CHP[39] have been set up at a regional level (e.g. green and CHP certificate markets in Belgium).

In France, a national attempt is undertaken to create a market for white certificates (related to GHG emission reduction in buildings).

Some voluntary credit markets have been designed between different companies from the private sector without any interference from public authorities.

Environmental efficiency

Market mechanisms are used as a complementary measure to regulation in order to offer more flexibility and lower global costs. Its environmental efficiency depends strongly on the underlying standard or cap. However, its design can induce several modifications in the environmental efficiency of the whole system.

Setting a penalty "in full discharge", for example, prevents the price of the emission credit from becoming unaffordable but at the same time, it reduces the environmental effectiveness of the system since it is possible to pay for not complying with the target. The lower the level of this fine "in full discharge", the less the measure is efficient from the environmental point of view.

Another point of environmental efficiency concerns the kind of emissions that are covered by the scheme. Since GHGs have a global impact on climate, it is quite normal and fair to consider that emission reductions can be realised wherever you want and that a company can invest elsewhere to mitigate its GHG emissions at a lesser cost. Concerning other emissions such as NO_x or SO_x with high local environmental impacts (e.g. on ecosystems through acidification or eutrophication, on human health through respiratory diseases, regional climate impacts[40], etc.), environmental efficiency of a market mechanism is far more questionable. Would it be fair to consider that road transport could reduce its NO_x impact, for example, by buying emission reduction certificates from the maritime transport sector and that the environmental effects of both emitters are equivalent?

Example in the transport sectors

There are few examples in the transport sector up to now. This kind of instrument is preferably used for big stationary emitters (cf. EU-ETS, NO_x or SO_x markets in the USA) very likely because the transport sector presents less homogeneity in the technologies used and in the characteristics of the markets, and because emission and activity data are more difficult to gather for these sectors (cf. different countries or even international spaces are involved).

As regards the maritime transport, a NO_x emission market has just been implemented several months ago to tackle NO_x emissions in certain sensitive marine zones.

Concerning the aviation sector, the European Commission made a proposal in December 2006 to include this sector in the EU-ETS. This proposal is still in negotiation at the European Parliament and Environment Council.[41]

2.3.1.4. Research and Development

A. Description

R&D can be improved in different ways, including a better scientific education programme in order to train future high level researchers, investments in the development or demonstration programmes of

[39] CHP : Combined Heat and Power ; equivalent to cogeneration.
[40] See point 2.2.3 and point 5.1 in chapter 5 for more details on this topic.
[41] For more details on this topic, see point 2.4.2

new technologies, alternative fuels or better operational management aiming at reducing emissions or increasing energy efficiency, etc.

As regards the aviation sector, point 3.2 in chapter 3 describes the potential emission reduction in the sector.

B. Tools

The instruments to support and improve R&D efforts are multiple and refer generally to other policy instruments such as investments coming from funds raised by a tax or a fee, financial / economic incentives to encourage research projects, the introduction of new regulations and standards aiming at favouring the market introduction of more efficient technologies, voluntary agreements of the private sector or negotiated agreements between public and private sectors to join the effort to invest in new technologies or new operational mechanisms, etc.

C. Action / competency levels

Efforts could be undertaken both by public authorities and/or the private sector (cf. voluntary agreement/action) but generally a joint effort from both sectors gives the best opportunities of improvement as different competences and factors influence the results (e.g. environmental regulation, technical and market knowledge, level playing field with competing technologies, need to adapt the legislation to introduce new operational measures, funds raised by taxes or fees and invested in R&D, etc.)[42].

D. Environmental efficiency

This policy instrument targets an emission reduction compared to a baseline scenario but it does not influence the total emission volume or global demand for transport. It is well known for example that concerning the road transport, R&D has greatly improved the energy efficiency of vehicles these last decades and reduces the amount of emissions per vehicle, but it has not been sufficient to offset the sharp growth in demand for transportation so that current emission levels are far more important nowadays than in the past.

Concerning the transport sector and specifically the aviation and maritime transport sectors, it is important to notice that the long lifespan of aircraft and ships is an important barrier for the rapid introduction of new technologies on the market.

Another point to highlight, specifically for aviation and climate change, is the existence of several trade-offs between the different potential improvements. For example, the improvement of engine energy efficiency reduces the fuel consumption and the related CO_2 emissions but can increase NO_x and water vapour emissions, which in total may make the climate impacts of new aircraft even worse. Environmental efficiency of a climate policy instrument has to be evaluated on a global scale, taking into account all side-effects having an impact on climate change. This is especially true for the aviation sector when policy instruments focus on CO_2 emissions only.

2.3.1.5. Command-and-control regulation

A. Description

Regulation consists of setting a constraint on activities or behaviours of target groups.

It is one of the most used policy instruments and one of the oldest measures in industrialized countries as regards environmental policy.

[42] E.g. airlines need the implication of air control entities (Eurocontrol, Belgocontrol, etc.) and the implication of public authorities to review legislation about flight management in order to implement new shorter routes.

The aim of such measures concerning the environment is mainly to protect the environment and human health against negative impacts, to guarantee the quality of a product/service, to prohibit dangerous activities, etc.

B. Tools

As regards environmental policy, regulations can consist of:

- a limit on certain emissions (specific standards or global cap on emissions of a sector/country),
- setting a minimum level of efficiency (e.g. energy consumption, emission per produced unit),
- standard definitions of product composition (e.g. fuels),
- an access / activity restriction under certain circumstances,
- etc.

C. Action / competency levels

When talking about regulations, international organizations or public authorities (all levels: EU, national, regional) are generally competent. The adoption of regulation measures at a high level of competences (e.g. at a national level instead of regional level, at the EU level instead of national level, etc.) guarantees a certain harmonization of practises to avoid market distortion between the different actors.

If some standards are adopted within the private sector without any obligations towards public authorities, it generally refers to a voluntary agreement.

D. Environmental efficiency

The environmental efficiency of regulation depends greatly on its compliance, and consequently on the control procedures implemented and on an "adapted sanction" against the offenders. These control and sanction mechanisms often require staff and technical or administrative equipment, which can be relatively costly.

One of the main drawbacks of a regulation is the need to regularly update it to take into account the evolution of the system, the changes that have taken place during a certain period of time, the progress in R&D, and new technologies available on the market.

As opposite to regulations adopted at a high competence level, regulations adopted at a low level of competence (e.g.: local authorities, small country) can induce an economic distortion between companies located close to each other as well as they can create an important evasion stimulus. Regulation offer a better level playing field, a greater scale to the measure and less evasion possibilities if they are adopted at a higher level (e.g.: international agreement). Unfortunately, international agreements generally require more time to reach a common position as there are more parties involved in the negotiations and they are often less ambitious as they are generally based on the lowest common denominator of the participants.

Chapter III of the IPCC AR4 report highlights that the overall success of regulation measures is significantly enhanced if it is combined with fiscal incentives and consumer information programmes.

E. Example in the transport sectors

Regulations are quite common in the transport sectors. They cover emission standards (e.g. EU regulation for road vehicles), strict fuel composition and security standards, etc., at the local level (e.g. emission limits on ships in several European ports) or national level as well as at the European or international level (cf. role of ICAO, IMO, etc. in setting international emission standards).

2.3.2. Policy tools related to transport and having an indirect impact on climate

These policy instruments are not specifically designed to respond to the climate impacts of the transportation sector, but may have an indirect influence on climate through impacts on demand / supply, on other pollutants, on the organization of economic activities, on support to alternative technologies or transport modes, etc.

2.3.2.1. Planning

Town-and-country planning has a huge influence on the development or the limitation of transport infrastructures (e.g. creation or expansion of airports, access infrastructures to and from airports by train or road vehicles, etc.), and therefore on supply of and demand for transportation.

It is to noteworthy that the development of road infrastructures in the EU was one of the main reasons to explain the rocketing growth in demand for road transport during the last decades. Congestion problems have led to large investments in the construction of new motorways and roads. This was followed by a sharp increase in the number of road vehicles and in the total amount of kilometres travelled, which in turn led to new congestion problems nowadays …

Restrictions on the development of transport infrastructures is however deeply unpopular because it is felt as an infringement of the right to travel and to make business all over the world.

In its 2005 communication[43] on tackling climate impacts from aviation, the European Commission rejected the option to restrict air traffic in the name of climate protection through town-and-country planning measures because this measure was judged too disproportionate and not in phase with the subsidiary principle of the EU policy. At the same time however, EU funds are used to develop transport infrastructures in new accession countries without thorough analyses on how to reduce as much as possible climate impacts from transport.

In this case, economic interests are in conflict with the issue of tackling climate change. In this context, it should be kept in mind that different market distortions exist due particularly to the lack of internalisation in market prices of negative environmental externalities from transport.

2.3.2.2. Financial / economic tools

Financial and economic instruments not designed to tackle the climate change may nevertheless play an important role in the fight against climate impacts from transport by at least setting up a level playing field between all transport modes.

A. VAT on air service

VAT does not directly influence GHG emissions related to the travel, but it increases the market price of travel, influences downwards demand for transportation and therefore indirectly associated emissions.

VAT on transportation is not harmonized at all in the EU: it differs from one Member State to another as well as from one transport mode to another.

International aviation and maritime transport benefit from a great advantage as regards VAT because they are generally exempted from VAT.

As VAT rules are determined at the European level and as it requires unanimity to change them, it is difficult to introduce VAT on international flights. In the future, with the general revision of the decision system inside the EU (less decisions need unanimity to be adopted) and a review of the VAT scheme on international travel (which is not dependent on the km travelled in each Member State anymore, but depending on the place of departure), a better level playing field could be set up between the different transport modes.

[43] See EC Communication outlining plans to reduce the impact of aviation on climate change

Otherwise an equivalent air passenger duty could be adopted with a more direct connection with climate impacts than VAT (e.g. the duty could depend on the kilometres travelled, the emission level of the aircraft, etc. instead of the market price of the ticket. Revenues levied by the duty could be invested in specific measures to tackle climate change while revenues from VAT are generally simply inserted in the general budget of the country).

B. Suppression of duty free sales

Another economic advantage of international aviation and maritime passenger transport compared to other international transport modes consists in the opportunity to organize duty free sales on board, which generates additional revenues and reduces the costs related to the travel for the operator.

There is no direct link between this advantage and climate impacts caused by the aviation sector but this kind of advantage creates a competition distortion between international transport modes. To guarantee a better level playing field, duty free sales could be banned as it is already the case on intra-EU flights.

2.3.2.3. Infrastructure

Beside town-and-country planning measures, it is also possible to define rules concerning, for example, the use and the attribution of transport infrastructures such as airport slots. This could be done by auctioning in order to optimize the use of existing capacities or by setting different environmental criteria (noise and/or emission limits) to reduce airport access for less environmentally efficient aircraft.

This possibility is however not easy to implement as more and more airports are sold by the public sector to private companies aiming essentially at maximising their profit and that it could be seen as a market distortion against airlines from different developing countries.

2.3.2.4. Environmental legislation (other than climate policy)

GHG emissions are generally concomitant with other air pollutants such as NO_x, SO_x, CO, etc. (see for example section 3.1 Figure 8 as far as aviation is concerned). For this reason different environmental standards may have an indirect influence (positive or negative[44]) on GHG emissions by putting a limit on other emissions.

European / national / regional noise regulations as well as different European legislations, such as the Directive 2001/81/CE (NEC) or Local air quality standards directives (Directives 96/62/CE, 1999/30/CE, 2000/69/CE, 2002/3/CE, etc.), could have a potential influence on aviation emissions.

2.3.2.5. Research and Development

Subsidies for raising public awareness and for supporting alternative solutions to air transport (more environmentally-friendly transport modes, videoconference, inter-modality, etc.) at the R&D level could have an indirect impact on the growing market share of the aviation sector.

Such an assessment should be done carefully since all aspects from the potential alternatives have to be studied in detail to know the global resulting impact on climate change (e.g. the indirect emissions for the production of alternative fuels could even worsen the total climate impact).

[44] A positive influence would reduce GHG emissions by respecting new standards on NO_x, SO_x, CO, etc. emissions. A negative influence would on the contrary increase GHG emissions with stricter standards on other air pollutants. Reduction of NO_x emissions from aircraft engines results generally in higher CO_2 emissions. A fuel shift from kerosene to hydrogen would lead to better air quality around airports but to more water vapour emitted in the high atmosphere which could dramatically increase aviation's regional climate impacts.

2.3.3. Summarizing remarks

The analysis of those instruments results in the acknowledgement that the environmental effectiveness of a policy mix is often better than the environmental effectiveness of a sole instrument, because no isolated instrument offers simultaneously a real limitation on the total climate impact and a satisfactory level of flexibility to minimise its related costs. In other respects, raising public awareness seems to be a basic element for a good comprehension and acceptance of other climate policy instruments. Moreover, ensuring a level playing field between all transport modes (cf. VAT, duty free sales, fuel tax) is necessary to avoid competition distortion.

In addition, the adoption of any policy measure should be done with the assessment of all its global consequences, seeing that even measures not focused on tackling climate change could have a substantial indirect influence on the efficacy and efficiency of other climate policy instruments.

Finally, the world-wide extent of global warming and transport modes such as aviation generally implies that international agreements could have a better environmental efficiency and a lower risk of market distortion than measures adopted at the local level (e.g. tax on kerosene or on CO_2 emissions ; emission standards ; airport taxes or fees ; etc.). On the other hand, this kind of agreement may take a long time to be implemented and is often limited to the adoption of the lowest common denominator between the parties.

2.4. International climate policy agreements

As that climate change is a worldwide environmental issue, international agreements aiming at tackling climate impacts from human activities seem to be the best way to treat the problem. On the other hand, their main drawback is the slow progress in reaching a global ambitious agreement and a harmonized implementation.

The following points review main international and European agreements having an impact on or aiming at tackling climate change as well as a description of how the different transport sectors are concerned by these agreements.

2.4.1. Montreal Protocol, UNFCCC and Kyoto Protocol

2.4.1.1. Brief history

A brief history of international climate policy agreements (Montreal Protocol, UNFCCC, Kyoto Protocol) is available on the website of the ABC Impacts project (see International climate policy agreements), as well as an overview of Belgian institutions (see Belgian institutions related to climate policy) and mechanisms (see Belgian climate policy mechanisms) related to these agreements.

2.4.1.2. Treatment of international transport modes

Since the UNFCCC and the Kyoto Protocol, no compromise has been reached concerning how to allocate direct GHG emissions from international aviation and maritime transport (bunker fuels) to the Parties, while GHG emissions from other transport modes (road, rail, domestic aviation, inland waterways) are covered by these international agreements.

2.4.2. The EU-ETS

2.4.2.1. Description

The synthesis "International climate policy agreements" on the website of the ABC Impacts project gives an overview of the principles governing the EU-ETS.

2.4.2.2. Inclusion of the aviation sector in the EU-ETS

When the EU decided to create a GHG emission market, related to the Kyoto Protocol, through the EU-ETS, no direct emissions from the different transport sectors were taken into account.

However, seeing the strong growth of international transport, mainly of the aviation sector during these last years, and the lack of progress in the negotiations with ICAO to tackle increasing climate impacts of aviation *(see the synthesis Aviation climate impacts for more details)*, the EU decided to act on its own to mitigate aviation emissions. The considered policy measures *(Communication outlining plans to reduce the impact of aviation on climate change)* include: the support to the development of cleaner air transport, a better air management system, the abolition of the obstacles to the taxation of kerosene and the inclusion of aviation in the EU-ETS.

In this context, on the 20th of December 2006, the **European Commission proposed to include the aviation sector in the EU-ETS**, based on:

- a preliminary study on the integration of aviation in the EU-ETS (July 2005, Giving wings to emission trading);
- the results of a Public Consultation on how to reduce aviation climate impacts (July 2005, consultation on Reducing the Climate Change Impact of Aviation);
- a former Commission communication (27 September 2005, Communication outlining plans to reduce the impact of aviation on climate change);
- the European Council conclusions on this communication (15/16 December 2006, Text of the conclusions);
- the European Economic and Social Committee opinion on the communication (April 2006, Text of the opinion);
- the conclusions of the Aviation Working Group (April 2006, Final report of the working group);
- and the European Parliament resolution in response to the Commission communication of September 2005 (4 July 2006, Text of the resolution).

The following points detail the proposal and the conclusions from the first reading of the European Parliament and Environment Council. The last point sets out the next steps needed for the adoption of this inclusion in the EU-ETS.

A. Commission Proposal

The proposal[45] to include aviation in the EU-ETS was made by the European Commission because it was seen as one of the most efficient and cost-effective policy instruments to curb the growing climate impacts of the aviation sector.

a. Main points of the proposal

The most important points of the proposal are summarised here:

- the operators concerned by this inclusion are the **air carriers** with **flights departing from or arriving in a EU Member State**;
- **only CO_2 emissions** would be taken into account;
- CO_2 emissions targeted by the scheme are **all emissions caused by flights departing from or arriving in a EU Member State**;

[45] Related documentation : Text of the proposal and Impact assessment

- the inclusion would take place in **two successive phases** : intra-EU flights would be included in the EU-ETS from 2011 and all other flights departing from or arriving in a EU Member State from 2012;
- the **CO_2 emission cap is determined by the EU** as the **average of 2004-2005-2006** emissions from flights departing from or arriving in one of the 27 EU Member States;
- **100% of the emission cap would be allocated** to air operators[46], the majority for free (on the basis of a benchmark system) and a certain % by auctioning (2011-2012 : average auctioning percentage of the National Allocation Plans, 2013-... : according to the general review of the EU-ETS);
- **different flight categories are exempted** (e.g. flights with less than 5.700 kg MTOW, government and military flights, VFR flights, etc.);
- aviation allowances can only be used and traded by the aviation sector, but air carriers may buy allowances from other sectors on the market (**semi-open emission trading system**).

b. The proposed benchmark system

The benchmark system of the proposal is based on a t.km activity indicator, the RTK. Each operator would receive for free a certain amount of allowances calculated as follows:

1. distances calculated in km for the proposed benchmark are based on the Great Circle Distance (GCD) and not on the real distance flown between two airports;
2. air carriers have to convert their number of passenger.km in 2010 (reference year for the benchmark) into t.km by using the default value of 100 kg per passenger transported;
3. the total emission cap to be allocated for free (e.g. global aviation emission cap minus emissions to be auctioned) is divided by the sum of all t.km concerned by the scheme in 2010 (passengers + cargo) to obtain the benchmark factor (kind of efficiency indicator);
4. each air carrier would receive for free, each year of the commitment period, the amount of allowances determined by the multiplication of the benchmark factor by its own amount of t.km concerned by the scheme in 2010.

The benchmark factor measures a kind of efficiency indicator of each air carrier: the average amount of CO_2 emitted per tonne transported on one kilometre distance. An efficient air carrier would proportionally receive more free allowances to cover its real emissions than an air carrier with a lower benchmark factor.

c. Main discussion points concerning the proposal

The integration in two-phases proposed by the Commission has provided food for thoughts and discussions because it raises an important risk of market distortion between European airlines and non-EU carriers (cf. the majority of EU carriers flights departs from or arrives in an EU Member State which is not the case of non-EU carriers that could therefore soften the EU-ETS cost thanks to other routes). Moreover, the Chicago Convention explicitly forbids treating two airlines operating on the same route in two different ways, which would be the case with an inclusion in two phases.

The emission allocation and the benchmark method have generated different reactions of countries or airlines fearing market distortion between the different aviation market segments (e.g. cargo versus passenger flights / short haul versus long haul, etc.).

Concerns about the application of the proposal to non-EU airlines have risen. On the one hand, ICAO had already expressed its support to voluntary agreements and to the integration of the aviation sector in existing emission markets, but on the other hand ICAO seems to be reluctant to accept the application of the EU proposal to non-EU carriers without bilateral agreements (cf. General Assembly of ICAO in September 2007). The EU has a formal reserve on this decision but negotiations are still in progress.

B. European Parliament and European Council first reading

[46] No national emission allocation is needed with this system: the emission cap is set on the sector, more specifically on the concerned air operators, and not on the countries as it is the case for stationary installations in the EU-ETS, or emission targets in the Kyoto Protocol.

Table 2 presents the position adopted in the European Commission proposal (December 2006), in the Parliament first reading vote[47] (November 2007) and in the conclusions of the Environment Council[48] (December 2007) for the major topics on which opinions diverge.

The only exception in the table concerns the emission ceiling defined as the average of 2004-2005-2006 emissions, about which it seems a global consensus was reached.

C. Next steps

As the positions of the European Parliament and of the Environment Council diverge on several points, a second reading will be necessary in order to reach a consensus on the legal text to include the aviation sector in the EU-ETS.

If no agreement can be obtained after this second reading, a conciliation procedure will have to be put in place.

In parallel, the review of the EU-ETS is progressing and a first proposal has been published by the European Commission on the 23rd of January 2008. Decisions taken in this framework could have a great impact on further negotiations about the design of the inclusion of the aviation sector in the reviewed EU-ETS.

Table 2 : Comparison table between the European Commission proposal, the Parliament and Environment Council first reading

Discussion points	Commission proposal (20/12/2006)	Parliament first reading (13/11/2007)	Council Environment conclusions (December 2007)
Start year	- 2011 for intra-EU flights - 2012 for all flights to/from an EU airport	2011 for all flights to/from an EU airport	2012 for all flights to/from an EU airport
Ceiling	average 2004-2005-2006 emissions	idem	idem
Exemptions	- government and military flights, - VFR, - training and test flights, - flights with a MTOW lower than 5.700kg	- military flights, - humanitarian flights, - training and test flights, - flights with a MTOW lower than 20.000kg	- government flights from third country, - humanitarian and rescue flights, - flights for public service obligations to/from peripheral regions, - flights from operators with a low frequency to/from EU (less than 243 flights concerned during 3 quarters), - flights with a MTOW lower than 5.700kg
Allocation	100% ceiling	90% ceiling	100% ceiling
Auctioning (%)	- average NAPs 2008-2012 for 2011 and 2012 - according to the general EU-ETS review	- 25% in 2011 and 2012 - growth up to the maximum % of other EU-ETS sectors from 2013	- 10% in 2012 - growth possible according to the general EU-ETS review
Revenues	used to tackle the climate change and administrative costs	have to be used for EU initiatives such as support to more environmentally-friendly transport modes, to peripheral regions or public service obligations	used according to Member State needs but preferably to tackle climate change
Benchmark (free allocation)	RTK where : - distance = GCD - passenger = 100kg	idem	RTK where: - distance = GCD + 95 km - passenger = 110kg
GHG	only CO_2	CO_2 multiplied by 2 (for NO_x emissions)	only CO_2
Reserve new entrants	no reserve	reserve for new entrants	reserve for new entrants and fast growing airlines
Flexible mechanisms	max. CERs and ERUs per operator = average % in NAPs	idem except for less efficient operators (no CER or ERU)	- max. 15% CERs and ERUs in 2012 - according to the general EU-ETS

[47] Related documentation : Clear skies ahead: MEPs vote to curb airline emissions by including them in European trading scheme

[48] Related documentation : Summary of the Conclusions of the Council of Environment Ministers (EurActiv)

			review
Emission trading type	semi-open system with possible exchange between aviation allowances and EUAs	semi-open system but closed system for less efficient operators	semi-open system
Sanction	idem other sectors EU-ETS	idem	idem + possibility for a Member State, as a last resort, to make a request at the EU level to obtain he suppression of the exploitation permit of the operator

Source : from WP6 of the ABC Impacts project,
based on Ruth Declerck's presentation at the Stakeholders' dialogue in January 2008
Remark : words appearing in blue in the table are detailed in the glossary

3. EMISSIONS FROM AIRCRAFT

Emissions from the aviation sector can cover a great range of activities according to what is considered as part of the sector or not.

Among these activities, we may consider:

- access to airports and related infrastructure (mainly train and road transport);
- airport infrastructures (buildings: construction, heating, dismantling, etc. ; operations: catering, fuel and other supplies, technical vehicles, maintenance services, etc. ; traffic generated by staff ; etc.);
- all the supply chain of aircraft (building, maintenance, dismantling, etc.);
- aircraft operations (flights).

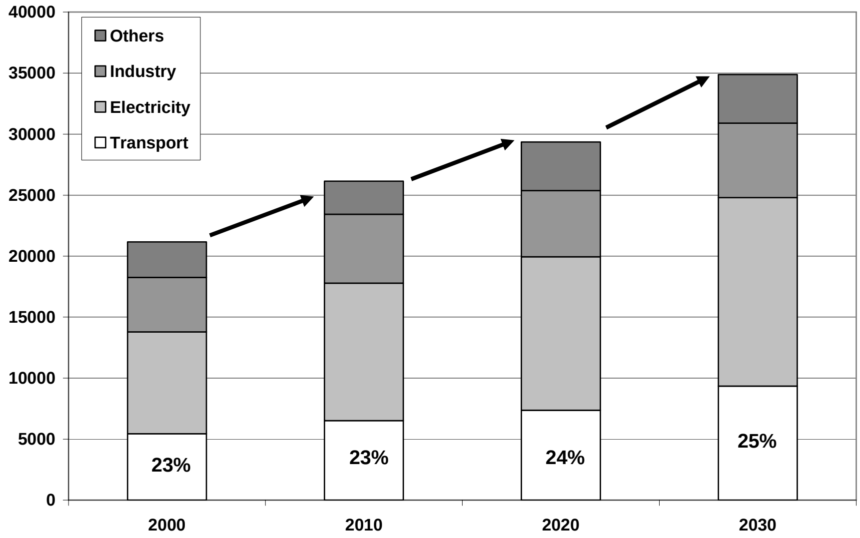
In the ABC Impacts project, the emphasis is on **emissions related to aircraft operations (flights)**.

The following points present the emissions related to aircraft and their main characteristics, the potential emission reductions in the aviation sector and the emission database gathered by the project for the emission and climate modelling.

3.1. Description of aircraft emissions and energy efficiency

Anthropogenic radiative forcing (or global warming caused by human activities) is mainly caused by CO_2 emissions[49]. Therefore, although some integrated approach over the different GHGs is necessary, it also seems sensible to pay some special attention to this greenhouse gas. Moreover getting an overview of the CO_2 emissions helps to get a better insight in the energy efficiency of different sectors and transport modes. When looking at the different sectors it seems clear that a significant part of the worldwide CO_2 emissions are currently due to transport. At the same time the share of transport in a growing total of worldwide CO_2 emissions is expected to increase in the coming decades (Figure 6).

Figure 6 : Prediction of the worldwide CO_2 emissions per sector (Mt CO_2)

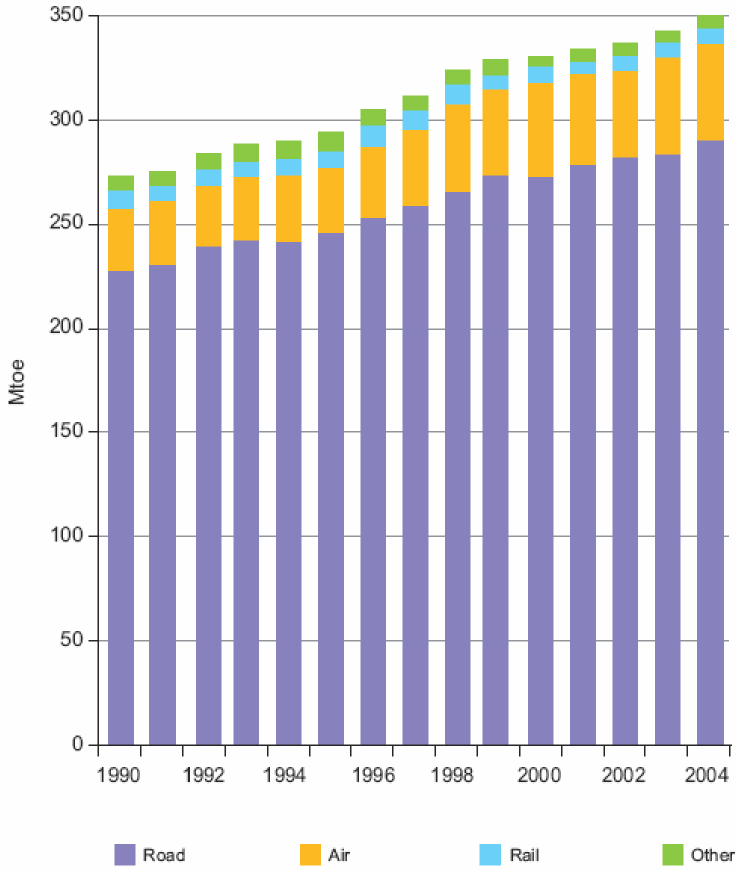


Source: adapted from Morcheoine, 2005

Air transport and road transport are the two main drivers for the growth in energy consumption (and its related CO_2 emissions) in the transport in the EU-25, as well as in Belgium (Figure 7). This situation is predicted to stay like that at least in the short to medium term[50].

[49] IPCC (2001)
[50] Festraets et al. (2007)

Figure 7 : Final Energy Consumption by mode of transport (EU-25)

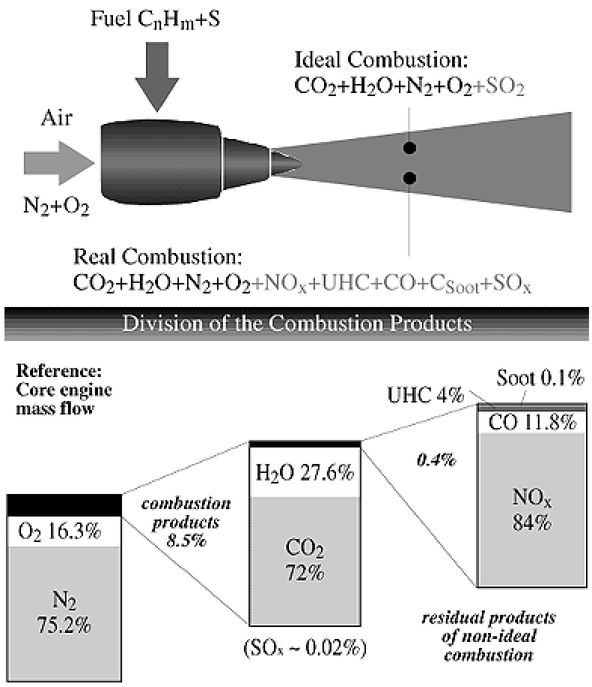


Source: Energy, transport and Environment indicators (2006)

Although on a global scale, CO_2 is the most important greenhouse gas issue, due to the location of an important part of the emissions, the analysis of the influence of aviation on climate just cannot be limited to the emissions of CO_2. As will be made clear in the next paragraphs and in chapter 5 point 5.1, the total contribution of the aviation sector on climate change is actually higher than its CO_2 impacts. As a consequence, the relative share of aviation's contribution within transport related climate impacts is bigger than its share of CO_2, which is depicted in Figure 7.

Even if some exploratory flights are being performed different kinds of biofuels, currently, aircraft usually burn 100% fossil fuels (e.g. aviation gasoline, jet kerosene) and emit noise and different pollutants that are either intrinsically related to combustion processes of any carbon based fuel (CO_2, H_2O), either related to fuel composition (SO_x, NO_x) and/or to the "quality" of the combustion process (NO_x, HC, CO, PM,).

Figure 8 : Combustion and related emissions from an aircraft



Source: IPCC special report, "Aviation and the global atmosphere", 1999

Those pollutants all imply specific impacts on the environment including climate change (Table 3). Until further progress is obtained in the development of biofuels for aviation use, the authors will consider that all of the fuel used in aviation consists of fossil fuel.

Table 3 : Environmental impacts of different pollutants from fossil fuel combustion

Pollutant	Environmental impacts
CO_2 (carbon dioxide)	Greenhouse gas ➔ **Role in climate change** (**global warming**)
CO (carbon monoxide)	Toxic gas ➔ impacts on living beings (a.o. health impacts)
NO_x (nitrous oxides)	. Irritant gas (impacts on living beings (e.g. respiratory diseases) . Role in the acidification and eutrophication of ecosystems . Role in the formation of tropospheric ozone (emissions at low altitude) . Role in climate change (emissions at higher altitudes result in CH_4 depletion)
PM_{10} and $PM_{2,5}$ (Particulate Matters)	. Impacts on living beings (e.g. respiratory disease) **. Role in climate change (emissions at higher altitudes)**
SO_2 (sulphur dioxide)	. Impacts on living beings (e.g. respiratory disease) . Role in the acidification of ecosystems **. Role in climate change (emissions at higher altitudes)**
HC (unburnt hydrocarbon) or **VOC** (Volatile Organic Compounds)	Impacts on living beings (e.g. respiratory disease) and ecosystems Indicator of the quality of the combustion and energy efficiency
Aerosols	**Role in climate change (emissions at higher altitudes)**

Given the fact that combustion conditions (e.g. temperature, atmospheric pressure, etc.) and fuel consumption change according to the engine power developed during each phase of the flight (e.g. taxi, take-off, cruise, etc.), the spreading of the emissions is not homogeneous through the different flight phases. The power setting of the engines during the LTO phase for example will result in higher NO_x, CO and unburnt hydrocarbons (due to a less complete combustion) emissions as compared to the power settings used during the cruise phase.[51] Emissions of CO_2 (see Figure 8) and SO_2 are proportional to the amount of fuel burned (idem for SO_2 emissions since they depend on the sulphur content in the fuel burned). The total distance flown, the fuel composition, the aircraft type and engine

[51] See also: aircraft emissions and climate impacts from the aviation for more details.

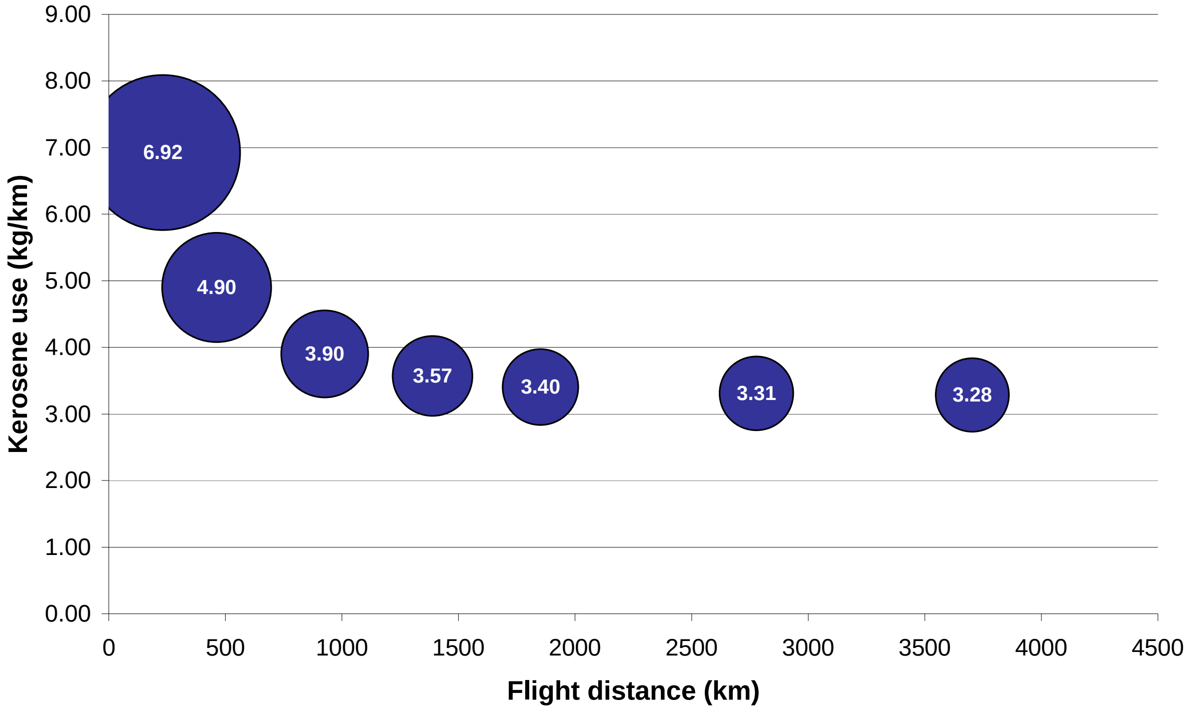
characteristics (e.g. technology, fuel efficiency, etc.) are the crucial influencing parameters to take into account when calculating those emissions.

As regards aircraft, jet fuel has a low sulphur content (typically 0,05% by mass). This factor results in relatively low SO_x emissions compared to other transport modes using marine or diesel fuels for example. These emissions should not be neglected by policy makers however, as a significant part of them takes place in very concentrated geographic areas (around the airports). As the focus of the project is climate change and as the effects of SO_x are mainly effects on health and not on climate, this report will not analyze the sulphur related emissions in detail.

3.1.1. Energy efficiency

Figure 9 illustrates the difference in energy efficiency for different flight distances covered by a typical medium-haul jet airliner (B737-400). It clearly appears that the length of a mission influences the energy efficiency of the (medium-range) aircraft. The longer the mission is, the higher the energy efficiency is (expressed in kg of kerosene consumption per km). This is due to the high amounts of energy needed to lift up the plane during take-off and climb of the aircraft, as well as to the fuel use during the landing phase of the flight. These parts of the flight do not involve the covering of large distances and consequently have a negative influence on the overall energy efficiency of the flight.

Figure 9 : Total kerosene use of a B737 400 for different flight distances
(radius of bubble represents consumption in kg/km)

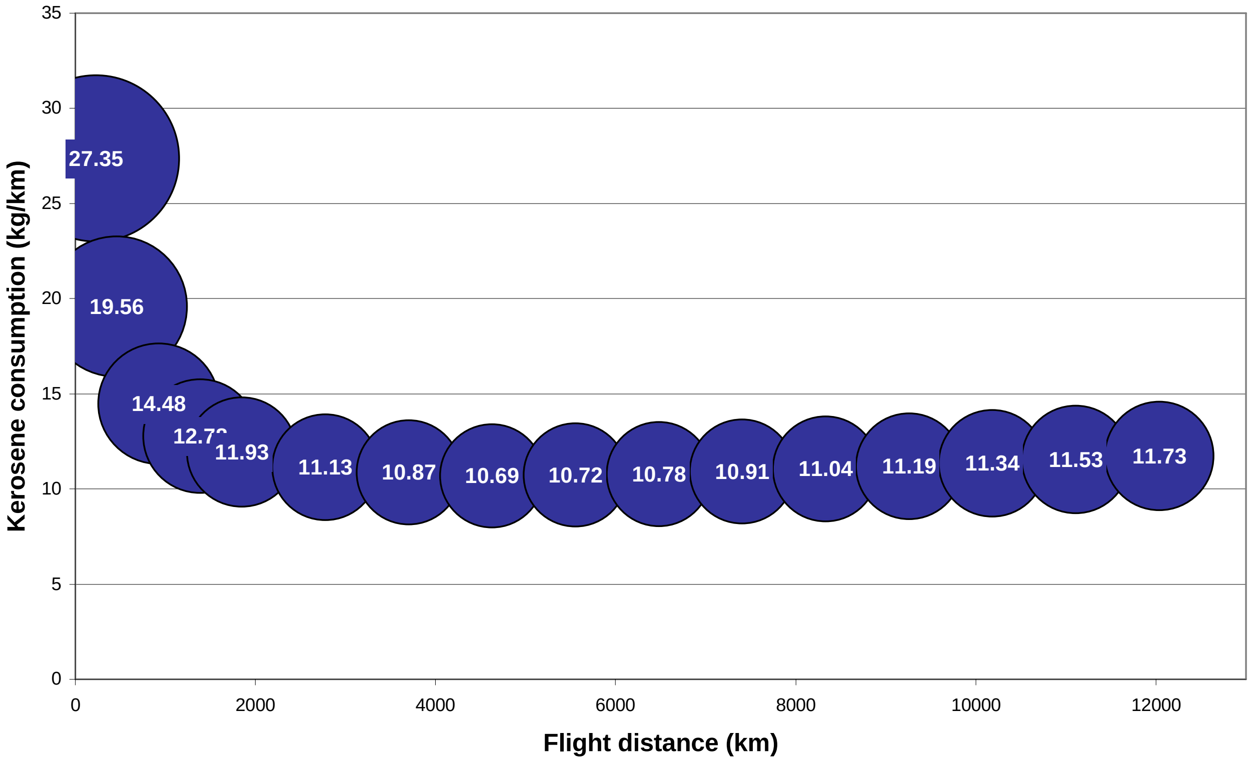


Source: based on EMEP/CORINAIR 2006,
Emission inventory guidebook, Group 8: Other mobile sources and machinery

Figure 10 describes the same parameters for a high-capacity, wide body aircraft with a higher operating range (B747-400 or Jumbo jet). In this case it appears that the energy efficiency increases together with an increasing flight distance as well. However, this rule only applies until a limited mission length (i.e. more or less 4.500 km), where an optimum energy efficiency is obtained.

When performing missions longer than that optimum, the energy efficiency declines again. Just like for the medium-range airlines described in Figure 9, the landing, climb and (especially) take-off parts of the flight are very energy intensive. Therefore, the energy efficiency improved according to the increasing trip length. However, once the mission becomes longer, the weight of the additional kerosene needed to perform the trip starts to deteriorate the energy efficiency during the first part of the flight (as more weight equals more energy consumption).

Figure 10 : Total kerosene use of a B747 400 (Jumbo Jet) for different flight distances
(radius of bubble represents consumption in kg/km)

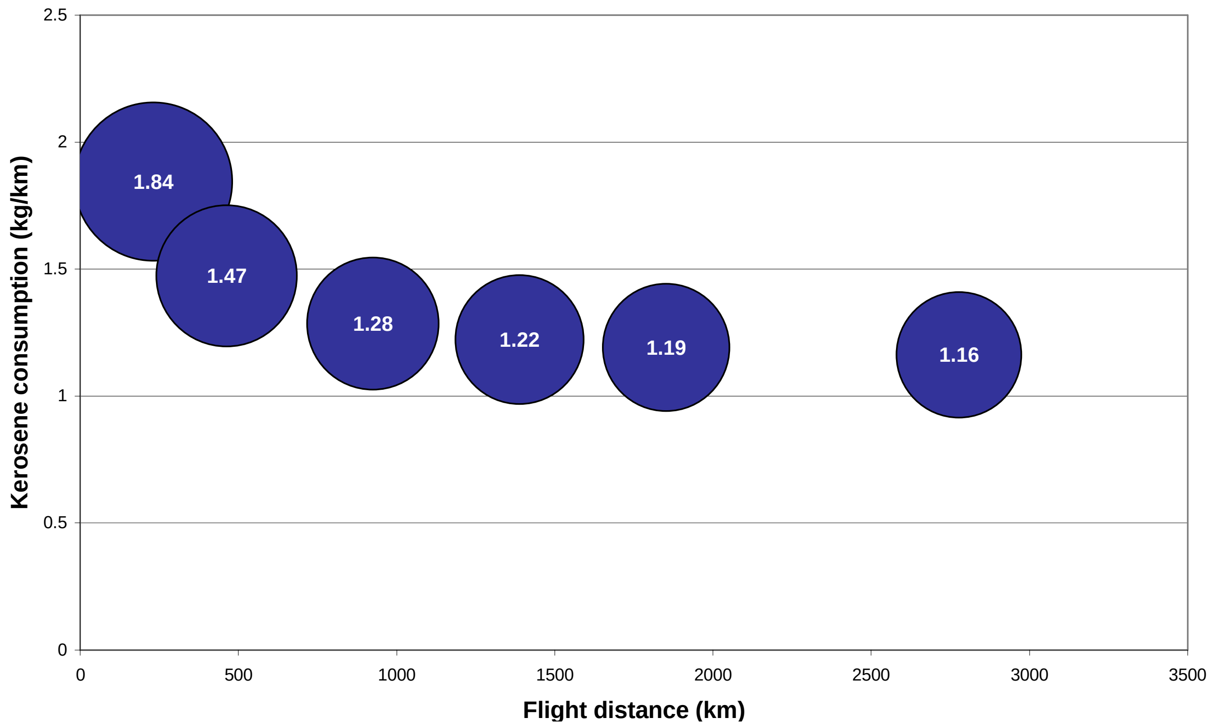


Source: based on EMEP/CORINAIR 2006,
Emission inventory guidebook, Group 8: Other mobile sources and machinery

Both of the previous figures demonstrate very clearly the low efficiency of typical jet aircraft when used over short distances (typically, less than 700-800 km for the B737-400 and less than 1.500-2.000 km for the B747-400).

Within the aviation sector, the influence of the higher energy consumption during the LTO cycle can be reduced when using turbopropellor aircraft, such as the Fokker 50 for example. However the main drawback of this type of aircraft is their lower speed, typically around half the speed of jet aircraft. This reduced influence of the LTO cycle appears in Figure 11. This figure clearly shows that the distribution of the energy efficiencies along the different flight distances still exists, but is reduced compared to the previous types of aircraft.

Figure 11 : Total kerosene use of a Fokker 50 (Turbopropellor**) for different flight distances**
(radius of bubble represents consumption in kg/km)



Source: based on EMEP/CORINAIR 2006,
Emission inventory guidebook, Group 8: Other mobile sources and machinery
Remark: "," is used to separate thousands

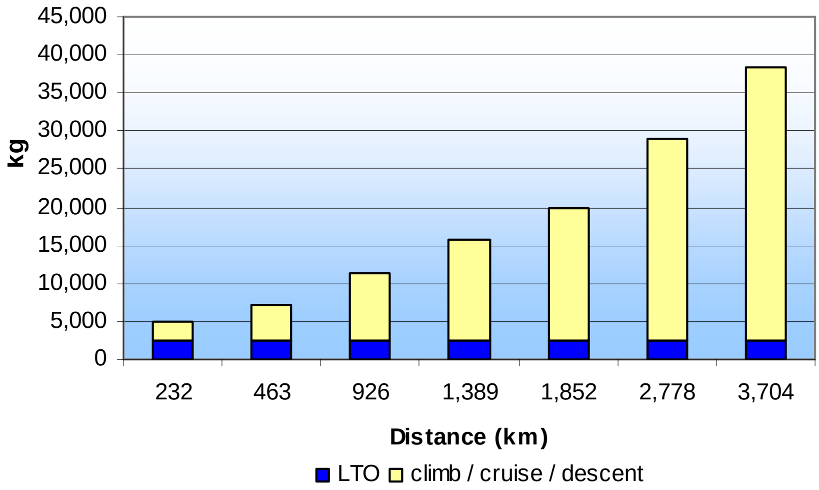
More generally, the previous figures clearly indicate that so-called low-hanging fruits (or relatively easy gains) regarding energy efficiency in air transport can be obtained through the shift from short-range flights towards less energy-intensive transport modes such as, for example, high-speed trains. Moreover for such distances, both transport modes (high-speed trains and short-range flights) are competitive regarding speed and comfort.

3.1.2. Emissions

CO_2 emissions being directly related to the fuel consumption and the effects of CO_2 emissions being independent of the place (or altitude where they occur), the remarks presented in the previous paragraphs are valid for CO_2 emissions as well. This implies high CO_2 emissions in high fuel consumption conditions and vice versa.

Figure 12 depicts the fuel consumption for a B737-400 for several flight distances. In this figure, the relative importance of the fuel use during the LTO phase of short missions clearly appears.

Figure 12 : Total CO_2 emissions from aircraft related to flight phase and distance

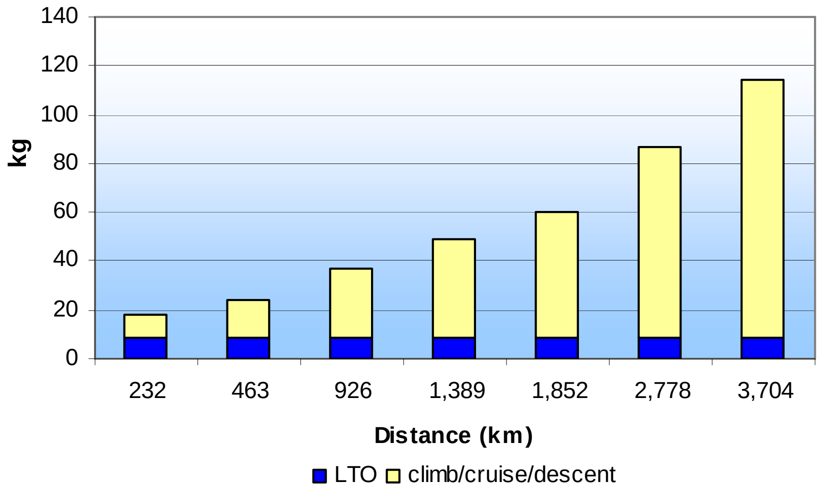


Source: based on EMEP/CORINAIR 2006,
Emission inventory guidebook, Group 8: Other mobile sources and machinery
Remark: "," is used to separate thousands

In a combustion process, NO_x emissions are influenced by three main factors: fuel composition (nitrogen content), combustion conditions (temperature, time passed in the combustion chamber) or prompt formation of NO_x.

For an aircraft, NO_x emissions depend mainly on the engine technology and related combustion conditions. As regards one specific aircraft burning kerosene, total NO_x emissions are mainly depending on the flight distance (see Figure 13).

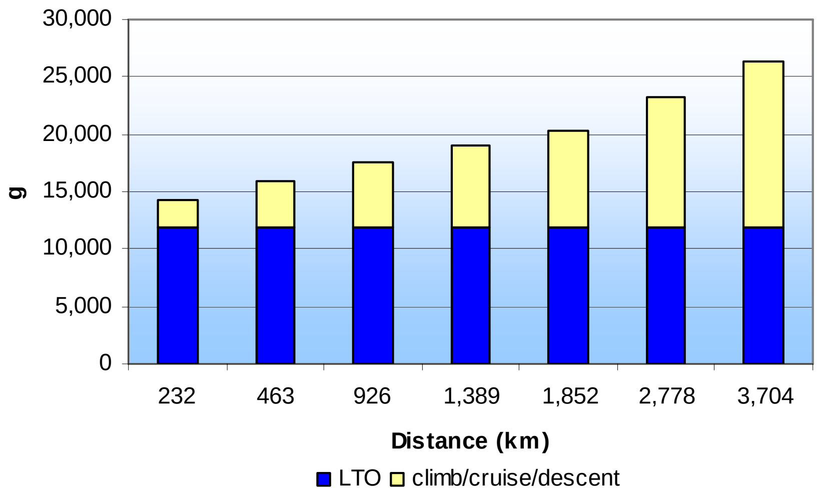
Figure 13 : Total NO_x emissions from aircraft (B737 400) related to flight phase and distance



Source: based on EMEP/CORINAIR 2006,
Emission inventory guidebook, Group 8: Other mobile sources and machinery
Remark: "," is used to separate thousands

CO and HC (unburned hydrocarbons) are principally generated due to imperfect fuel combustion during the LTO phase. Figure 14 and Figure 15 show that even for longer missions, the bulk of the CO and HC emissions take place during the LTO phase.

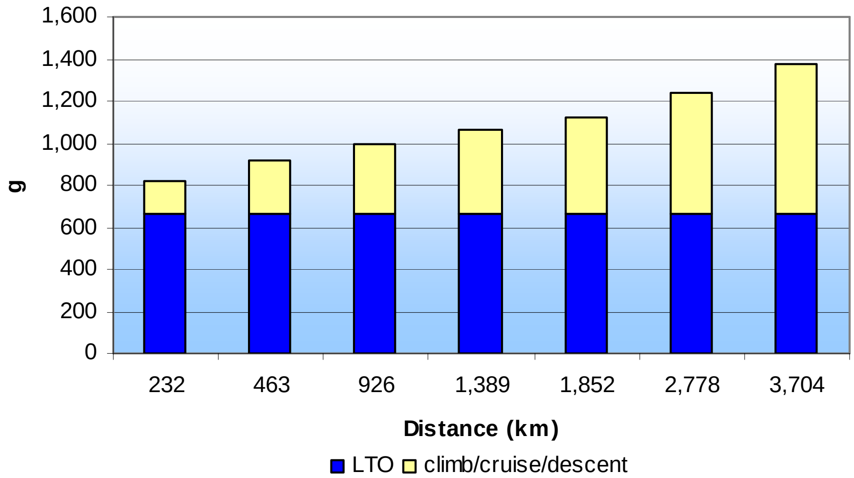
Figure 14 : Total CO emissions from aircraft related to flight phase and distance



Source: based on EMEP/CORINAIR 2006,
Emission inventory guidebook, Group 8: Other mobile sources and machinery
Remark: "," is used to separating thousands

Those emissions are mainly a concern for local air quality issues and local environmental impacts of aviation operations at airports and have no significant impact on climate as compared to the other emissions of aircraft, such as CO_2, NO_x, water vapour, etc.

Figure 15 : Total HC emissions from aircraft related to flight phase and distance



Source: based on EMEP/CORINAIR 2006,
Emission inventory guidebook, Group 8: Other mobile sources and machinery
Remark: "," is used to separating thousands

3.2. Activity database and emission calculations: evolution of the different kinds of emissions in the Belgian airspace

To perform a calculation of aviation emissions that is as precise as possible, it is essential to start from the most accurate available data concerning the activities in the Belgian sky. Like in many countries, the air traffic management operator owns the most reliable and exhaustive flight data. In this case, collaboration was sought with Belgocontrol. The consortium obtained an extensive database containing origin/destination data, aircraft types, flight distances etc. for all flights that passed through the Belgian airspace (including overflights). The data were provided in dbf format and were sorted and transformed to enable the calculation of the emissions.

The emission data were calculated according to the following procedure:

1) Organize data
2) Allocation of the type aircraft
3) Calculation of the total distances covered per type aircraft
4) Calculation of the emissions related to the aircraft operating from the different airports
5) Calculation of the emissions and fuel consumption through the Corinair methodology (the fuel use and emissions per km are determined through linear regression of the Corinair data)
6) Calculation of the emissions related to the aircraft from the different airports (this report shows only the aggregated data)

In the near future, the obtained results are to be validated using calculations from the Eurocontrol Experimental Centre and Headquarters.

The evolution of the emissions in the Belgian airspace is depending on the type of aircraft used and on the magnitude of the activities both locally in Belgium as in the surrounding countries (these activities implying additional overflights).

In this chapter the terms "LTO flights" will be used as opposed to "Overflights". This term stands for the operations including a landing and/or take-off on a Belgian airport or airfield (in other terms, the "local activities"). Overflights are flights passing through the Belgian airspace without landing or taking-off on a Belgian airport or airfield.

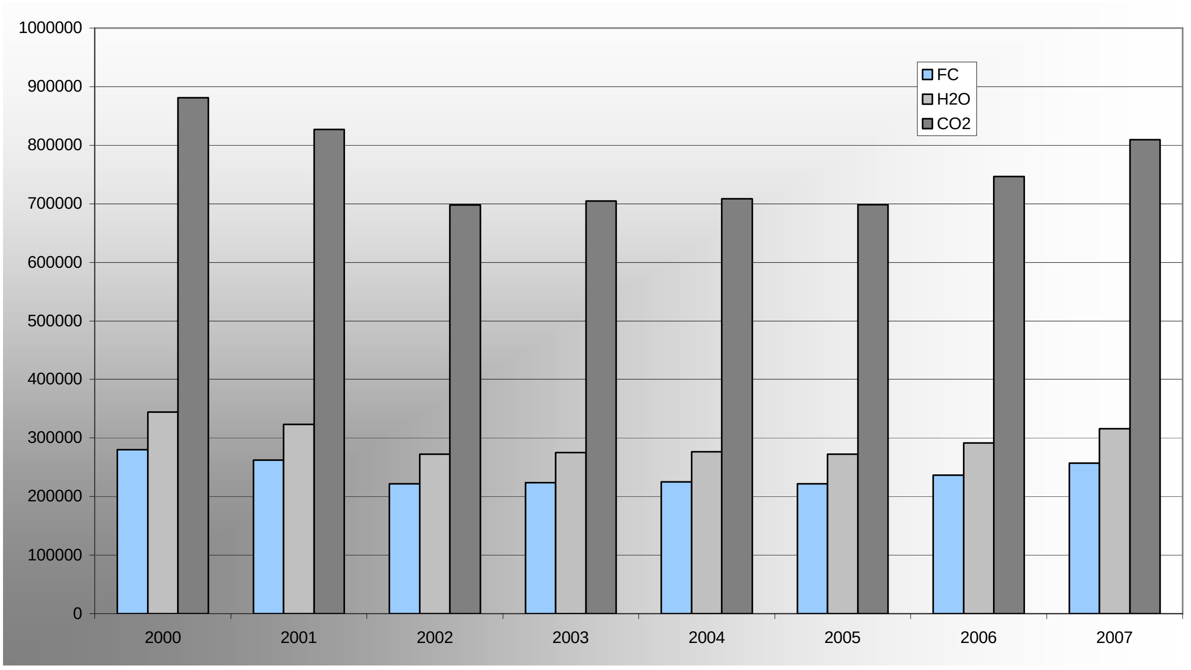
3.2.1. Evolution of the fuel consumption and of its intrinsically associated emissions (CO_2 and H_2O)

3.2.1.1. Local activities

The following figure shows the evolution of fuel consumption and of its directly related combustion products (CO_2 and H_2O).

These three products evolve in parallel, thus the conclusions drawn from them are identical. Following the reduced activities after the 9/11 attacks and the Sabena bankruptcy (in 2001), a substantial reduction in fuel consumption appears in 2002. After this, the fuel consumption remained more or less stable during four years (2002-2005) and increased in 2006 and 2007, as a consequence of a recovery of the activities in Brussels Airport and to the increasing success of regional airports, both for passenger and cargo transport. Nevertheless, although the activities significantly increased during the last two years, the fuel consumption and its CO_2 emissions originating from the LTO flights in Belgium are still below the 2000 and 2001 figures. If the current growth was sustained in 2008 though, 2000 fuel consumption levels might be reached.

Figure 16 : Fuel consumption and intrinsically related emissions LTO flights in Belgium
(tonnes / year)



Source: based on data from Belgocontrol

3.2.1.2. Overflights

Regarding the overflights, a decrease in fuel consumption can be seen in 2002 after 9/11/01 as well.

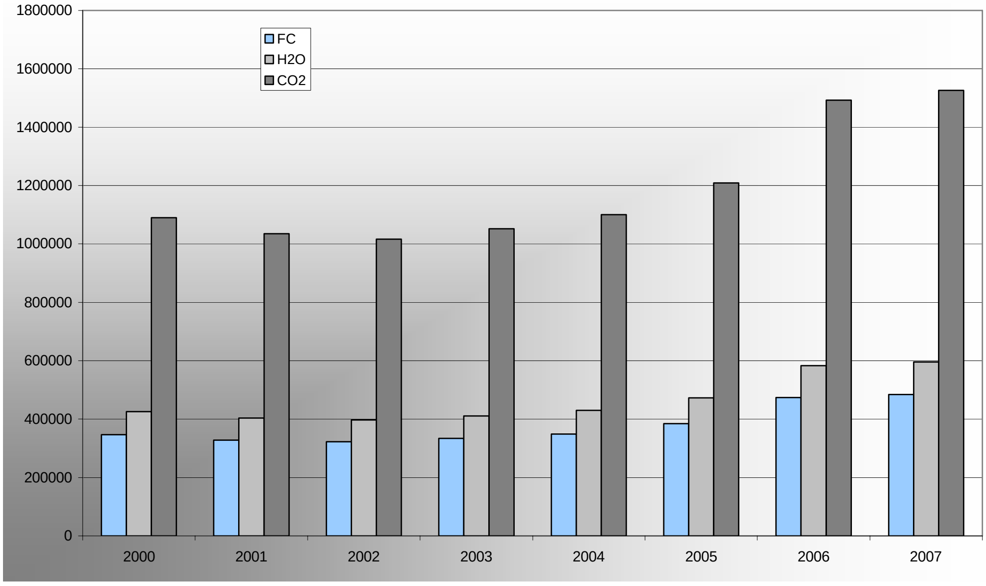
However, the decrease was compensated much more quickly than in the local activities. This is largely due the higher aviation growth rates in the surrounding countries from 2002 to 2006 and to the fact that the effect of the 9/11 attacks mainly have had an influence that was limited in time, while the bankruptcy of Sabena has had a more structural, long-lasting reduction of the activities as a result. 2007 is the first year during which the growth of fuel consumption was higher for the LTO flights in Belgium as compared to the growth of the fuel consumption during overflights of the country.

When comparing both the previous and the following bar chart, it appears that the scales of the fuel consumptions are very different for the overflights and the LTO flights.

Even including the comparatively high amounts of fuel used during the take-off and climb phases of the flights, the fuel consumption of the overflights within the Belgian airspace is much higher than the fuel consumption of the local activities.

This is due two aspects: firstly the higher number of overflight operations compared to the LTO flights, and secondly the size of the aircraft flying over Belgium is bigger on average, as compared to the size of the aircraft operating on Belgian airports.

Figure 17 : Fuel consumption and intrinsically related emissions overflights above Belgium
(tonnes / year)



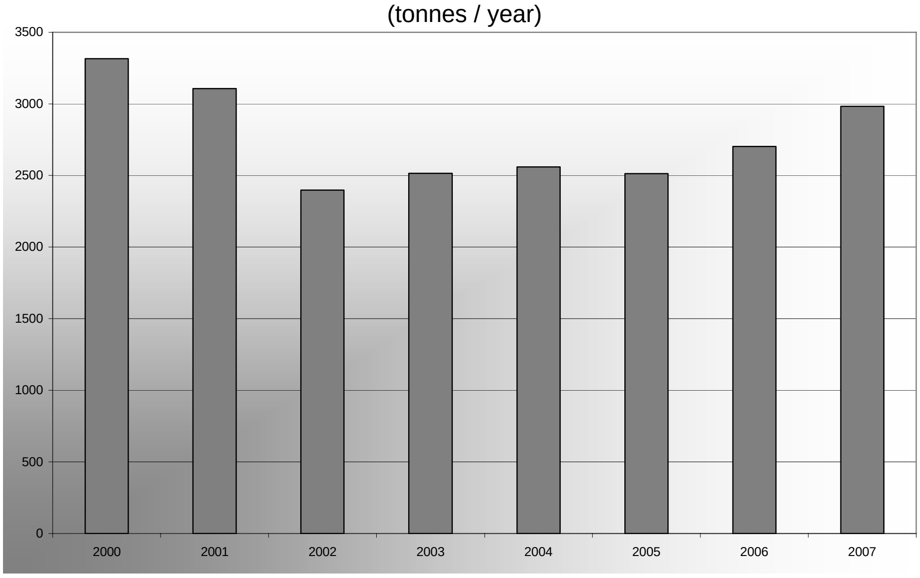
Source: based on data from Belgocontrol

3.2.2. Evolution of the NO_x emissions

3.2.2.1. Local activities

Similarly as for the fuel consumption, the emissions of NO_x present a sharp drop in 2002, as compared to the previous year, followed by a stabilization period between 2002 and 2005. Finally an increase in emissions took place in 2006 and 2007, but nevertheless the amount of NO_x emissions due to LTO flights in 2007 is still significantly lower than the total emissions in the year 2000.

Figure 18 : NO_x emissions from LTO flights in Belgium
(tonnes / year)



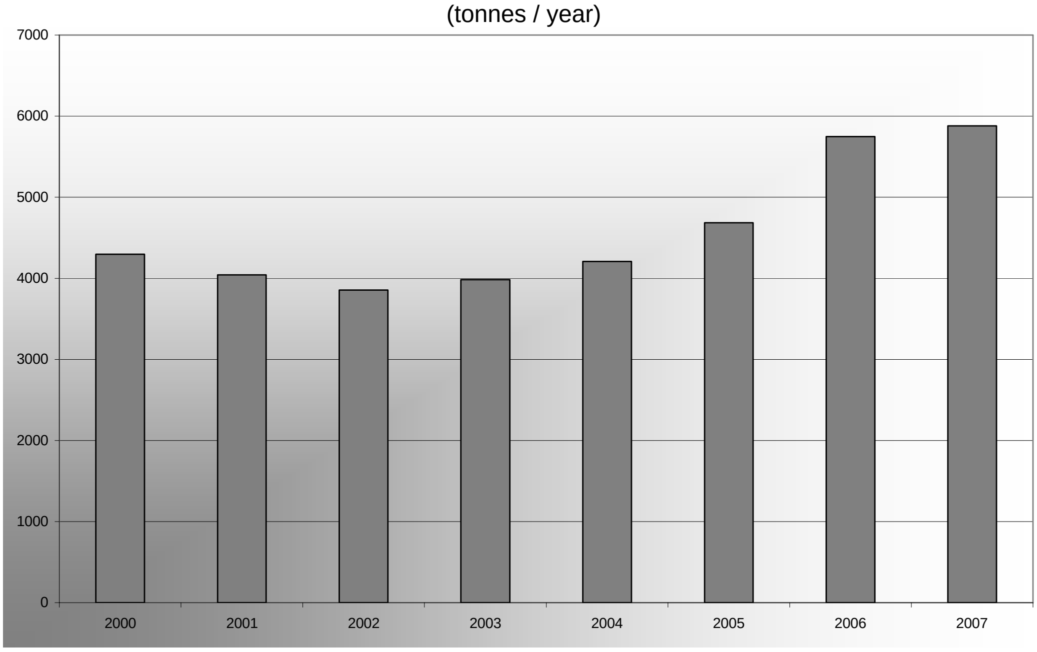
Source: based on data from Belgocontrol

3.2.2.2. Overflights

Comparably as for the fuel consumption, NO_x emissions in 2007 are about twice as high for the overflights as compared to the NO_x emissions originating from LTO flights involving local activities to/from Belgian airports. The evolution of the NO_x emissions over the last years is also similar.

The reasons for this similarity are largely identical to the figures concerning fuel consumption, i.e. a higher number of flights, and the use of larger aircraft.

Figure 19 : NO_x emissions from overflights above Belgium
(tonnes / year)



Source: based on data from Belgocontrol

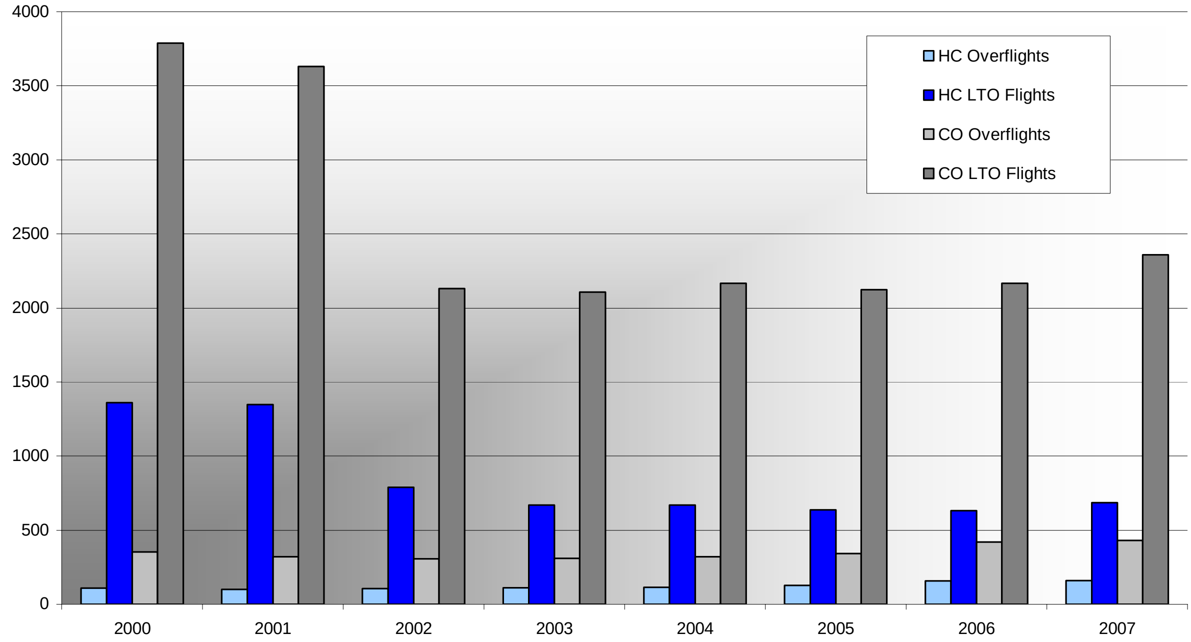
3.2.3. Evolution of the CO and HC emissions

Unburned hydrocarbons (HC) and CO are typical indicators of the quality of the combustion process. Also, when engines are set on high power levels (for instance during take-off) it implies higher amounts of unburned HC and CO being emitted.

The consequences clearly appear in Figure 20.

A lower number of flights taking off and landing in Belgium (LTO flights) using smaller and lighter aircraft produce significantly higher amounts of HC and CO when compared to the emissions of the overflights. Most of these emissions occur during the LTO phase of the flight.

Figure 20 : CO and HC emissions from LTO flights in Belgium and overflights above Belgium
(tonnes / year)



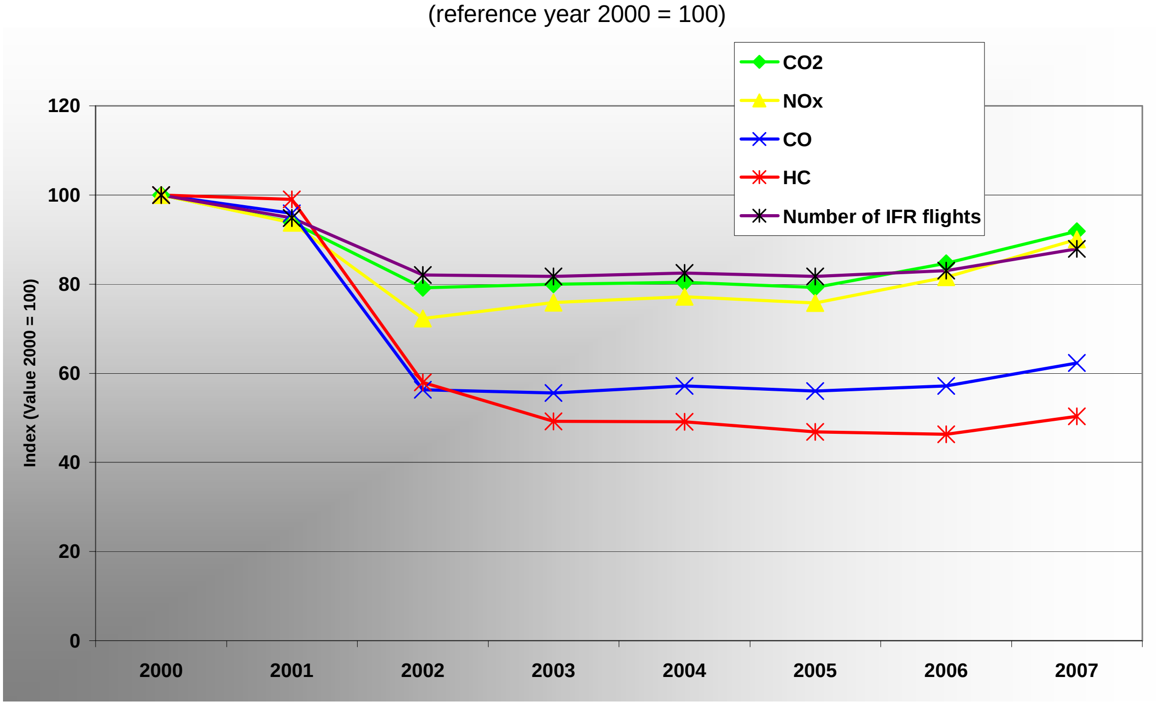
Source: based on data from Belgocontrol

3.3. Relative evolution of the emissions

The figures in this paragraph summarize the evolutions of the traffic and of its related emissions during the previous years. As the general trends of the different pollutants have been described with the previous graphs, no additional descriptions are provided here, except for Figure 23, which allows analysing the different growth rates of the two segments in one graph.

3.3.1. Evolution of the emissions due to LTO Flights

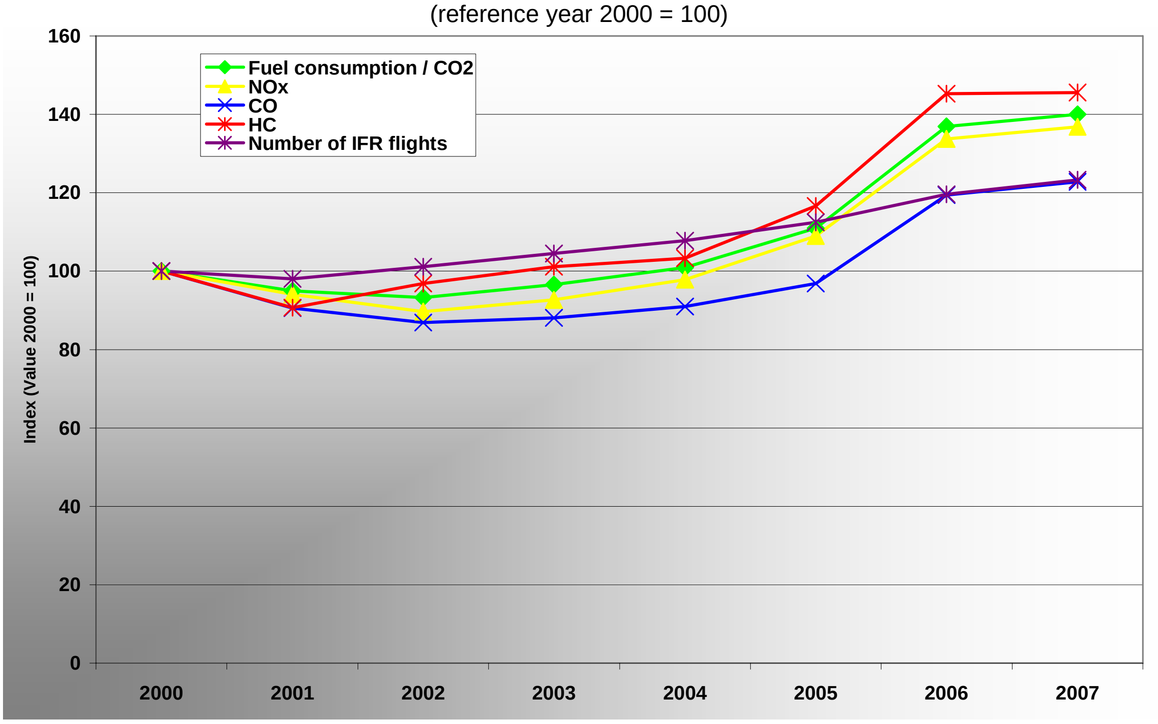
Figure 21 : Relative evolution of the number of IFR LTO flights and of the related emissions
(reference year 2000 = 100)



Source: ABC Impacts, 2008

3.3.2. Evolution overflights

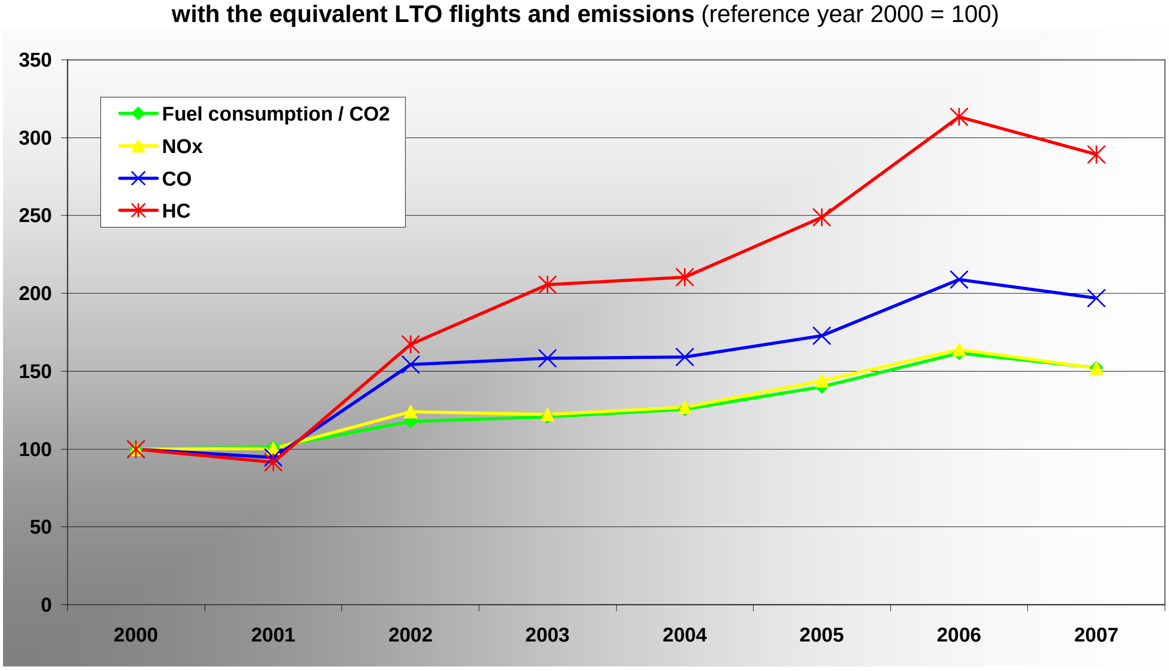
Figure 22 : Relative evolution of the number of IFR overflights and of the related emissions
(reference year 2000 = 100)



Source: ABC Impacts, 2008

3.3.3. Relative evolution of the LTO flights and overflights

Figure 23 : Relative evolution of the number of IFR overflights and of the related emissions as compared with the equivalent LTO flights and emissions (reference year 2000 = 100)



Source: ABC Impacts, 2008

Figure 23 clearly shows that the overflights (and their emissions) grow more rapidly between 2001 and 2006, while 2007 is the first year during which local activities (LTO flights) grow faster than overflights.

3.4. Potential climate-impacting emission reductions in the aviation sector

3.4.1. The individual aircraft

Improving individual aircraft performances is one the main ways to walk if wanting to improve aviation's environmental characteristics. Improving the environmental performances of the whole fleet will occur slowly, as new aircraft with better ecological features enter operation. This is due to the very long total lifetimes (sometimes up to 50 years) of today's aircraft (IPCC, 1999).

3.4.1.1. Principal technological factors influencing the nature and extent of the emissions of aircraft:

The highest priority in civil aviation is safety. Bearing this in mind, aircraft are developed to provide high-speed cruising at high altitudes altogether with acceptable environmental performances at ground level. To increase efficiency, the drag and weight of the aircraft must be reduced. This results in a constant drive towards the highest possible energy conversion efficiency from the engine. These factors are consistent with minimization of carbon dioxide and water outputs.

The most efficient engines used for today's civil aviation are high bypass, high pressure ratio gas turbine engines. There is no realistic alternative in sight for large-scale implementation in the short-term. These high bypass, high pressure ratio engines present high combustion pressure and temperature characteristics. These features result in high fuel efficiency. However, this also results in higher NO_x formation, especially at high power (take-off) and during the cruise phase at high altitudes (Chapter 7, IPCC, 1999).

In the past 40 years, since the dawn of the jet age in aviation, aircraft fuel efficiency has grown with more than 70% through some progress in airframe design, engine technology and higher load factors. It's assumed more than half of this improvement is due to increased engine efficiency. It needs to be noted though, that before the jet technology was introduced some aircraft technologies showed even higher efficiencies in some specific conditions (turbo propellers, pistons…). However, this higher efficiency usually implies some drawbacks like lower speeds or higher noise levels for example. In the future, the largest improvements are expected from a shift towards enhanced aerodynamic efficiency; new materials and better control and handling systems

Eurocontrol evaluated that similarly sized aircraft manufactured by 2015 would be 5,4% more fuel efficient than the aircraft manufactured in 2004. If an estimated 29,77% of the fleet is replaced by then, it means that a similarly sized worldwide fleet would be approximately 1,6% more efficient. However, it is to be expected that the fleet and traffic will grow significantly more (approximately 5% growth of traffic per year) than with 1,6% by 2015, so **the increase in fuel efficiency will not be sufficient to reduce or even to stabilize the fuel consumption and its related CO_2 emissions**.

A similar quick analysis of the evolution of the NO_x emissions leads to the following predictions. A similar activity with a replacement of 29,77% of the fleet and aircraft manufactured by 2015 predicted to emit 16% less NO_x would result in a reduction of the NO_x emissions of 4,8 %. Combining this figure with traffic growth however, would result in an increase of 30% of the total NO_x emissions at least.

3.4.1.2. Specific adaptations with a potential to reduce the climate impact of aviation

Furthermore, many potential simple or radical adaptations of the aircraft frame show some potential to reduce the fuel consumption or the emissions of the individual aircraft. However, giving some generally applicable figures on the emissions or consumption reductions is inappropriate as they will differ depending on the aircraft they are applied to as well on the specific design applied to the aircraft.

Nevertheless, some potentially interesting concepts are listed below:

- winglets or raked wingtips are used to reduce the turbulence, and consequently the drag of the wings, thus reducing fuel consumption;
- rear-mounted "open-rotor" engines (better environmental performance for short-haul flying);
- shorter design range to reduce the weight of the aircraft (dedicated to relatively short range missions < 2.000 nm);
- lower design cruise speed allowing to reduce drag and thus consumption;
- weight reducing materials (cf. Carbon fibre B787 instead of aluminium casting);
- variable camber wings (camber can be adapted to fit best to the different flight phases);
- fly-by-wire (all electric control) or fly-by-light systems (all glass fibre control) avoid the use of heavy hydraulic or mechanical systems;
- laminar components, smooth surfaces and computational fluid dynamics allow to improve aerodynamic design and to reduce fuel consumption.

3.4.2. The sector as a whole

3.4.2.1. Alternative fuels

Current low-sulphur fuels result in low SO_x emissions. Small concentrations (400-600 ppm) of sulphur and sulphur associated organic acids are present in the fuel. These molecules provide some essential lubricant properties for critical fuel system components. Removing all traces of sulphur would remove these indispensable organic acids. Therefore, it's unlikely to see sulphur free fuels in the short term. Additionally, sulphur removal would result in a small net rise of well-to-tank CO_2 emissions.

A. Biofuels

Similarly as for other transport modes biofuels are often cited as an alternative for fossil Jet-A fuel in aviation. Even though some properties of the first types of biofuels (energy density, freezing propensity and thermal stability for example) implied some serious issues impeding the use of biofuels for modern aviation, experience with smaller-sized turboprop aircraft and recent demonstrations with big-sized passenger aircraft (B747) demonstrated that these fuels are technically able to replace Jet-A fuel. However, just like for the other sectors, the implications of the use of biofuels on food production and prices, land use and land use changes should be thoroughly analyzed before its large-scale introduction on the market.

Moreover, even if biofuels can possibly reduce the energy dependency of some countries towards fossil fuels, the real climatic benefit of the use of (the different types of) biofuels still needs to be analyzed in-depth. Although the well-to-wing CO_2 emissions can potentially be reduced in some cases, lower energy densities of the biofuels might lead to other issues regarding climate. The use of biofuels might induce higher water emissions and lower combustion temperatures indeed. In turn, these higher water emissions and lower combustion temperatures could actually lead to increased contrail formation.

B. Synthetic fuels (or Synfuels)

Synthetic fuels are obtained through a Fisher-Tropsch process from coal, gas or other hydrocarbons. One of their advantages is that their sulphur and aromatics contents are very low (close to zero), which reduces their particulate emissions. Moreover they show very good viscosity in low-temperature environments and can reduce dependency on fossil oil. This last characteristic explains why these fuels have been used in several periods and areas throughout history (coal-based during the Second World War in Germany, as well as in South Africa both in the past and at this very moment).

On the other hand, synthetic fuels are still fossil based and don't solve the issues related to CO_2 and H_2O emissions. On the contrary, coal-to-liquid Jet fuels even induce an 80% increase of the well-to-wing CO_2 emissions according to Daggett et al. (2007).

C. Hydrogen

The use of hydrogen as a fuel for civil aviation has the advantage of eliminating exhaust CO_2 emissions and to further reduce NO_x emissions from aircraft. However, the use of hydrogen implies some specific characteristics which should be kept in mind. The use of hydrogen entails major changes in supply, ground handling and storage in the airports. Moreover the use of hydrogen substantially increases the quantities of (climate-impacting) water vapour emissions from aircraft. Finally, the added value of hydrogen as far as its benefits towards tackling climate change and increasing energy efficiency is strongly dependent on the way hydrogen is produced (well-to-wing approach). Also, the energy efficiency of the hydrogen concept should be analyzed before implementation, as the additional weight and volume of the system is likely to increase the energy consumption of the aircraft. Kerosene-type fuels (Jet-A, Biofuels and Synfuels) are thus considered as the only viable large-scale fuel for civil aviation for the coming 40-45 years (up to 2050).

Nevertheless, some interesting figures were presented by Hendrick & Verstraete (2002). Reduced formation of NO_x is obtained thanks to a lower flame temperature and the shorter residence time in the combustion chamber. Moreover the use of hydrogen would make it possible to use renewable energy sources (photovoltaic, wind, hydropower, etc.) to power the aircraft and would reduce (NO_x) or even solve many of the local pollution issues around the airports (related to SO_x, Soot, CO, HC)

3.4.2.2. Improvement of the ATM system

A. To reduce fuel consumption and emissions

Avionics improvements provided improvements in the accuracy of navigation. This resulted in more fuel efficient flight paths (Chapter 7, IPCC, 1999). Apart from that, some specific procedures could reduce the current fuel consumption by approximately 10%. The current system of flight corridors induces routes which are sometimes longer and thus not the most economic routes from a fuel consumption point of view. Additionally to the optimalization of the corridor flight systems; airborne holdings and flying less-than-optimum flight levels (FL) should be avoided to reduce fuel consumption.

Next to this, the implementation (or generalization) of the Reduced Vertical Separation Minima (RVSM) and of the Continuous Descent approach could result in a reduction of the fuel consumption by 6%-12% according to IPCC-Eurocontrol. Noteworthy is that these measures do not require any specific policy measure (as the extension of the ETS for example) or any new technology (these gains are obtained without any need to adapt the aircraft fleet).

B. To reduce contrail formation

As it is explained in the next chapters of this report, the exhaust of hot water vapour in the cold, moist air zones, can lead to the formation of contrails. These contrails can evolve to form cirrus clouds, which in turn contribute to global climate change. Eurocontrol has performed some analysis of the air traffic management (ATM) contrail mitigation options (Eurocontrol, 2005). Based on this analysis, Eurocontrol (2005) simulated moist and cold areas avoidance to assess the impact on fuel burn and emissions and estimate the resulting contrails coverage. Assessing actual meteorological conditions allow identifying moist and cold areas and once these high-contrail risk areas have been localized in the airspace, avoidance algorithms can provide avoidance strategies can be simulated to bring out the best balanced solution.

Avoiding high contrails risk airspace volumes may result in flying longer routes and/or not using the optimal flight level, which would increase fuel burn and emissions. Therefore a judicious balance between "avoidance of contrail formation" and "increase of fuel use" should be pursued.

3.4.2.3. Other specific emissions

Climate-impacting emissions are mostly related to aircraft operations in the air. However some other emissions occur in and around airports and some efforts are or can be provided to reduce them.

A. Refuelling system

As the refineries are rarely situated close to an airport site, the fuel used by the aircraft needs to be transported from the refinery to the airport. This is often performed by truck. However in some airports, such as the Brussels airport, the transport of the fuel (performed by Hydrant Refueling Systems, HRS) occurs through pipelines. This minimizes the number of trucks on the road altogether with the well-to-wing emissions of the aircraft.

B. Auxiliary Power Unit (APU)

In order to provide the aircraft with the electricity needed for the on-board appliances, air conditioning, etc., aircraft are fitted with a so-called auxiliary power unit. This unit needs to keep on running when the aircraft are not flying and consequently cause an extra combustion of fuel. In some cases (this is the case for the main gates at Brussels Airport), the aircraft can rely on on-the-grid facilities of the airport company. For example some 400Hz electric connection as well as a pre-conditioned air connection can be provided. This minimizes the fuel use and thus the consequent emissions while the aircraft are at the gate.

4. AVIATION SECTOR PROSPECT AND BELGIAN CHARACTERISTICS

This chapter presents an overview of past trends and forecasts in the air traffic market (and in the maritime transport sector) on a global, European and Belgian scale with a focus on the Belgian aviation market and its characteristics.

4.1. General trends and characteristics in the aviation sector

This section will discuss the past trends (see point 4.1.1) and forecasts (see point 4.1.2) in the air traffic market on a global, European and Belgian level. The given data relate to the Instrument Flight Rules (IFR) flights.

4.1.1. Past trends in air traffic market

4.1.1.1. Global trends

The air transport sector faced hard times from 2001 on, due to 9/11, the Iraq war and the SARS virus. Thanks to the strong growth of the freight segment, the air transport sector recovered sooner than expected and attained its 2001 level back by 2004. Since 1980 the number of departures increased with an average annual growth rate of 2,5%. Larger aircrafts were constructed so that the number of seats rose with 0,5% per year[52].

4.1.1.2. European trends

Table 4 and Figure 24 show the evolution of the flight movements within the ESRA[53]. Between 1975 and 2005 there was an average growth rate of 3,8% per year. In 2001 and 2002, the air traffic of the ESRA faced a crisis due to 9/11, the Iraq war and SARS, just as the global air transport sector. In the ESRA this sector fully recovered by 2004. In 2005 the number of flight movements went up to 9.086.000[54].

The internal flights represent the largest share of the ESRA flights. Overflights stand for only a small part in the total number of movements.

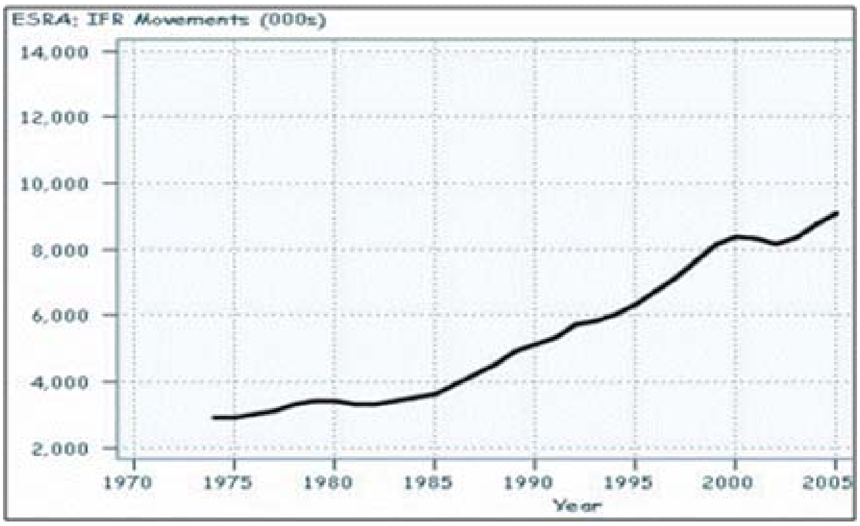
Table 4 : IFR flight movements 2003-2005 (in thousands)

	IFR Movements (000s)		
	2003	**2004**	**2005**
Total: Internal	6.887	7.115	7.320
Total: Arr/Dep	1.397	1.558	1.689
Total: Overflights	58	71	77
Grand Total	**8.342**	**8.744**	**9.086**

Source: Based on Eurocontrol (2006 b), p. 130

Figure 24 : Instrument Flight Rules (IFR) flight movement evolution in the ESRA (in thousands)

[52] Airbus, 2004
[53] ESRA stands for "Eurocontrol Statistical Reference Area"
[54] Eurocontrol, 2006 a



Source: Eurocontrol (2006b), p. 129

Factors that affect the present traffic growth within the ESRA are:

- economic growth
- the increasing capacity constraints at air- and landside of several European airports
- the strong local Turkish market that attracts a lot of tourism
- the implementation of fuel surcharges that increases the ticket prices
- the coming of the high speed railway
- the growing market share of low cost carriers
- the rising load factor : after a strong decline in 2001, the load factor shows again a rising trend. This means that airlines prefer a higher load factor to putting on more flights.

4.1.1.3. Belgian trends

Table 5 and Figure 25 give an overview of the evolution in flight movements for the Belgium-Luxembourg region. As the rest of the world, Belgium-Luxembourg experiences falling air traffic in the beginning of the millennium. Still, by 2005, in Belgium/Luxembourg the level of movements of 2000 has not been attained[55].

In 2005 the air traffic in Belgium-Luxembourg counted 1.005.000 movements of which the overflights represent the largest part, as distinct from the small share of overflights in the ESRA. In 2005 the movements in the Belgian-Luxembourgian region stood for 1/9 of the ESRA movements.

Table 5 : IFR flight movements 2003-2005 (in thousands)

	IFR Movements (00ds)		
	2003	**2004**	**2005**
Total Internal	6	7	6
Total Arr/Dep	361	365	364
Total Overflights	595	609	635
Grand Total	**962**	**981**	**1.005**

Source: Based on Eurocontrol (2006 b), p. 19

Figure 25 : IFR flight movement evolution in Belgium- Luxembourg (in thousands)

[55] Eurocontrol, 2006 b

Source: Eurocontrol (2006b), p. 18

4.1.2. Air traffic forecasts

4.1.2.1. Global forecasts

The following global air traffic forecasts are based on mid-term and long-term prognoses of Airbus, who made in 2004 air traffic forecasts until 2023.

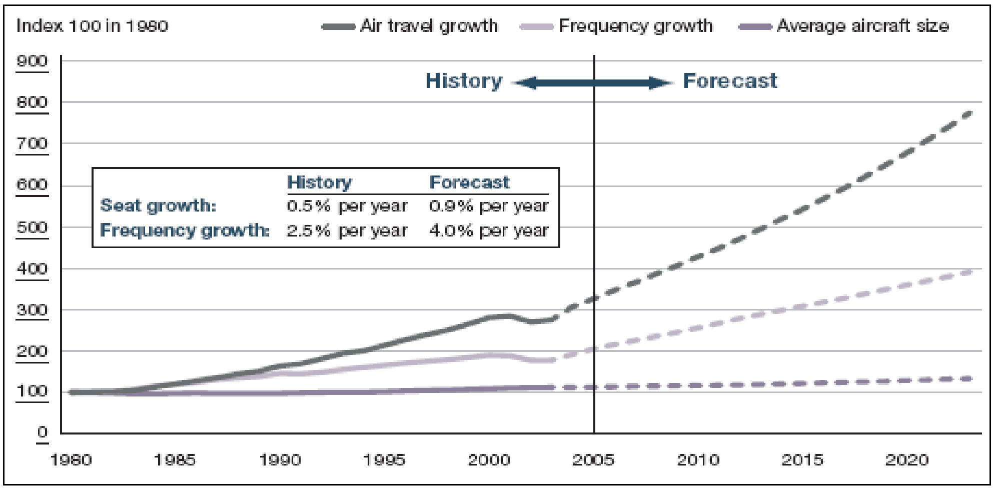
Airbus based this prognoses on projections of economic growth and other indices, such as the oil prices, the growing importance of low cost carriers and the Asia-Pacific region, the effect of liberalization, increasing environmental and congestion constraints, the type of transported goods (high-tech, perishable), etc…These individual bottom-up traffic prognoses are compared to a global top-down prognosis in order to confirm the initial results[56].

A. Passenger traffic

The number of departures of passenger flights will increase with an average annual rate of 4,0%. This means that the frequency of passenger flights will double by 2023 (see Figure 26).

Figure 26 : Traffic component development

[56] Airbus, 2004

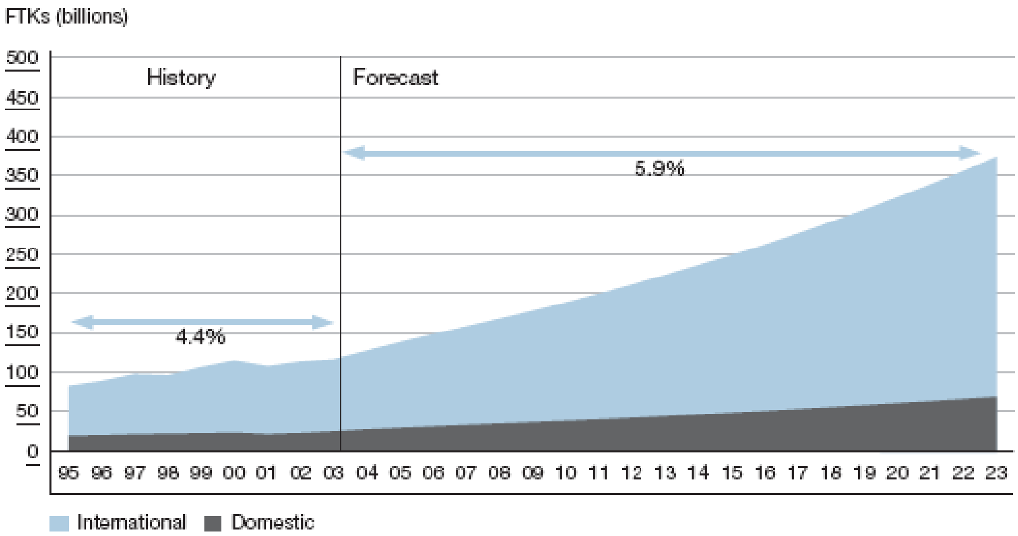


Source: Airbus (2004), p.37

B. Cargo traffic

In the past cargo traffic grew with an annual average rate of 4,4%. In the future this rate will rise up to 5,9% (see Figure 27).

Figure 27 : Cargo traffic development



Source: Airbus (2004), p.58

The share of full freighters is forecasted to attain 66% by 2023. This means that the role of passenger aircrafts in air freight transport will decrease with 7%. Over 20 years the traffic by dedicated freighters will be increased by 235%.

This evolution will result from:

- more aircrafts
- larger aircrafts (996 large freighter aircrafts by 2023)
- higher load factors.

C. Growth region

Rolls Royce (2006) and Airbus (2004) both predict that the Asian-Pacific region will become the biggest player with a share of 33% of the global air traffic market. This means that by 2023 this region will have passed the US and Europe who now occupy the first and second place in the world market.

4.1.2.2. European forecasts

A. Medium term forecasts

The medium-term forecasts of Eurocontrol are split up in three outlooks: an optimistic, a normal and a rather pessimistic one. The high and low variations are developed around the base forecast. The effects of economic and industrial growth just as the growth of the low cost carriers, the impact of the high-speed train and the airport capacity constraints are taken into account. These forecasts of Eurocontrol predict that by 2012, the number of IFR movements will rise with an average growth of 3,3% up to 11,4 million movements.

Figure 28 : Prognoses for the ESRA

		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Annual Average 2012/ 2005
IFR Movements (thousands)	High	.	.	.	9,525	9,961	10,398	10,826	11,217	11,634	12,019	**4.1%**
	Base	8,344	8,745	9,087	9,424	9,759	10,065	10,389	10,738	11,065	11,405	**3.3%**
	Low	.	.	.	9,336	9,589	9,820	10,081	10,375	10,654	10,925	**2.7%**
Growth (compared to previous year)	High		.	.	4.8%	4.6%	4.4%	4.1%	3.6%	3.7%	3.3%	**4.1%**
	Base		4.8%	3.9%	3.7%	3.6%	3.1%	3.2%	3.4%	3.0%	3.1%	**3.3%**
	Low		.	.	2.7%	2.7%	2.4%	2.7%	2.9%	2.7%	2.5%	**2.7%**

Source: Eurocontrol (2006), p.

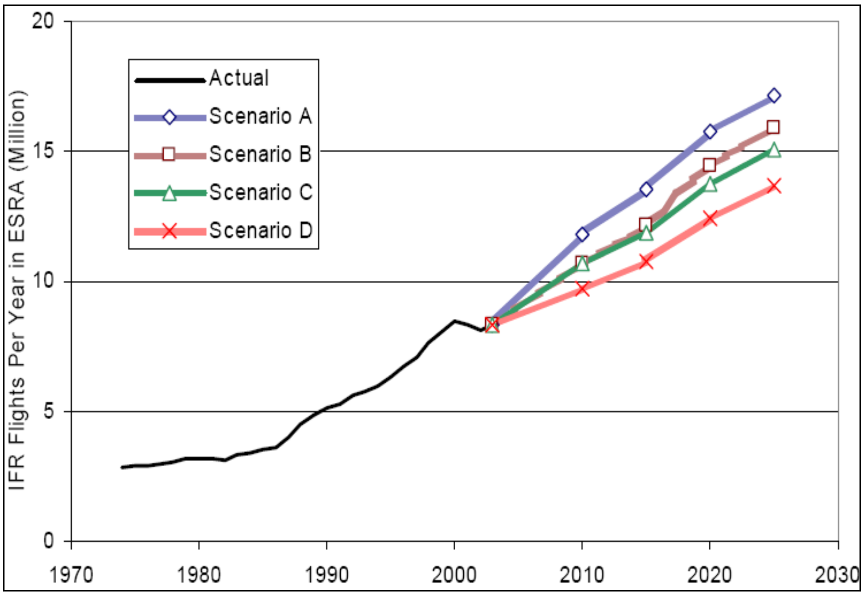
B. Long term forecasts

The long-term forecast of Eurocontrol gives predictions for the period 2004-2025 and is based on the medium-term forecast of this organization.

Four scenarios are worked out:

- *Scenario A* assumes a high level of globalization and strong economic growth within the ESRA
- *Scenario B* supposes a moderate economic growth, but in this scenario the EU expansion is faster than in the others
- *Scenario C* is based on strong economic growth in combination with a high level of government regulation to protect the environment and limited liberalization of trade and air traffic
- *Scenario D* assumes that political tensions between regions and high oil prices will have a negative impact on trade and the economic growth.

Figure 29 : Total IFR flights in ESRA



Source: Eurocontrol (2004), p.3

Table 6 : Growth prognoses for ESRA (2004-2025)

	A	B	C	D
Average growth 2025 v 2003	3,4%	3,0%	2,7%	2,3%
Total growth by 2025 as a multiple of 2003	2,1	1,9	1,8	1,6

Source: Eurocontrol (2004), p.3

Out of Figure 29 and Table 6, the following growth prognoses can be seen:

- Scenario A leads to the highest average growth of 3,4% by 2025 in number of flight movements, although the mid-term forecast, with 2,5% average growth by 2010, is not the highest. The strong long-term evolution is supported by free trade and Open Skies agreements. In this scenario traffic will more than double by 2025.
- The "business as usual" assumption of scenario B results in an average growth of 3,0% by 2025 which is the second highest long-term growth rate after the one of scenario A. Scenario B shows the strongest mid-term average growth rate of 2,7% by 2010 because of low security costs. By 2025 air traffic will almost double.
- Because of heavy environmental costs an limited liberalisation the growth in scenario C is lower than in scenario A and B and attains an average of 2,7%.
- Due to the tension between regions scenario D shows the weakest results. Tourism shifts from long to short haul and security costs keep rising between 2004 and 2025. Traffic will only grow by 1,6% over the next 20 years. As a matter of cost saving airlines will use larger aircrafts and intensify there hub and spoke system.

The predicted growth rates will not exceed the growth rate of the last 30 years (3,8%). There are two reasons for this: markets are expected to mature and the airport capacity constraints will also temper the growth in air traffic.

4.1.2.3. Belgian forecasts

The forecasts of Eurocontrol give no results exclusively for Belgium. The prognoses are made for the region of Belgium and Luxembourg. Since the share of the Luxembourgian air traffic is rather small, these forecasts are useful to learn more about how the Belgian air traffic will evolve.

A. Medium-term forecasts

By 2012, the total of flight movements of the Belgian/Luxembourgian region will grow by 2,8% in the base forecast and increase to 1,2 million movements.

In the more optimistic variation there will be a growth of 3,5% and in the pessimistic one only 2,2%. By 2012 the overflights represent the largest share of all flight movements while the number of internal flights is almost negligible small.

Table 7 : Main flow categories for Belgium/Luxembourg (2003-2012)

		IFR Movements(000s)										Growth										2012/2005
		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
Total: Internal	High	.	.	.	6	6	7	7	7	7	7	.	.	.	1.6%	2.1%	3.1%	2.6%	2.7%	2.6%	2.7%	2.5%
	Base	6	7	6	6	6	6	7	7	7	7	.	9.0%	-9.8%	0.9%	1.4%	2.4%	2.2%	2.3%	2.2%	2.2%	1.9%
	Low	.	.	.	6	6	6	7	7	7	7	.	.	.	1.3%	1.7%	1.9%	1.9%	2.0%	1.8%	1.9%	1.8%
Total: Arr/Dep	High	.	.	.	372	383	399	413	426	439	451	.	.	.	2.2%	3.0%	4.0%	3.5%	3.4%	2.9%	2.8%	3.1%
	Base	361	365	364	369	376	387	396	406	417	428	.	0.9%	-0.1%	1.3%	2.1%	2.8%	2.3%	2.4%	2.7%	2.7%	2.3%
	Low	.	.	.	369	375	382	390	399	408	417	.	.	.	1.3%	1.7%	1.7%	2.3%	2.3%	2.2%	2.2%	2.0%
Total: Overflight	High	.	.	.	664	692	721	751	777	803	825	.	.	.	4.6%	4.1%	4.2%	4.1%	3.5%	3.4%	2.7%	3.8%
	Base	595	609	635	658	679	697	716	739	762	786	.	2.3%	4.2%	3.5%	3.2%	2.6%	2.8%	3.1%	3.2%	3.1%	3.1%
	Low	.	.	.	651	664	677	694	714	732	751	.	.	.	2.5%	2.0%	1.9%	2.6%	2.9%	2.5%	2.5%	2.4%
Grand Total	High	.	.	.	1,044	1,082	1,127	1,171	1,211	1,250	1,284	.	.	.	3.7%	3.7%	4.1%	3.9%	3.4%	3.2%	2.7%	3.5%
	Base	964	982	1,006	1,034	1,062	1,091	1,120	1,152	1,187	1,223	.	1.9%	2.5%	2.7%	2.8%	2.7%	2.6%	2.9%	3.0%	3.0%	2.8%
	Low	.	.	.	1,027	1,047	1,066	1,092	1,122	1,149	1,176	.	.	.	2.0%	1.9%	1.8%	2.5%	2.7%	2.4%	2.4%	2.2%

Source: Eurocontrol (2006 b), p.19

B. Long-term forecasts

The long-term prognoses (2004-2025) for the Belgian air transport sector are based on the same scenarios as the prognoses for the ESRA (see 4.1.2.2.).

These scenarios all predict a different traffic growth. The prognoses for Belgium/Luxembourg follow the same trend as the prognoses for the ESRA, only on a lower level. Scenario A shows the strongest air traffic growth with a rate of 2,9%.

Table 8 : Average growth by 2025 for Belgium/Luxembourg versus ESRA

	A	B	C	D
Belgium/Luxembourg	2,9%	2,6%	2,4%	1,9%
ESRA	3,4%	3,0%	2,7%	2,3%

Source: Eurocontrol (2004)

A comparison of the growth rates of the different ESRA states proves that the air traffic in Belgium/Luxembourg will have a low medium growth in the future[57].

4.2. The Belgian aviation sector and its characteristics

4.2.1. Introduction

Before taking a closer look at the Belgian aviation sector it is important to have a clear idea about what is understood under this formulation. A sector can be defined in different ways according to data availability or research purpose. It is often necessary to use different definitions of the sector in order to get a clear idea of the specific topic that is being highlighted.

The Belgian aviation sector can be defined through:

- the companies that have a Belgian operating licence,
- the flight movements to/from/over Belgium or
- the companies reporting their financial obligations in Belgium.

4.2.2. Number of licensed operators

In Table 9 all businesses and their main operational activities in Belgium that have obtained a Belgian operating license are listed. These licenses are issued by the Belgian Civil Aviation Authority (part of the Federal Public Service Mobility and Transport).

Defining the Belgian aviation sector through the country where the operating licenses are delivered results in a list of 15 national operators in 2007, a very limited number of companies of which two are helicopter businesses.

The total fleet related to these Belgian operators includes 173 aircrafts and two helicopters, among which 20 have a MTOW lower than 5.700 kg[58].

[57] Eurocontrol, 2004

[58] Aircraft with a MTOW lower than 5.700kg are exempted from the European Commission proposal to include the aviation sector in the EU-ETS (see point 2.4.2.2 in chapter 2 for more details).

Table 9 : Belgian licensed air carriers as registered in 2007

Air carrier	Date of licence	Expiration date of licence	Exploitation
Abelag Aviation S.A.	15-07-1994	31-05-2008	Pax Air taxi
Air Service Liège N.V.	13-01-1994	31-03-2007	Pax Non scheduled
Airventure B.V.B.A.	30-04-1993	27-01-2007	Pax Air taxi
Brussels Airlines Fly S.A. (ex Virgin Express, ex Euro Belgian Airlines)	14-12-1993	31-10-2007	Pax & cargo Scheduled / Non scheduled
CARGO B Airlines	28-09-2007		Cargo
Delta Air Transport N.V. (Trading as Brussels Airlines)	25-04-1994	25-01-2008	Pax & cargo Scheduled / Non scheduled
European Air Transport N.V.	12-09-1994	15-03-2008	Pax & cargo Scheduled / Non scheduled
Flying Service N.V.	07-10-1998 10-11-1993	31-03-2008	Pax Non scheduled
Heli Service Belgium N.V.	07-06-1993	30-06-2007	Pax Air taxi
Noordzee Helikopters Vlaanderen N.V.	06-02-1998	28-10-2007	Pax Air taxi
Sky Service NV	09-04-1993	31-05-2008	Pax & cargo Scheduled / Non scheduled
Thomas Cook Airlines Belgium NV	12-03-2002	31-03-2007	Pax & cargo Scheduled / Non scheduled
TNT Airways S.A.	14-02-2000	08-12-2007	Scheduled Cargo ; Non scheduled Pax & cargo
TUI Airlines Belgium NV (Trading as Jetairfly)	19-03-2004	18-03-2007	Pax & cargo Scheduled / Non scheduled
VLM Airlines N.V.	06-05-1993	30-06-2008	Pax & cargo Scheduled / Non scheduled

Source: based on data from the FPS Mobility and Transport, Belgian Civil Aviation Authority

4.2.3. Flight movements

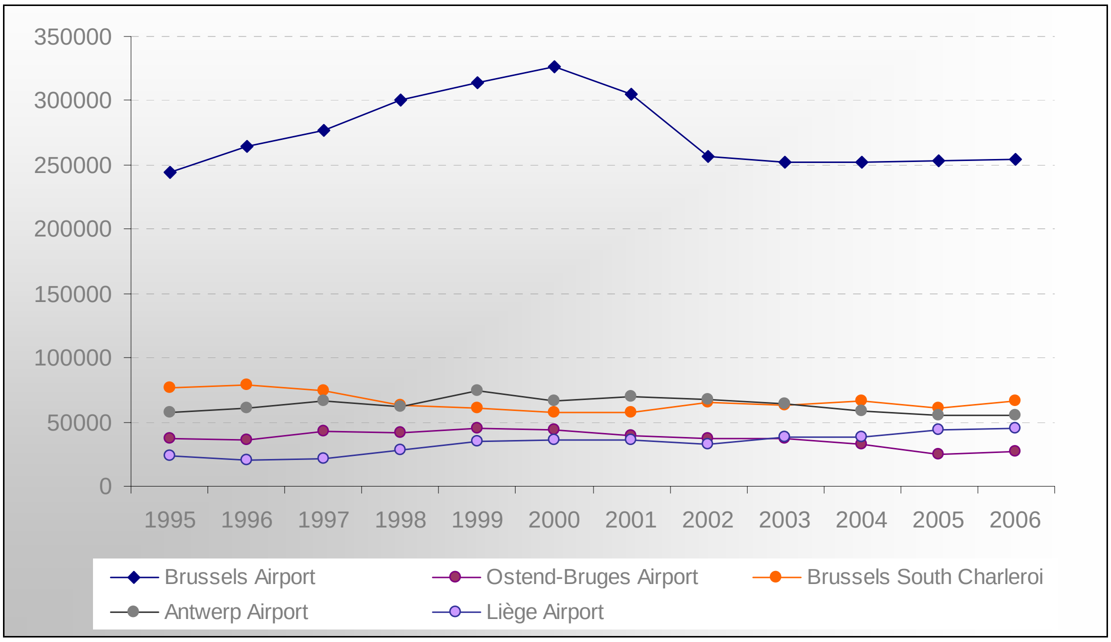
4.2.3.1. General overview

Figure 30 provides an overview of the number of flight movements during the period 1995 up until 2006.

For Brussels Airport the bankruptcy of Sabena had an important effect on the number of movements. In 2006 the number of movements is still more than 70.000 movements below the record year of 2000. Between 1995 and 2006 the number of movements for Brussels Airport only increased 4% which means that this airport has still a lot of capacity available certainly with the 2000 figures in mind and the fact that the new A terminal has been inaugurated in 2002.

Interesting to see is that for three out of four of the regional airports the number of movements has decreased and that only Liège Airport has had a considerable increase of the number of movements.

Figure 30 : Number of flight movements at Belgian airports (VFR + IFR)



Source: own setup based on annual reports and statistical reports from the regional airports
See also: Air movements in Belgium on the ABC Impacts website for more details on the figures

When taking a look into the division of movements between the regional airports and the national airport, it appears this figure has remained quite stable over the years.

The total number of movements increased only by 2,4% between 1995 and 2006 for all major Belgian airports.

4.2.3.2. Detailed analysis for passengers, cargo and overflights

Based on data for the period 1995 till 2006, an overview of the passenger numbers, as well as of the amount of airplane movements and of the transported cargo are presented.

The period under scrutiny has been quite turbulent for the Belgian aviation sector. Just after the 9/11 attacks the national flag carrier Sabena went bankrupt on the 7th November 2001. Another blow for the sector occurred in 2004 when DHL decided to move its centre of operations from Brussels Airport to Leipzig.

Belgium has one main national airport, Brussels Airport, and four regional airports of which two, Ostend-Bruges International Airport and Antwerp International Airport, are situated in the Northern part of the country, Flanders, and two, Brussels South Charleroi Airport and Liège Airport, in the Southern part of the country, Wallonia.

The national airport (Brussels airport) has been privatised at the end of 2004 and a majority of the shares, 70%, is in the hands of an Australian investment group fronted by Macquarie Airports with the remaining shares held by the Belgian government[59].

The four regional airports are state-owned by the regions where they are located but some plans for a privatisation of these airports exist.

The figures for the number of passengers as well as for the number of movements are derived from the Belgian National Institute for Statistics[60], which derived these data from data obtained from the four regional airports, the national airport, the federal department for mobility and transport, the department of environment and infrastructure of the Flemish ministry and the Walloon ministry of equipment and transport. These data do not include transit passengers, who remain in the airplane

[59] http://www.brusselsairport.be/nl/brusselsairport1
[60] Algemene Directie Statistiek en Economische Informatie (http://www.statbel.fgov.be/home_nl.asp)

after landing before flying to their next destination, nor transfer passengers, who change from one airplane to another in order to continue their travel to their destination.

Cargo data are derived from the department of studies of the Flemish government[61] for the period 1995 up until 2005. For 2006 cargo amounts mentioned on the websites of the four regional airports were used and for Brussels Airport the data was obtained from Airports Council International.

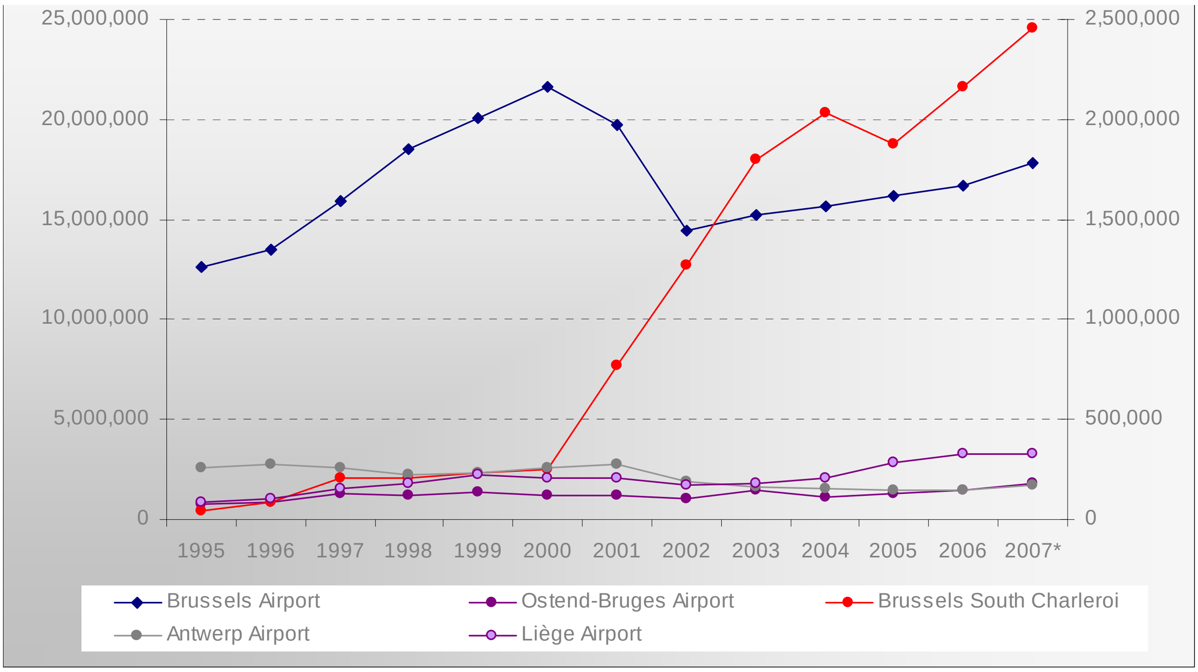
A. Passengers

Figure 31 provides an overview of the evolution of passenger numbers during the last twelve years in Belgium.

For Brussels Airport the enormous impact of the bankruptcy of the national flag carrier Sabena in 2001 immediately appears with a decline of passenger numbers in 2001 as well as in 2002. It appears that even today, in spite of the worldwide growth in aviation, the Belgian aviation business is still recuperating for this blow in 2001 and passenger numbers in 2006 are 5 million below the all time high figures of 2000 for Brussels Airport.

Three out of the four regional airports have seen their passenger numbers grow substantially and in the case of Brussels South Charleroi Airport even spectacularly during the last twelve years. Antwerp International Airport has been the only regional airport with a decline in passenger numbers as compared to 1995 figures.

Figure 31 : Number of passengers at main Belgian airports (1995-2007)
(National airport on the left axis and regional airports on the right axis)



Source: own setup based on annual reports and statistical reports from Belgian airports (Brussels Airport to be read on the left Y-axis, Regional Airports to be read on the right Y-Axis), figures for 2007 are to be confirmed.
See also: Air passengers in Belgium on the ABC Impacts website for more details on the figures

The total Belgian aviation market for passengers has grown by almost 49% between 1995 and 2005 but the total market in 2006 was still three million passengers below the highest activity figures (year 2000).

As a whole, and despite the slight decline of the Antwerp International Airport, the four regional airports have achieved a spectacular growth of 496% as compared to 1995 figures. In 1995 the regional airports accounted for a market share of 3,6% of the total passenger numbers in Belgium,

[61] Studiedienst van de Vlaamse Regering (http://aps.vlaanderen.be/statistiek/cijfers/stat_cijfers_mobiliteit.htm#luchtverkeer)

while this figure climbed till 14,3% in 2006. This was achieved through a continuous growth of the market share for the regional airports year after year during the twelve years under scrutiny.

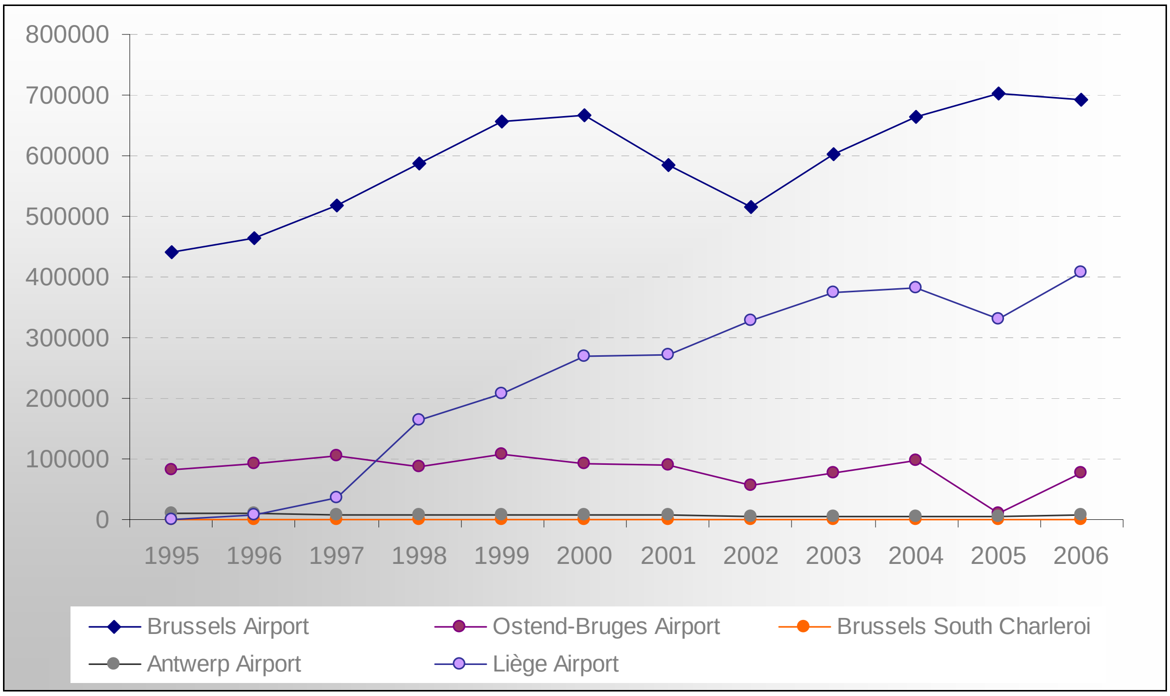
When taking a closer look at the regional airports, it appears that specifically the ones situated in Wallonia achieve important growth figures. Brussels South Charleroi Airport grew by 2.436% as compared to 1995 and Liège Airport by 286%. The spectacular figures for the Brussels South Charleroi Airport are mainly explained by the arrival of Ryanair and other low cost carriers to the airport[62] since 1997. When looking at the passenger numbers since 1997, it appears that this has had a major influence on the traffic of the airport.

For the two airports situated in Flanders, only Ostend-Bruges International Airport shows some strong growth relatively to 1995 with an increase of passenger numbers of almost 82%, while Antwerp International Airport has noted a decline of passenger numbers of 43%. When comparing these figures to the ones of the national airport, Brussels Airport, it appears that in spite of the disappearance of the national flag carrier, a relative growth of 32% of passenger number relative to 1995 figures is still noted.

B. Cargo

In Figure 32, a closer look is taken at the amounts of cargo handled at the different airports in Belgium.

Figure 32 : Cargo tonnage at main Belgian airports (1995-2006)



Source: own setup based on annual reports and statistical reports from the regional airports

Total cargo has risen much more than the number of passengers for Belgium as a whole. Relatively to 1995 figures it increased by 121,5%.

For Brussels Airport, a dip is observed in 2001 and 2002, just as with the passengers numbers but in contrast to the passenger traffic, the pick up of the market takes place much faster. 2005 seems to be the busiest year for cargo up till now, as even more cargo has been handled than in 2000, the busiest year for passengers. When comparing growth figures between passengers and cargo, cargo becomes more and more important for Brussels Airport, with an increase of 56,5% since 1995.

The market share of the regional airports grows from 17,4% in 1995 to 41,6% in 2006. When comparing this figure to the market share of the regional airports for passengers handled comparable

[62] http://www.charleroi-airport.com/BSCA/siteEN.nsf/.NouvelleW/CD8277BFD56BB06FC12572CF0026980C?OpenDocument&Key=no

growth figures are obtained: 41,6% for cargo and 43,2% for passengers. Over the last twelve years, the regional airports have gained enormous importance within the Belgian aviation market.

Noteworthy is that especially the Walloon regional airports have realised large growth figures; Brussels South Charleroi Airport concerning passenger traffic and Liège Airport concerning the handling of cargo. When taking a closer look at cargo handling and at the regional airports, it appears that this evolution is entirely due to the massive growth of Liège Airport since the three other regional airports handle less cargo as compared to 1995 figures.

Three airports handle the bulk of the air cargo in Belgium:

- Brussels Airport with 58,4% of total cargo,
- Liège Airport with 34,5% and
- Ostend Airport with 6,6%.

This implies that almost 42% of cargo is handled through regional airports. This is in contrast with the passenger traffic, where only 14% is performed through the regional airports.

C. Types of flights

Table 10 provides an overview of the distribution between Instrument Flight Rules (IFR) movements and Visual Flight Rules (VFR) movements for the major Belgian airports for 2005. Visual flying is common for helicopters, balloons and small airplanes while instrument flights are intensively used for commercial aviation. It is noteworthy that regional airports still have considerable numbers of flights under VFR which is an indication that in regional airports the capacity of the airport (runways, etc.) is still sufficient to allow the practice of different types of flights (i.e. typically with smaller aircraft), which is much less the case at the national airport.

Table 10 : Distinction between IFR and VFR at the major Belgian airports

2005	IFR flights per airport	VFR flights per airport
Brussels Airport	~100%	~ 0%
Brussels South Charleroi	41,1%	58,9%
Antwerp International Airport	33,4%	66,6%
Ostend-Bruges Airport	28,0%	72,0%
Liège Airport	62,4%	37,6%

Source: own setup based on airport specific data

Table 11 gives an overview of the purpose of the flights aggregated into five categories: scheduled, non-scheduled, cargo, military and other flights). The overview is made for 2005 and the total number of movements differs from these mentioned in table 2 because another data source was used, namely the public annual reports of the airports themselves. For Liège Airport no detailed information was obtained but many of the flights are expected to be for cargo purposes since this airport is the main European base of operations for TNT Airways, the express freight carrier[63].

Non-scheduled flights include: business, charter, tourism, private and taxi flights.

"Other flights" are: state, sanitary, mandatory, administrative, policy, photograph, local, training and test flights.

Most of the flights from Brussels Airport are scheduled flights as one could expect from the national airport.

In the regional airports most flights are, as opposed to the flights from the Brussels Airport, other types of flights which require more flexibility. Noteworthy is also that only 10% of the flights from Brussels Airport are dedicated cargo flights.

[63] http://www.tnt.com/country/en_ta/about/company/airlinesmainbase.html

Table 11 : Overview of the purpose of the flights from the major Belgian airports

Source: own setup on the basis of airport specific data

Brussels Airport	2005	Percentage
Scheduled flights	183.400	72,4%
Non-scheduled flights	23.000	9,1%
Cargo flights	24.700	9,8%
Military flights	6.500	2,6%
Other	15.600	6,2%
Total	**253.200**	**100,0%**

Ostend-Bruges Airport	2005	Percentage
Scheduled flights	36	0,1%
Non-scheduled flights	7.340	29,2%
Cargo flights	2.770	11,0%
Military flights	0	0,0%
Other	14.986	59,6%
Total	**25.132**	**100,0%**

Brussels South Charleroi Airport	2006	Percentage
Scheduled flights	14.129	21,3%
Non-scheduled flights	2.320	3,5%
Cargo flights	0	0,0%
Military flights	664	1,0%
Other	49.325	74,2%
Total	**66.438**	**100,0%**

Antwerp Airport	2005	Percentage
Scheduled flights	2.928	5,3%
Non-scheduled flights	17.276	31,5%
Cargo flights	0	0,0%
Military flights	0	0,0%
Other	34.667	63,2%
Total	**54.871**	**100,0%**

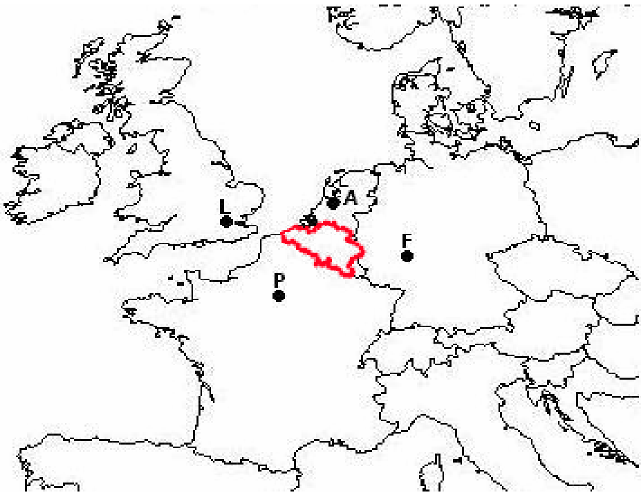
Liège Airport	2005	Percentage
All flights	42.672	100,0%

D. Overflights

As explained more in detail in point 5.1 of chapter 5, aviation induces global climate change not only through CO_2 and NO_X emissions, but also regional climate change through the formation of contrails and/or cirrus clouds.

In this context, it appears that the location of Belgium in the so-called FLAP zone (Frankfurt-London-Amsterdam-Paris) area is critical. This zone includes the four busiest airports in Europe both in terms of passengers, as in terms of movements[64]. Moreover, the surrounding area includes other airports in the direct vicinity of Belgium (Luxembourg, Lille, Maastricht, Eindhoven, Dusseldorf, Köln, etc.). These facts make it relevant to compare the climate change induced by the aviation sector in Belgium with the climate change effects of the overflights of the Belgian air space.

Figure 33 : Location of the Belgian territory in the FLAP area



Source: Adapted from Rosenberg, 2007

In order to be able to analyse these different contributions it is required to evaluate the overflying traffic.

Some data obtained through collaboration with the Belgian Air Traffic Safety Management Organisation (Belgocontrol) allowed an evaluation of the number of flights over the country (not only originating from the FLAP airports).

As Belgocontrol is responsible for the Luxembourg air traffic management as well, some insight on the number of LTO cycles in Belgium's and Luxembourg's airspace have been provided.

Figure 34 gives the division of the Belgium's and Luxembourg's air space limits into inzones and outzones. Respectively, these are the zones where aircraft enter or exit the air space. While originally these main zones are subdivided in several parts, for more clarity they have been grouped in North, East, South and West zones and are shown in blue, yellow, green and red respectively.

Figure 34 : Definition of the different inzones and outzones for the Belgian airspace

[64] ACI, 2007

Source: Adapted from CIA, 2007 and based on Belgocontrol data

The traffic entering the different inzones and exiting the different outzones is shown and grouped by main flight directions (combinations of the different points of the compass) in Table 12.

Table 12 : Overview of the overflights over Belgium and Luxembourg in 2006

Inzone	Outzone	Number of flights in one direction	Number of flights in both directions
North	South	86.687	165.095
South	North	78.408	
North	East	30.109	153.897
East	North	123.788	
North	West	121.663	122.835
West	North	1.172	
East	West	0	163.717
West	East	163.717	
East	South	77.887	159.973
South	East	82.086	
South	West	0	146
West	South	146	
Total number of movements		**755.663**	

Source: own setup on the basis of the Belgocontrol database

204.730 LTO (Landing and Take-off) cycles took place in Belgium in 2006.

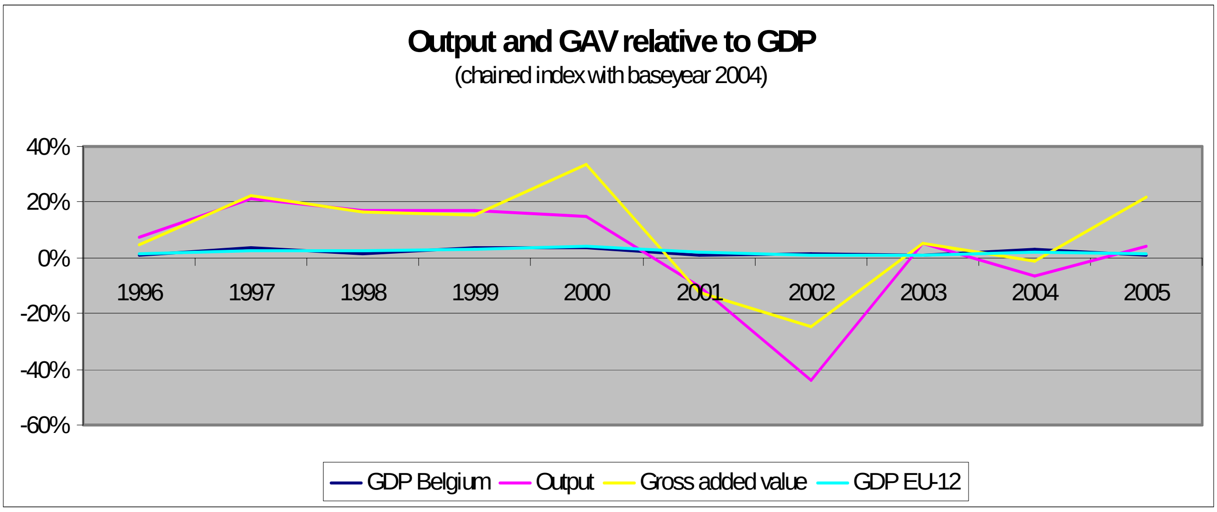
The comparison of this number of LTO cycles with the total number of overflights of the territory of Belgium and Luxembourg shows that the local climate is likely to be influenced by air traffic transiting through its air space in a considerable manner.

Consequently, the ABC Impacts project tries to calculate in a more precise way what the relative contributions of both categories of flights are. A first attempt is described in chapter 5, but during the second phase of the project, more detailed calculations will be made according to the type of aircraft that cross the Belgian air space.

4.2.4. Financial statistics

Concerning the financial aspects, the sector reports a better efficiency and "profitability" since the 2000-2001 events (bankruptcy of Sabena and 9/11 attacks).

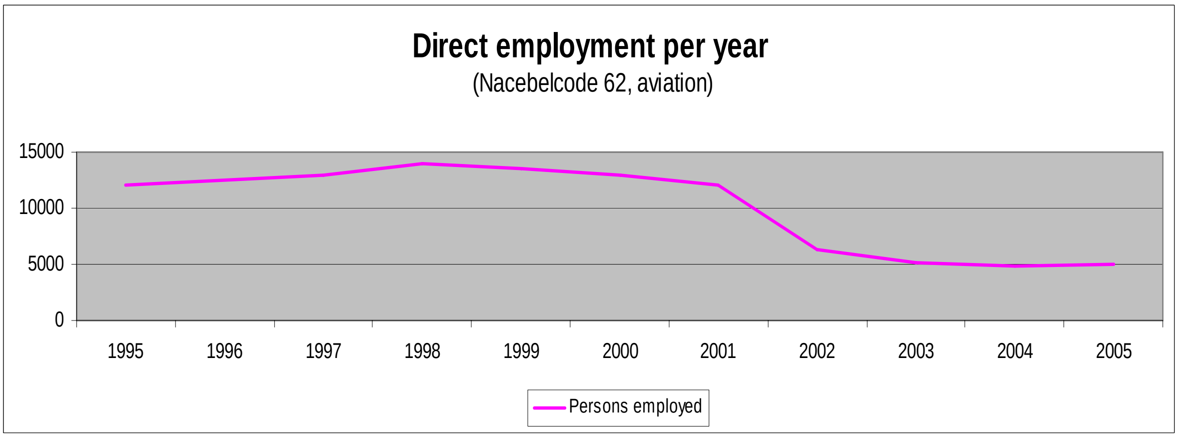
Figure 35 : Trends in the Output and the Gross Added Value of the Belgian aviation sector compared to GDP



Source: own setup based on data of the Belgian National Bank and the European Central Bank

Employment in the Belgian aviation sector dropped heavily after 2001 but it is important to note that the NACEBEL code aviation (62) is strictly limited to "personnel who really flies"[65].

Figure 36 : Trends in the number of direct employment per year of the NACEBEL code aviation (62)

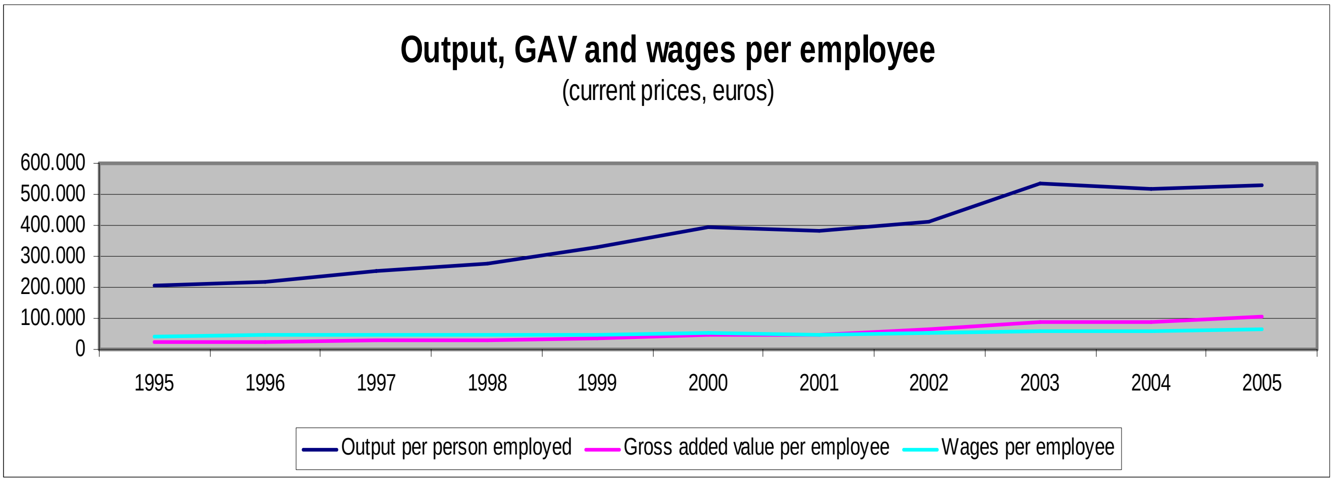


Source : own setup based on data of the Belgian National Bank

The Belgian aviation sector is specific because it has never been profitable as a whole during the last ten years which illustrates that margins are very low and that the sector is, at the moment, on one part still recovering from the 9/11 attacks, the SABENA bankruptcy, the SARS virus and the DHL-debacle and on the other part is restructuring itself to become a profitable sector as is illustrated by the Figures hereafter.

Figure 37 : Trends in the output, Gross Added Value and wages per employee of the Belgian aviation sector

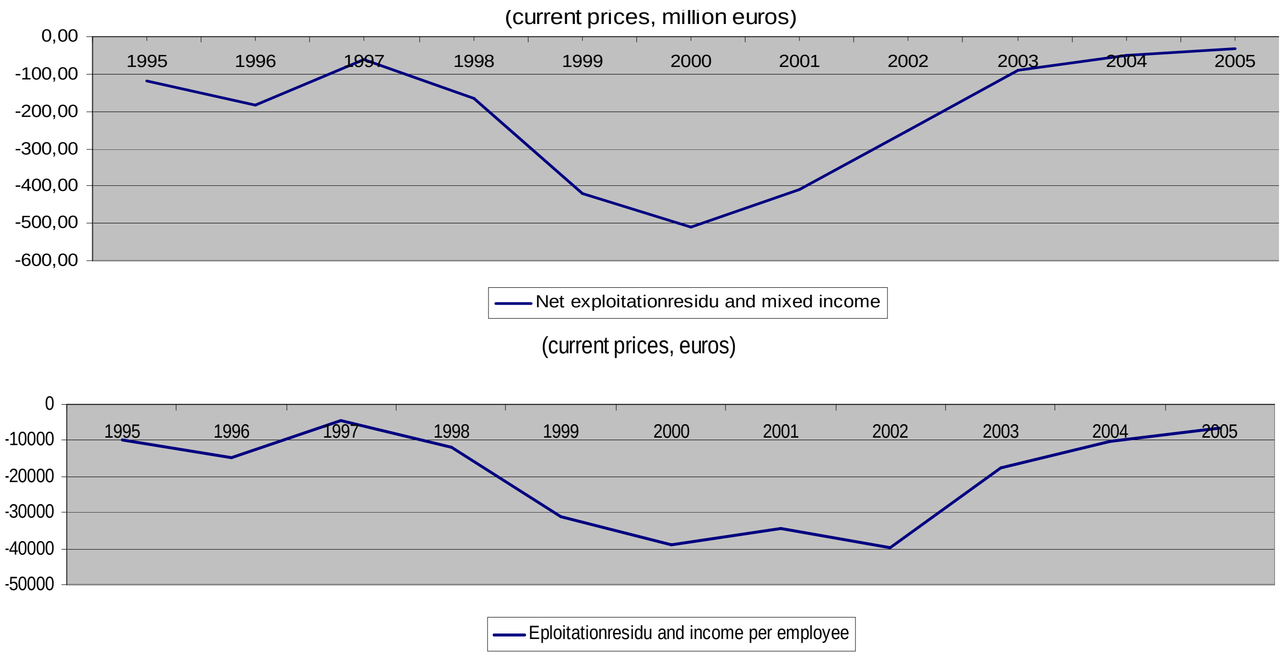
[65] In 2000 the technical subsidiary, SABENA Technics, which was up to then part of the full cost carrier Sabena has been sold and was no more part of the company) and is not a part of the same NACEBEL code anymore. Moreover staff hired and paid in another country, as it is the case for the Ryanair staff (hired following the Irish rules) for example, is not included in this NACEBEL code either.



Source: own setup based on data of the Belgian National Bank

"Profitability" of the sector is better in 2005 than in 2000 even with a lower number of passengers transported.

Figure 38 : Trends in the Net Exploitation Residue, Mixed Income and Income per employee of the Belgian aviation sector



Source: own setup based on data of the Belgian National Bank

4.3. General trends in transport and particularly in the maritime transport sector

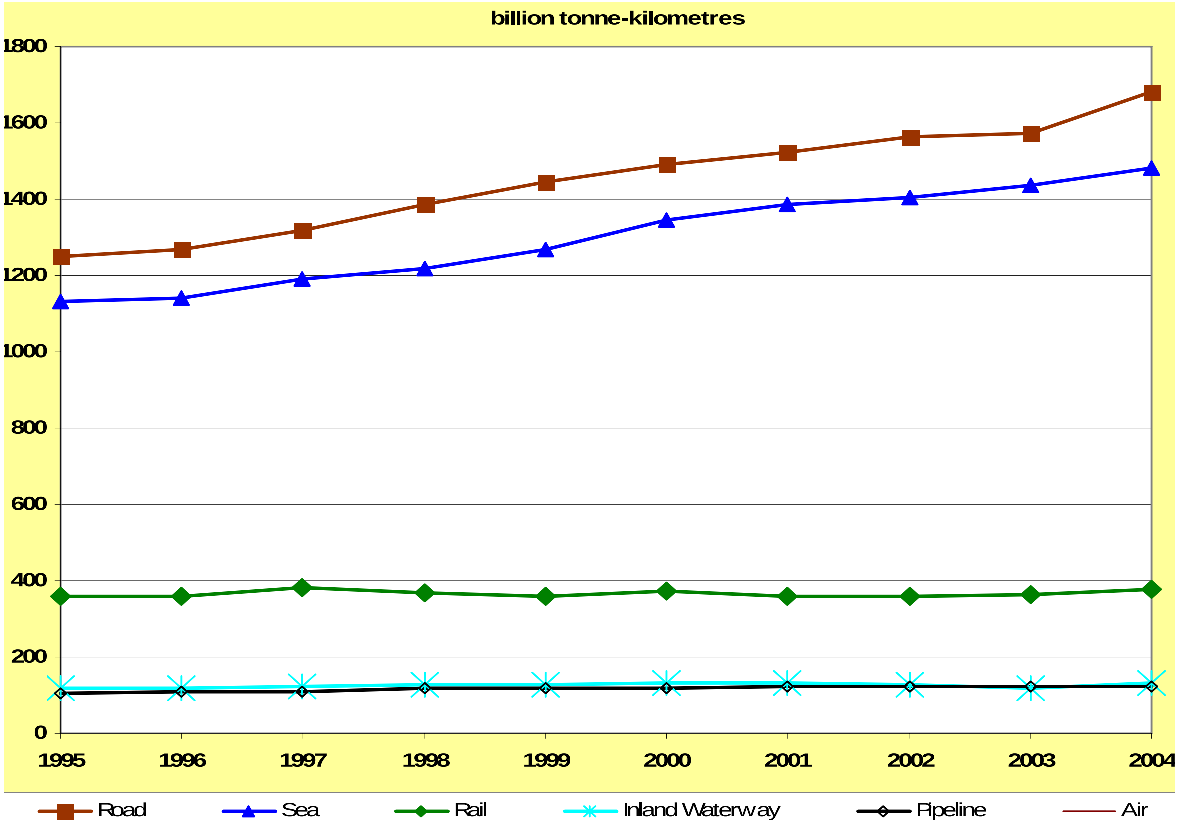
This point aims to discuss the past, present and future trends in the freight transport with a main focus on international maritime transport.

4.3.1. General trends in transport

Considering the last decade between 1995 and 2004, volume of **freight transport** in Europe increased by 28%.

Although this growth is distributed more or less evenly over time, the annual growth rate of 2,8% is not equally distributed between transport modes. As seen in Figure 39, the domination of road transport and shipping is accompanied by a stable inland waterway and railway transport activity. Comparing the performance by mode in freight transport for 2003 and 2004, an increase of 8,7% is seen for inland waterway and of 6,9% for road transport. Over a longer time period, railways declined by 4,3% and maritime transport by 3,4%.

Figure 39 : Performance by mode for Freight Transport EU-25



Source: Eurostat, Statistical pocketbook 2005

4.3.2. Evolution in the maritime transport

See the synthesis on the ABC Impacts website: Maritime transport global trends.

5. INTERACTIONS BETWEEN THE CLIMATE AND THE AVIATION SECTOR

This section summarises the work on:

- the identification of aviation global as well as regional climate impacts,
- the way aviation has been integrated in an existing climate model JCM5 and
- considerations about stakes related to the regional climate modelling of aviation climate impacts.

5.1. Climate impacts from aircraft

Air transport has specific climate impacts compared to other transport modes mainly because most emissions (see also Aircraft emissions) occur at high altitude. A second characteristic aspect concerns the geographical location of aviation's climate impacts: aircrafts cause global warming as well as more local/regional climate impacts.

Therefore, the total climate impact from aircraft is more important than the climate impact from "classic GHGs" (see Kyoto GHGs) only and has to be qualified according to the time horizon considered.

5.1.1. Altitude and climate impact

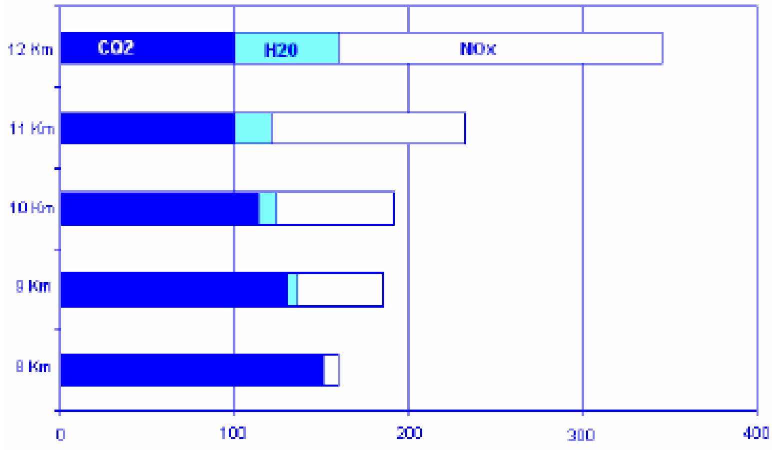
Due to the combustion of fuel, aircrafts produce different emissions which are harmful to the environment and to human health.

As aircrafts fly at high altitude, some of the emitted pollutants have stronger environmental effects than if they were emitted at ground level: they influence the local atmosphere chemistry (e.g. NO_x interacts with methane and with ozone in the high atmosphere). Under specific meteorological conditions (when the temperature is low and the humidity high enough), aircrafts induce condensation trails (contrails), which can evolve into cirrus clouds. This additional cloud cover is referred to as aircraft induced cloudiness (AIC).

Figure 40 illustrates the influence of flying altitude on the forcing of the climate system from different aircraft emissions (CO_2, NO_x and water vapour, not considering contrails or changes in cirrus clouds). The value of reference (100) corresponds to the CO_2 radiative forcing at an altitude of 12 km. Even if the importance of CO_2 forcing climate impacts tends to diminish with increasing altitude (due to lower fuel consumption when flying in less denser air), the overall forcing of considered emissions grows sharply because of the increasing effects of NO_x and H_2O. Consequently, on average, the total climate impact of an aircraft at 12 km is more or less twice as large as the impact at 8 km.

As regards climate policy tools and mitigation efforts, it is essential to tackle the climate impacts from the aviation sector in a comprehensive way; keeping in mind that the adoption of incomplete measures that could worsen the total climate impact of the sector.

Figure 40 : Relative climate impact of CO_2, NO_x and H_2O according to the altitude



Source: Öko-Institut eV, Emissions trading in international civil aviation, 2004, p.62

5.1.2. Local/regional versus global climate impacts

Aircraft emissions induce climate impacts because they modify the radiative forcing balance of the atmosphere through chemical interactions with existing gases (e.g. methane and ozone) and through the increase of the concentration of CO_2 and water vapour.

Given the fact that CO_2 has a long lifespan, it accumulates and is mixed homogeneously in the atmosphere. Its forcing occurs therefore occurs on a global scale (global warming effect). Methane destruction by NO_x emissions in the higher atmosphere also has a global impact due to the relative long lifespan of methane in the atmosphere (global cooling effect).

The climate impacts of other aircraft emissions are more closely located along the main aircraft routes (the majority of them are localised in the northern hemisphere) because they (or their indirect effects) are short-lived and/or do not have the time to mix homogeneously in the atmosphere (see Table 13). Note that climate impacts generated by water vapour and ozone have an overall warming effect.

Table 13 : Climate influence of different aircraft pollutants

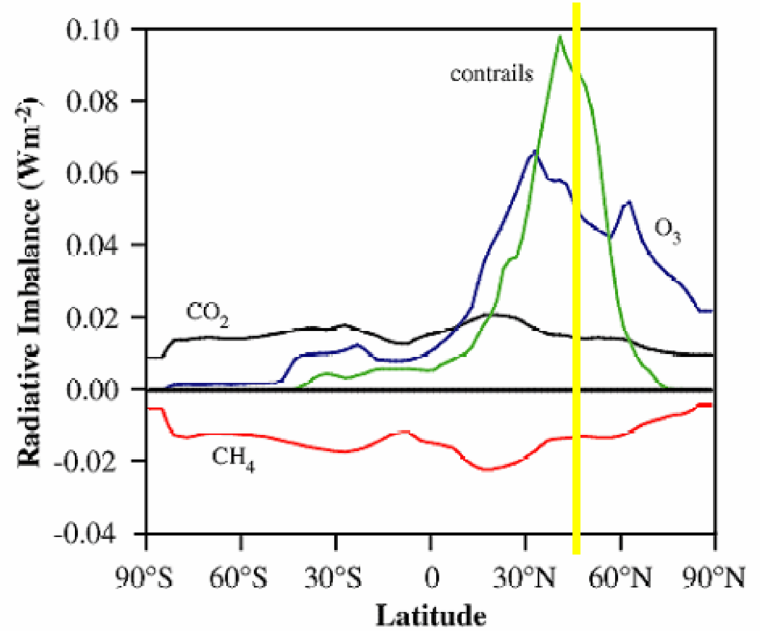
	Interactions with climate system	Climate forcing
CO_2	Contributes to the increase in carbon dioxide concentrations	global positive
H_2O	Increases the local concentration of water vapour at cruising altitudes Initiates the formation of condensation trails which can evolve into cirrus clouds	local/regional positive
NO_x	Increases natural ozone concentrations at cruising altitudes	regional positive
	Decreases the natural lifetime of methane	global negative
PM, soot	Interacts with outgoing infrared radiation Serves as cloud forming nuclei	local/regional positive
Sulphur aerosols	Interacts with incoming solar radiation	local/regional negative
	Serves as cloud forming nuclei	local/regional positive

Source: ABC Impacts, 2007

Figure 41 illustrates the different regional importance of aircraft induced climate forcings : CO_2 and CH_4 generate a well distributed radiative imbalance as a function of latitude, while the radiative imbalance caused by contrails and ozone (O_3) is much greater between the latitudes 30°N and 60°N (Belgium is situated around 50°N, see the yellow line).

The regional impact is quite clear since most contrails are induced along the main air corridors and the intensity of the cover increases with the growth in air traffic on the main routes. It is to be noticed that Belgium is right in the middle of the main European air knots and will suffer from one of the most important contrail covers. Moreover, this contrail cover is essentially due to overflights of the Belgian territory (see Figure 44).

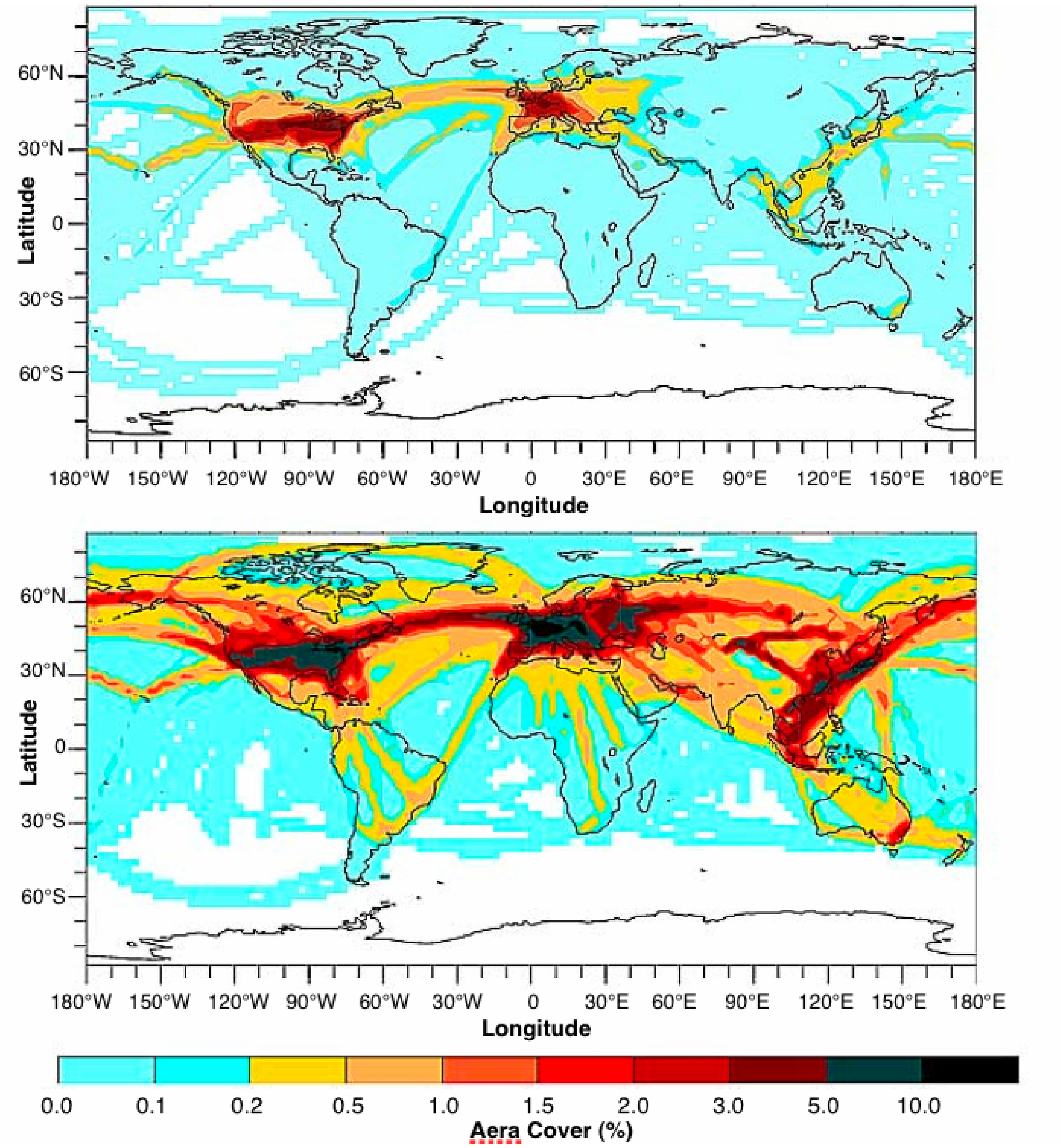
Figure 41 : Repartition of aircraft climate impacts according to the latitude



Source: IPCC special report, "Aviation and the global atmosphere", 1999

The geographical coverage of persistent contrails is illustrated in Figure 42 with a comparison between 1992 and 2050 according to the forecasted air traffic growth from the IPCC development scenario Fa1.

Figure 42 : Persistent contrails cover (in % area cover) **for 1992** (left) **and 2050** (right)**, linear weighting**



Sources:
Sausen et al., A diagnostic study of the global distribution of contrails part I : present day climate, *Theoretical and Applied Climatology* 61, 127-141, 1998 (left graph)
Gierens et al., A diagnostic study of the global distribution of contrails part II : future air traffic scenarios, *Theoretical and Applied Climatology* 63, 1-9, 1999 (right graph, under Fa1 development scenario of the IPCC)

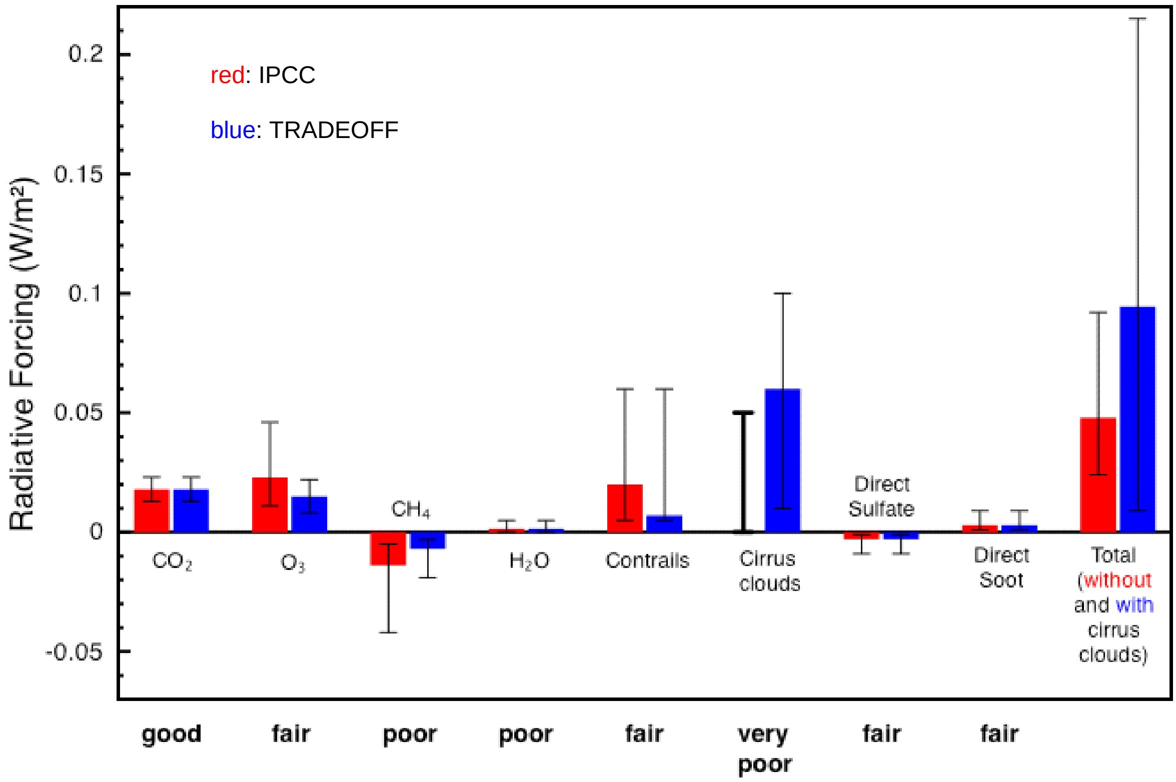
5.1.3. Total climate impacts from aircraft

The first global assessment of the total climate impact from the aviation sector was provided by the IPCC special report "Aviation and the global atmosphere" (1999).

The red bars in Figure 43 illustrate the results obtained for the total aircraft fleet in 1992, and includes direct (e.g. concentration increase in CO_2, H_2O, soot, etc.) or indirect climate effects (e.g. influence of NO_x emissions on methane destruction and ozone formation/destruction; formation of contrails and cirrus).

More recent results from European projects such as TRADEOFF (see blue bars in Figure 43) show that the estimation of the contribution to radiative forcing due to NO_x (via methane and ozone) and due to linear contrails has been lowered since IPCC 1999. This project gives a first best estimation for the radiative forcing due to spreading cirrus clouds which is similar in magnitude as the total of all other gases including CO_2. The uncertainty range for the cirrus (expressed with black error bars in Figure 43) remains very large, whilst that for other gases has been reduced.

Figure 43 : Relative importance of aircraft climate impacts (expressed in radiative forcing)



Source: adapted from Schumann 2005
"Formation, properties and climatic effects of contrails"
Comptes Rendus Physique 6 4-5, 549-565

5.1.4. Aviation and climate impacts: consequences for Belgium

Table 14 gives an estimation of the traffic in 2002 in the different considered areas (Belgium and Europe) as well as for aircraft taking off and landing (LTO) in these areas and those overflying it. Please note that these figures are only first estimations and are based on a number of assumptions that are detailed hereafter and are to be improved during phase II of this project.[66]

Table 14 : Relative importance of overflights above the Belgian territory and above the EU (2002)

Region	**Flight Distance** (million nm[67])	**Percentage of region movements**	**Fuel use >FL240** (Gg)	**Fuel use <FL240** (Gg)	**NO_x emitted** (Gg)

[66] Sources: Global and European figures: AERO2k and Eurocontrol, 2006; Belgian figures derived from Matheys et al., 2007
[67] 1 nm = 1,852 km

Belgium	147	100,0%	234	346	17
Belgium overflights	103	70,5%	225	184	12
Belgium LTO	44	29,5%	8	163	5
Europe	2.935	100,0%	12.427	9.272	287
Europe overflights	21	0,7%	152	~0	2
Europe LTO	2.914	99,3%	12.278	9.272	285
World	**17.720**	**100,0%**	**91.736**	**62.232**	**2.033**

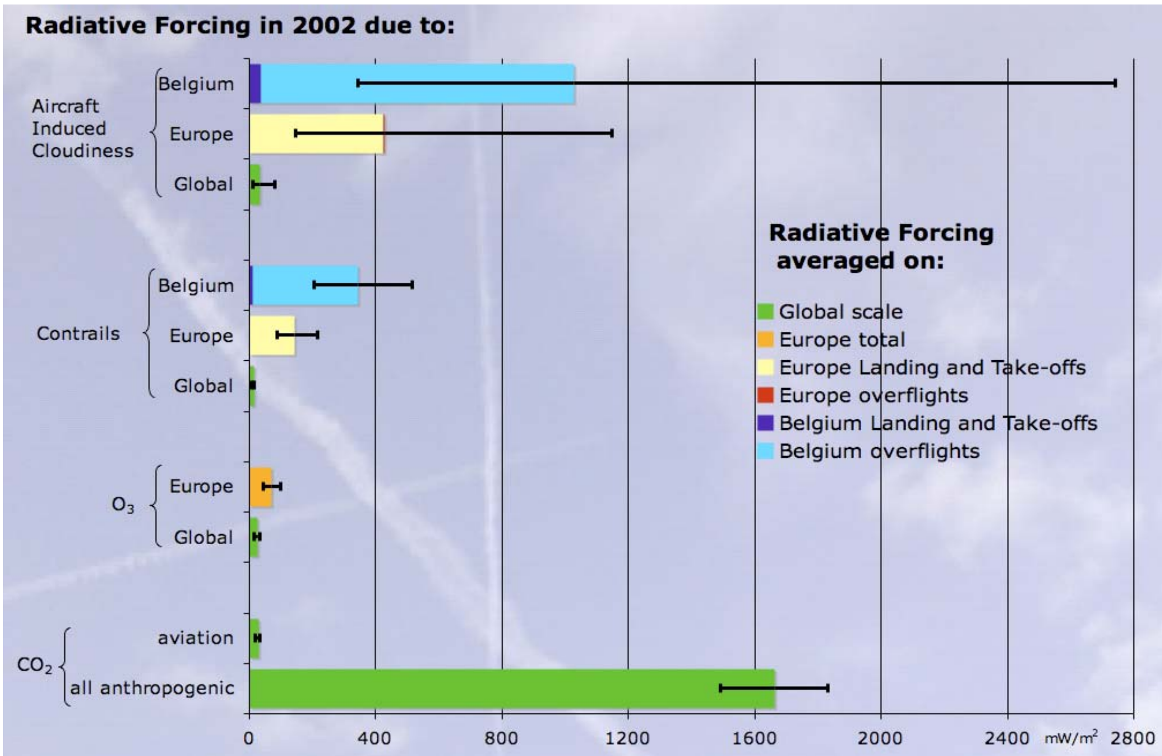
Source: ABC Impacts, 2007

The bar chart below gives the radiative forcing (RF) of:

- total anthropogenic CO_2,
- CO_2 emitted by aircraft,
- the RF of ozone produced by air traffic, contrails and aircraft induced cloudiness (AIC),
- an estimated likeliness range (error bars).

Where applicable, a distinction was made between the different regions considered (World, Europe, and Belgium).[68]

Figure 44 : Relative importance of Radiative Forcing induced by the aviation sector (2002)



Source: ABC Impacts, 2007

Calculations for RF of ozone and contrails/AIC (flight level (FL) 240 ~ 8000m):

$$RF_{O3,EU} = \frac{RF_{O3,glo}}{T_{O3,glo}} T_{O3,EU}$$

[68] Sources global RF O_3: Sausen, 2005 ; all other global RF: IPCC AR4

$$RF_{cont/AIC,EU/BE} = \frac{FuelUse_{EU/Be,FL>240}}{FuelUse_{glo,FL>240}} \frac{Surface_{glo}}{Surface_{EU/Be}} RF_{cont/AIC,glo}$$

Although this chart does only represent preliminary results of the ABC Impacts project based on certain hypothesis that need to be confirmed[69], it is interesting to note that the situation in Belgium is very different from that of Europe in general.

Whereas in Europe as a whole, overflights (without landing or taking off in any European airport) represent only a tiny portion of all flights (less than 1%), they represent the majority of the flights over the Belgian territory (~70%). This is reflected in the RF of contrails and AIC produced by these flights.

In Belgium the impact of LTO flights represent only ~4% of RF due to contrails or AIC as most of the flights taking off or landing in Belgium do not reach an altitude where contrails can be produced before leaving the Belgian airspace.

Belgium is thus submitted to important climate impacts (imbalance in radiative forcings inducing local temperature changes, enhanced cloudiness) from these flights that do not or barely contribute to the economy of the country (It is important to note that although the RF from AIC in Belgium is of the same order of magnitude than that of all anthropogenic CO_2, this does not imply that the temperature increase generated by these radiative forcing imbalances will be the same, as the climate system will be able to disperse the impact of such a strong local forcing).

One implication of this result is that it would be in the interest of Belgian policymakers to propose a strong mechanism to include the non-CO_2 gases, either within the Emissions Trading System or some parallel process.

A fixed multiplier of CO_2 as proposed in the initial draft of the EU-ETS does not actually provide an incentive to operators to reduce NO_x emissions or avoid supersaturated levels. The choice of multiplier (RFI, GWP, GTP, etc.) is also problematic as discussed below.

On the other hand, calculating the effect of each gas separately, depending on the actual weather conditions during each flight, would be too complicated in terms of data collection and processing.

Some compromise option may be needed, for example a variable multiplier calculated by a formula applied to each route (rather than each flight) dependent on technology, typical flight altitude, and operational measures to avoid cirrus formation. Meanwhile, it is important that the EU-ETS legislation leaves the door open to extensions to other gases. As risk is a combination of a probability and the extent of the associated impact, uncertainty does not mean that risk is low, as long as there is a significant probability that the effect will be large. Uncertainty is thus not a good reason to delay action and measures that contributes to action.

5.2. Climate modelling and the aviation sector (JCM5)

The Java Climate Model (JCM) model was created to investigate the relationship between emissions and climate under diverse and flexible scenarios. In particular, its interactive interface and rapid response enables users (both researchers and stakeholders) to quickly explore the sensitivity of results to a wide range of both policy options and scientific uncertainties.

The core science of JCM was based very closely on IPCC-TAR, and is now being updated to be consistent AR4. JCM has been developed within UCL-ASTR since 2002 (and earlier in DEA-CCAT Copenhagen, UNEP-GRID Arendal and KUP Bern), and has evolved to become a quite complex "integrated assessment" model.

The computational efficiency and flexibility required for its interactivity has also proved useful for probabilistic risk analysis. JCM has been applied in this way within the Belgian project ClimNeg II[70], as

[69] Sources: global RF O_3: Sausen, 2005 ; all other global RF: IPCC AR4
see also Calculations RF bar chart, Andrew Ferrone 2007

[70] http://www.econ.kuleuven.ac.be/ew/academic/energmil/climneg/

well as to the international project "Modelling and Assessment of Contributions to Climate Change" (MATCH[71]) and to analysis of the EU 2°C stabilisation target[72].

JCM is particularly suited to the evaluation of the diverse impacts of aviation on climate and their comparison with other sectors within this project, as there are a number of uncertainty sources and analysis criteria.

The relative effect of the short-lived gases compared to CO_2 is very dependent not only on scientific uncertainties, particularly aviation induced cloudiness (AIC) (as noted in section 5.1.3), but also on policy choices such as the timescale for integration, the spatial scale (regional vs. global) and scenario considered.

Therefore, whilst there is so little consensus, it is unwise to simply calculate and report our best-guess numbers regarding the magnitude of the climatic impact of aviation. Instead, developing an interactive model enables stakeholders as well as researchers to explore the sensitivity to the policy choices and uncertainties. Later we also anticipate applying this model to more systematic probabilistic analysis of aviation impacts on climate.

5.2.1. Modules

Two new modules have been added to the interactive Java Climate Model JCM5.

One module calculates global emissions from aviation and maritime transport (each split by domestic / international and industrialised / developing) from 1900 to 2100+, connecting various historical data sources (such as UNFCCC, IEA, etc.) and the range of "F" scenarios from IPCC SRAGA (1999).

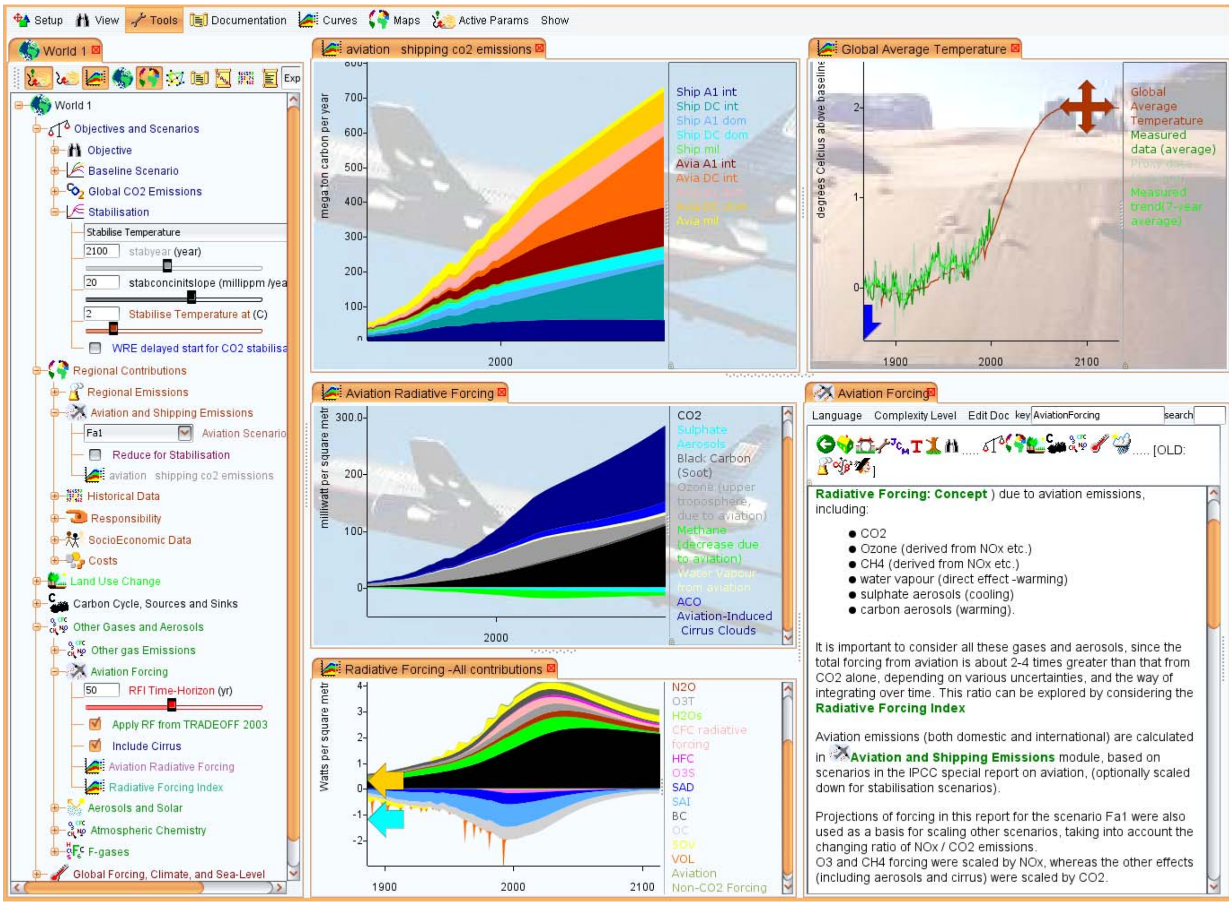
Regional emissions from other sectors are adjusted to retain the totals given by SRES.

To investigate scenarios to stabilise concentration or temperature (for example, the EU policy to limit warming below 2°C), an option is provided to scale down these international transport emissions – in this case aviation CO_2 emissions are reduced by the same fraction of the aviation baseline scenario as the total CO_2 emissions are reduced with respect to one of the SRES baselines.

NO_x emissions are derived using a time-varying NO_x / CO_2 ratio taken from the Fa1 scenario[73].

[71] see Den Elzen et al 2005
[72] Matthews and VanYpersele 2003
[73] IPCC SRAGA 1999

Figure 45 : Introduction to aviation emissions and radiative forcing, in the context of a 2°C stabilisation scenario



Source: Snapshot of the JCM model, please go the following site (www.climate.be/jcm/jcm5/wsjcm5_aviation.jnlp) to investigate other scenarios

A linked module calculates the changing radiative forcing due to aviation, from CO_2, O_3, CH_4, sulphate and carbon aerosols, water vapour, linear contrails and cirrus, based on either IPCC SRAGA (1999) or more recent TRADEOFF data[74].

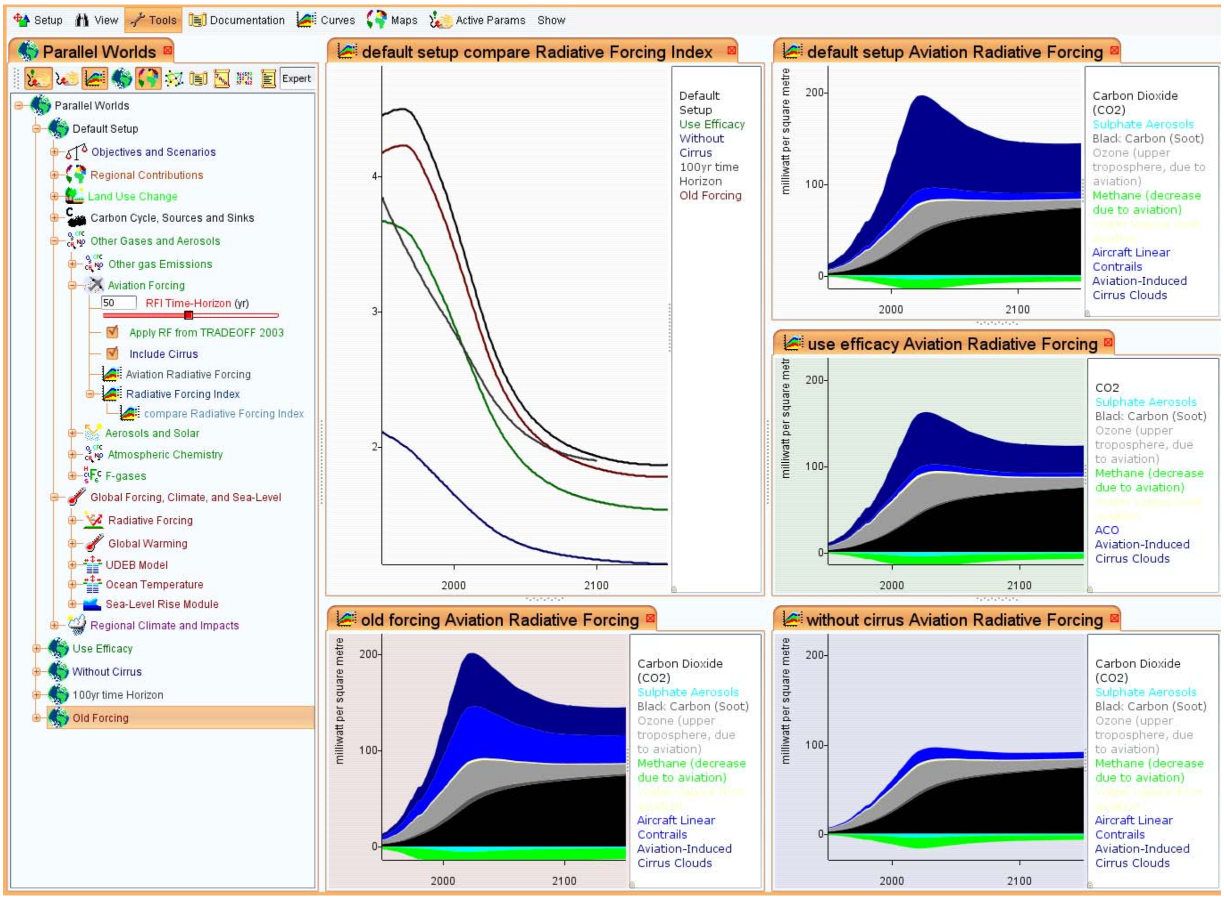
The accumulating aviation CO_2 concentration is derived using the nonlinear "Bern" carbon cycle model[75].

New "efficacy" factors[76] which adjust the relative global warming effect of gases according to the distribution of their forcing can optionally be applied. The aviation forcing feeds into the rest of JCM to calculate the effect on global temperature, sea-level etc., enabling exploration of the sensitivity to diverse scenarios and uncertainties. The effect of various options on the Radiative Forcing Index (ratio all-gases / CO_2 integrated over time) may also be explored.

The update of JCM core science has been partly updated to match IPCC AR4. As adapting simple climate models to 3D complex models that form the basis of AR4 proved challenging (see IPCC AR4 WG1 Appendix 10.A), this work is still in progress.

[74] Stordal at al 2005, Sausen et al 2005
[75] Joos et al. 1996
[76] Ponater et al 2005

Figure 46 : Effect of various options on the Aviation Radiative Forcing and the RFI



Source: Snapshot of the JCM model, please go the following site (www.climate.be/jcm/jcm5/wsjcm5_aviation.jnlp) to investigate other scenarios
Remark: "old forcing"= IPCC (1999), default is from Stordal (2005), without efficacy

5.2.2. Availability

This version of JCM5 is already available online, and can be launched easily with one click from a web browser, assuming that Java 5+ is installed.

To make it easier to find the new plots and parameters, a system has recently been developed to automatically set up the model settings and layout to illustrate a specific topic such as aviation. The aviation setup includes a documentation page linking to other examples, illustrating the changing mixture of radiative forcing from different aviation gases and also a variety of scenarios, both unmitigated within the context of the EU 2°C limit.

This aviation version can be launched directly from www.climate.be/jcm/jcm5/wsjcm5_aviation.jnlp. The general page www.climate.be/jcm/jcm5 may help to resolve any technical issues with java.

5.2.3. Model interface for stakeholder interaction

After each scientific addition to the interactive model JCM, further work must be done on the interface to make it simple enough for use by the general public – this is an iterative process, responding to user feedback. Significant efforts have been done to simplify user access, as reported above (section 5.2.2).

A separate interactive tool was also anticipated for calculating the marginal climate impacts of individual flights (or local policy initiatives), with options for routes, plane type etc. Feedback from users of a simple map-calculator at www.chooseclimate.org/flying has been gathered during eight years, but this tool now needs updating and extending. As a first step its code has been fixed to work with modern web browsers. Meanwhile, many similar simple "calculators" have recently appeared, mostly in association with the rapidly growing "offsets" market. Most of these do not take into account the non-CO_2 effects of aviation, except in some cases via a simple fixed multiplier, nor do they put the emissions in a long-term global context, thus our calculator is still a valuable tool.

The current challenge is to make something significantly better. An appropriate niche for continuing our project may be to illustrate the sensitivity to scientific assumptions and different metrics for other gases (as discussed above), and also placing the individual emissions in the context of global/European budgets consistent with climate stabilization targets. This may be done using a dynamic link to the more complex model JCM (as described above). A more ambitious variant could be to incorporate future options to mitigate impacts including technological / operational changes studied in other parts of this project, and also potential development of alternative modes of international transport (such as high-speed rail and shipping).

5.3. Introduction to the Regional Climate Modelling

As a large fraction of radiative forcing is acting on climate at the regional/local scale (compare Figure 42 and Figure 44), it is useful to investigate its effects with a regional climate model (RCM), focusing in particular on Europe. RCMs also include a more detailed representation of physical processes than coarser climate models, and are thus well suited for in-depth analysis of aviation impacts on clouds.

During a first step this study will focus on the study of the impact of condensation trails (contrails) and aircraft induced cloudiness (AIC) with a regional climate model, as these impacts are strongest on the regional and local scale.

Results are only anticipated for the second phase of the project, due to the relatively slow calculation speed of regional climate models (to simulate one year the model runs during approximately 24h on 16 processors, but for climate simulations a least 10 years are needed), the complexity of their parameterisation and validation, and the need for ensembles (ie. several runs) to identify clear signals above natural variability.

5.3.1. First runs with CCLM

At the start of the project a choice of model to be used had to be made. After a thorough study of the different models (e.g. Modèle Atmosphérique Régional: MAR ; Unified Model of Hadley Center: HadUM) that are freely available, our choice fell to CCLM[77], which is derived from the operational meteorological model (COSMO) of the "Deutscher Wetterdienst" (DWD).

The fact that this model has an explicit and prognostic representation of high altitude ice clouds and has also been validated over Europe[78] led us to this choice. Moreover this model was written in a way that it can run in parallel on several computer processors, which permits to reduce the "clock" time for a given simulation.

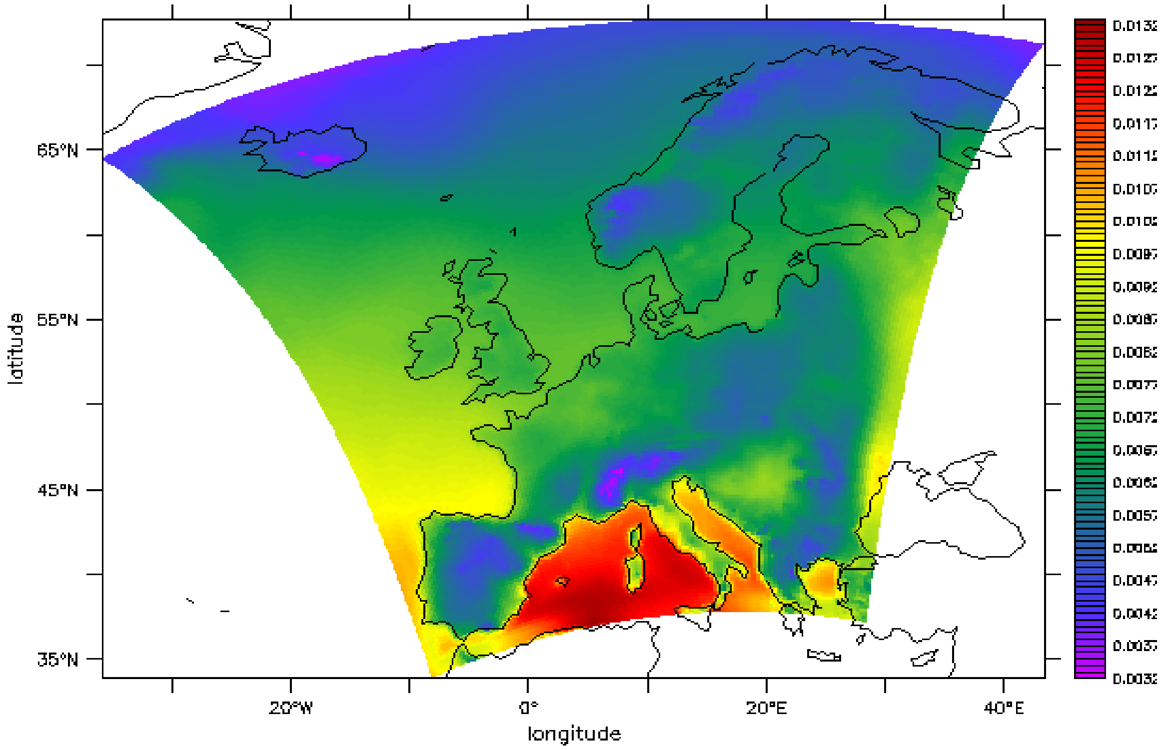
In the model, the humidity and temperature at high altitudes, which are crucial for this work, have been recently compared to radiosonde data[79] and the agreement in the high atmosphere is good. A more systematic validation with respect to satellite data (CM-SAF) is currently in preparation. In this project a validation of the model with a higher vertical resolution is planned which concentrates particularly on ice-supersaturation and cirrus clouds.

Figure 47 shows one example of the specific humidity as simulated with CCLM at a resolution of 0.22°x0.22° (~25x25km) forced by NCEP reanalysis. On this figure the influence of the topography

[77] Cosmo model in CLimate Model (Doms and Schätter, 1999).
[78] Böhm et al., 2006
[79] Brockhaus et al., 2008

can clearly be seen as well as a difference between humidity over sea and land surfaces (especially for the Mediterranean region).

Figure 47 : Monthly averaged surface specific humidity (in kg water/kg air) **for June 2005 as calculated by CCLM during a simulation for the year 2005, forced by NCEP reanalysis**

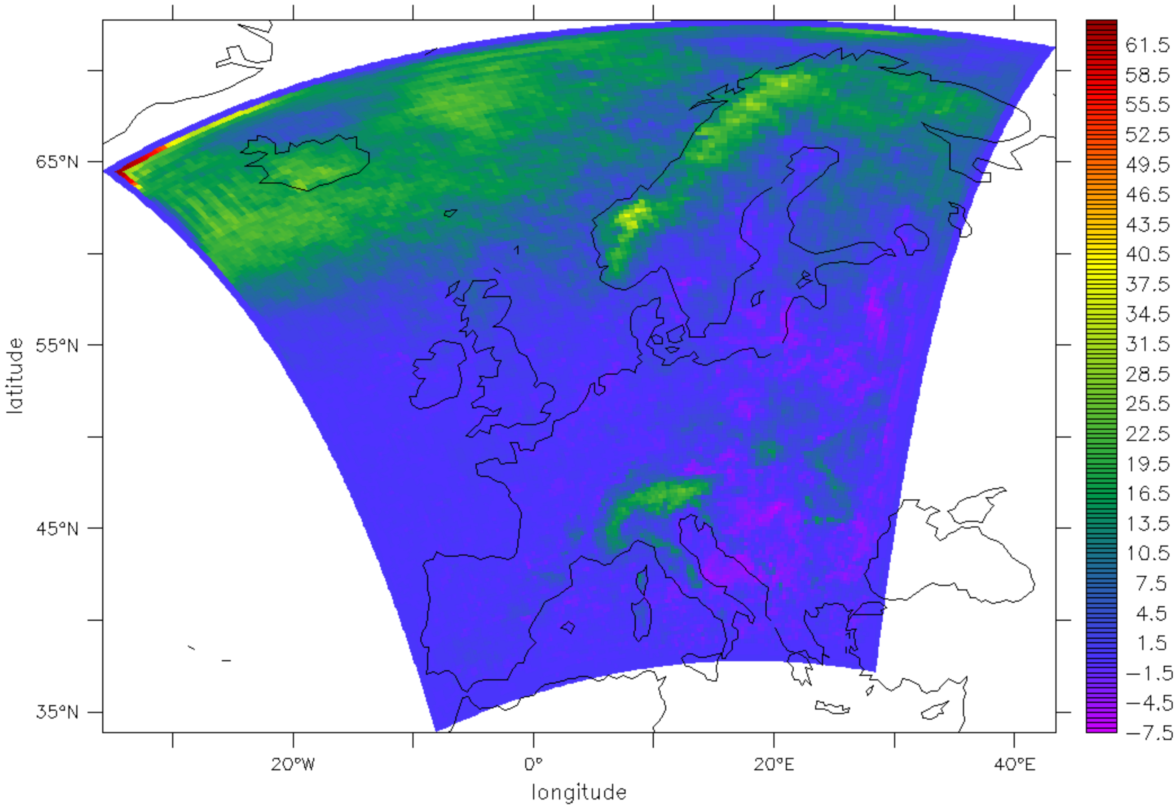


Source: ABC Impacts, ASTR calculations 2007

A first parameterisation of contrails has been introduced into the model. This approach transforms the water vapour emitted by aircraft (which is directly proportional to fuel use, see section 3.2.1) into ice clouds and simulates the water uptake by these clouds from the atmosphere (as contrails do mainly consist of water already present in the atmosphere). This parameterisation needs to be calibrated to reproduce observations.

Figure 48 shows a first preliminary result where a constant water vapour emission (an average value for Europe) has been introduced into the model at an altitude of 300 hPa (~9 km). This simulation is thus not based onto real observed flight paths. The figure shows the difference between the cloud cover at 300 hPa of a simulation with this parameterisation and a reference run, averaged over January 2005. The calibration has been done to reproduce the mean additional cloud cover by contrails as given by IPCC (1999) over Europe.

Figure 48 : Differences in cloud cover for a simulation with contrail parameterisation and a reference run, averaged for January 2005 (in % of cloud cover ; resolution of 0.22°x0.22° ~20kmx20km)



Source: ABC Impacts, ASTR calculations 2008

We can particularly observe a strong increase of cloud cover over Iceland and the Alps. These locations present a very low humidity and a relatively low natural cover of high clouds. As these are only preliminary results further investigation are needed to understand the processes that lead to this results and to conclude if they are realistic or not. However, it can be assumed that these features are specific to the month studied and will be less pronounced for longer simulations.

For the moment the impact of these changes on climatic indicators (such as for example surface temperature) have not been investigated as the changes are very small and need to be filtered out from natural variability (e.g. by longer simulations and ensembles studies).

6. THE MAMCA ANALYSIS

6.1. Evaluation methods used in transport projects

Several evaluation methods can be employed for the evaluation of transport related projects. Five common used evaluation methods can be identified, namely the private investment analysis (PIA), the cost effectiveness analysis (CEA), economic effects analysis (EEA), the social cost-benefit analysis (SKBA) and the multi criteria decision analysis (MCDA).

The private investment analysis (PIA) or private cost-benefit analysis takes the pure financial cost and benefits of the project into account. It is being executed from the point of view of the private or public investor and does not take more broad objectives into account.

The cost-effectiveness analysis (CEA) looks at the effectiveness of the measure in terms of the costs that government puts in. The CEA has thus a one criterion - one actor perspective. It looks at the effectiveness with regard to one specific goal.

The economic-effect analysis (EEA) or regional economic impact study (REIS) looks at the projects' impact on added value, employment and fiscal revenue. Input-output tables are used and indirect effects are captured through the use of multiplicators. The EEA is specifically designed for mapping of the government perspective and takes only three criteria of this particular stakeholder into account.

To conclude, it can be stated that the private investment analysis (PIA), the cost effectiveness analysis (CEA) and economic effects analysis (EEA) are not interesting if stakeholders have to be included into the analysis.

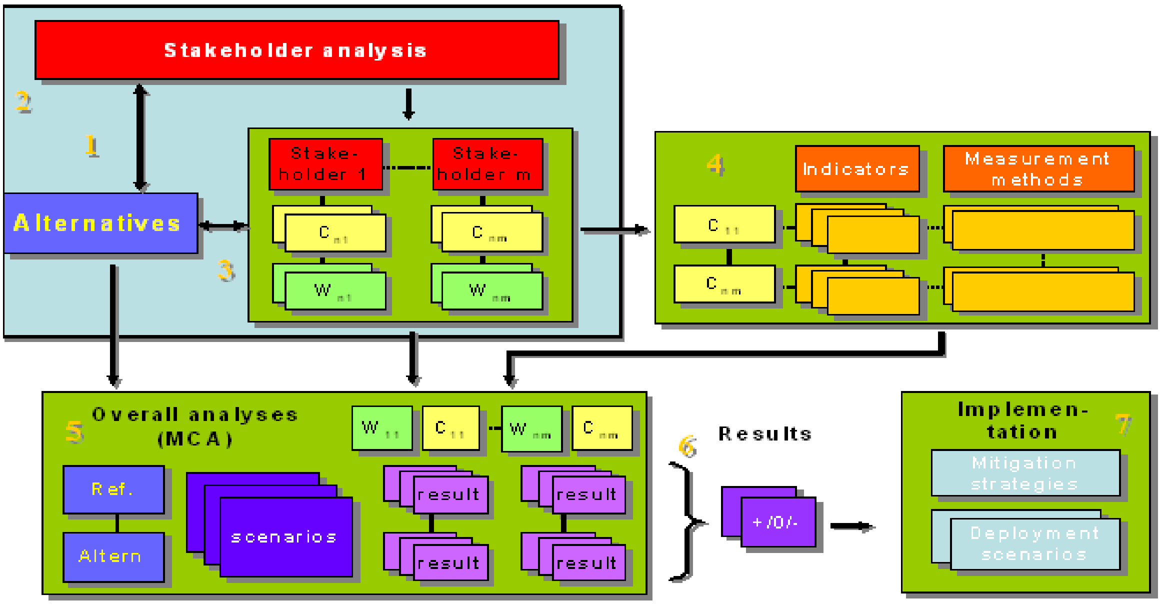
The social cost benefit analysis (SCBA) is grounded in welfare theory. It takes a wider societal perspective and in this sense it can also include the external costs of transport into the analysis. It is mainly used when there are only a few possible alternatives to be examined. A discount rate is used to calculate the net present value and the internal rate of return of the project. All the costs and benefits have to be expressed in monetary terms. Some of the external effects of transport are difficult to assess and translate in monetary terms. The SCBA is based on the compensation criterion. The introduction of a stakeholder analysis in a SCBA is in principle possible if the costs and benefits are structured according to the stakeholders. So for each stakeholder the costs and benefits would be listed and calculated. However, in the end of the process the costs of one stakeholder can be compensated by the benefits of another. The redistribution effects are not clearly coming out of such an analysis. This problem can be avoided by creating an end table per stakeholder so as to get a cost-benefit analysis of the project per stakeholder. The problem of monetarisation will however exclude many more subjective or qualitative costs or benefits from the analysis.

The multi criteria decision analysis (MCDA) provides a framework to evaluate different transport options on several criteria. The concept of stakeholders was first introduced in MCDA by Banville et al. (1998). As denoted by them, the multi criteria analysis is useful for the introduction of the stakeholder concept. In their paper, a first framework for the introduction of the concept of stakeholders is introduced. They argue that certainly in the first three stages of a multi criteria analysis the concept of stakeholders can enrich the analysis, but they do not include the stakeholders within the methodology further on. The multi actor multi criteria analysis on the other hand does incorporate stakeholders in all stages of the analysis.

6.2. The multi stakeholders multi criteria analysis evaluation framework

The methodology consists of seven steps (see Figure 49). The first step is the definition of the problem and the identification of the alternatives (**step 1**). The various relevant stakeholders are then identified as well as their key objectives (**step 2**). Secondly, these objectives are translated into criteria and then given a relative importance (weights) (**step 3**). For each criterion, one or more indicators are constructed (e.g., direct quantitative indicators such as money spent, number of lives saved, reductions in CO_2 emissions achieved, etc. or scores on an ordinal indicator such as high/medium/low for criteria with values that are difficult to express in quantitative terms, etc.) (**step 4**). The measurement method for each indicator is also made explicit (e.g. willingness to pay, quantitative scores based on macroscopic computer simulation, etc.). This enables the measurement of each alternative performance in terms of its contribution to the objectives of specific stakeholder groups. **Steps 1 to 4** can be considered as mainly analytical, and they precede the "overall analysis", which takes into account the objectives of all stakeholder groups simultaneously and is more "synthetic" in nature. Here, an evaluation matrix is constructed aggregating each alternative contribution to the objectives of all stakeholders (**step 5**). The MCDA yields a ranking of the various alternatives and gives the strong and weak points of the proposed alternatives (**step 6**). The stability of this ranking can be assessed through a sensitivity analysis. The last stage of the methodology (**step 7**) includes the actual implementation.

Figure 49 : MAMCA scheme



Source: Multi actor multi criteria analysis (MAMCA), Macharis 2004

6.2.1. Define alternatives

The first stage of the methodology consists of identifying and classifying the possible alternatives submitted for evaluation. These alternatives can take different forms according to the problem situation. They can be different technological solutions, possible future scenarios together with a base scenario, different policy measures, long term strategic options, etc. There should be at least two alternatives to be compared. If not, a social cost benefit analysis might prove to be a better method for the problem.

6.2.2. Stakeholder analysis

In step 2 the stakeholders are identified. Stakeholders are people who have an interest, financially or otherwise, in the consequences of any decisions taken. An in-depth understanding of each stakeholder group's objectives is critical in order to appropriately assess the different alternatives. Stakeholder analysis should be viewed as an aid to properly identify the range of stakeholders to be consulted and whose views should be taken into account in the evaluation process. Once identified they might also give new ideas on the alternatives that have to be taken into account.

6.2.3. Define criteria and weights

The choice and definition of evaluation criteria are based primarily on the identified stakeholder objectives and the purposes of the alternatives considered. A hierarchical decision tree can be set up. Several methods for determining the weights have been developed. The weights of each criterion represent the importance that the stakeholder allocates to the considered criterion. In practice the pair-wise comparison procedure proves to be very interesting for this purpose. The relative priorities of each element in the hierarchy are determined by comparing all the elements of the lower level in pairs against the criteria with which a causal relationship exists. The applied multi actor multi criteria analysis method and software (see step 6) allow an interactive process with the stakeholders in order to perform a sensitivity analysis.

6.2.4. Criteria, indicators and measurement methods

In this stage, the previously identified stakeholder criteria are "operationalized" by constructing indicators (also called metrics or variables) that can be used to measure whether, or to what extent, an alternative contributes to each individual criterion. Indicators provide a "scale" against which a project's contribution to the criteria can be judged. Indicators are usually, but not always, quantitative in nature. More than one indicator may be required to measure a project's contribution to a criterion and indicators themselves may measure contributions to multiple criteria.

6.2.5. Overall analysis and ranking

The MCDA method used to assess the different strategic alternatives can be any MCDA-method. Most of the cases discussed below are analysed with the Analytical Hierarchical Process (AHP). This method, described by Saaty (1988), allows to build a hierarchical tree and to work with pair-wise comparisons. The consistency of the different pair wise comparisons as well as the overall consistency of the whole decision procedure can easily be tested in AHP that can handle both quantitative and qualitative data, the latter being very important for transport evaluations. Certain criteria in transport concern ecological impact or road safety issues. On the one hand, these criteria are difficult to quantify, but on the other hand the method is relatively simple and transparent to decision makers and to the public. The method does not act like a black box since the decision makers and the stakeholders can easily trace the way in which a synthesis was achieved.

6.2.6. Results

The multi criteria analysis developed in the previous step eventually leads to a classification of the proposed alternatives. A sensitivity analysis is performed in this stage in order to see if the result significantly changes when the weights are changed. More important than the ranking, the multi criteria analysis allows revealing the critical stakeholders and their criteria. The multi actor multi criteria analysis provides a comparison of different strategic alternatives and supports the decision maker in making his final decision by pointing out for each stakeholder which elements have a clearly positive or a clearly negative impact on the sustainability of the considered alternatives.

6.2.7. Implementation

When the decision is made, steps have to be taken to implement the chosen alternative by creating deployment schemes. This implementation process can be complemented by a cost-benefit analysis for well defined projects.

Different examples of the successful use of the MAMCA methodology in the transport sector are available on the website of the ABC Impacts project: Synthesis Multi Actor Multi Criteria Analysis Methodology.

7. INTERMEDIARY RESULTS, PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

7.1 Through important innovative adaptations the aviation sector succeeded in implementing an important reduction of the emissions (CO_2, H_2O, Soot, CO, SO_x, NO_x, etc.) and fuel consumption of individual aircraft. However, the **reductions of the emissions (fuel consumption decreases by 0,5% - 2% per year) are less than the high growth rate of the sector** (average of 6,4% per year between 1991 to 2005, European Commission).

In the future several improvements are to be expected. In the long term some radical changes (like the use of hydrogen as a fuel for aircraft) might occur. In the meantime some other technological evolutions are to be expected (implementation of synthetic fuels, biofuels, etc.) all of which present some specific strengths and weaknesses. Some other innovative concepts have recently been presented (adapted rear turboprop mounting, adapted empennage and air frame, improved aerodynamics...) and form promising options for the future.

7.2 On the other hand, some **sector management changes** (improved ATM, implementation of the Single European Sky, Reduced Vertical Separation Minimum (which is already largely implemented), Continuous Descent Approach…) might reduce the impact of aviation on climate by more than 10% without the need for new technologies to be implemented onboard and without the delay that is necessary for fleet renewal when new technologies are implemented.

7.3 The Belgian aviation market has a very specific position within Europe due to its geographical situation; in the middle of the so-called FLAP area which is demarcated by the four main airports of Europe: Frankfurt, London, Amsterdam and Paris. This also implies that the **number of overflights is already considerable through Belgian airspace and could become even more important due to the sectoral growth and potential route adaptations** (according to Statfor-Eurocontrol, the adoption of shorter routes could increase overflights above the Belgian territory by 10%).

7.4 Furthermore Belgium has a specific situation regarding the way the airports are managed. There is one national Airport, Brussels Airport which is privatized, there are two regional airports in the Flemish region (Ostend, Antwerp) which are now operated by the regional government but for which privatization plans exist and, in Wallonia there are two regional airports (Liège, Charleroi) operated by the regional government which operate in specific niches, express cargo and low cost, and have known a spectacular growth in the past ten years.

Due to the very complicated structure of the Belgian aviation business, it is of great importance to obtain data from a reliable source in order to make predictions and to forecast further evolutions.

7.5 A key factor to be taken into account in the project concerns **the time horizons** at different levels :

- As regards policy options, time horizons are determinant concerning the time needed before the real implementation of the selected policy measure or before the first significant results (e.g. decreasing of CO_2 emissions). These time horizons strongly determine the environmental efficiency and socio-economic impacts of the selected policy measure.
- As regards climate impacts of the aviation sector, it has to be noted that emissions causing regional impacts such as contrails, cirrus formation or change in the ozone concentration (induced by NO_x emissions) have a shorter term of action compared to emissions responsible for global warming. On a short term horizon, regional climate impacts of the aviation sector are proportionally more important, while on a longer term horizon, the balance of the climate impacts of aviation between regional and global impacts is reversed.
- As regards development scenarios, it is quite impossible to determine a market development scenario longer than 20 years, even a period of 10 years is already quite difficult considering the rapid pace of change in this sector. Nevertheless, climate modelling researchers need scenarios on global emissions for a period of time of more than 50 to 100 years. It is indeed essential to consider aviation within the context of stabilisation scenarios

considering a 50 years time horizon – anticipating substantial changes in technology, operations, infrastructure, modal-shift and demand management.

The research team will have to be very careful with the hypotheses to choose for the reference scenario in phase II in order to keep a coherent view along the time scale.

7.6 The **role of ozone and cirrus clouds**, especially for regional climate, is fundamental and so operational measures to reduce them should be considered, despite remaining uncertainties. This is especially important as tradeoffs are to be found between the different impacts. In general a reduction of CO_2 emissions for an engine induces an increase in NO_x emissions, thus producing more ozone. Also it is shown that more fuel efficient engines produce more contrails at higher temperature (i.e lower altitudes).

7.7 It is important to note that on the one hand the impacts of the Belgian aviation sector on global climate change will be relatively small compared to other sectors or other countries (Belgium's contribution to aviation **emissions** is not particularly remarkable), but that on the other hand regional climate impacts due to contrails, cirrus formation and change in the ozone concentration could have a large influence on the country (not specifically on average temperature but more on sunshine and possibly on precipitation, but these effects need further investigation in the second phase of the project) because of the concentration of flights over the Belgian territory. **One focus for Belgian policy makers could be to reduce the impacts from transit aviation**, especially via operational measures targeting non-CO_2 gases, as well as shift to other transport modes.

7.8 It would be essential to gather **statistical official data** on the quantity of fuel present in tanks at the arrival of the aircraft/ship on the Belgian territory or to collect official data on fuel consumption related to specific trips from or to Belgian airports/ports to be able to measure emissions of the sector that will be covered by the EU-ETS.

7.9 As regards the analysis of the different **studies on policy options** to take into account climate impacts from the aviation and maritime transport sectors, it appears that **impact assessment** is generally limited to the estimation of the change in demand for transport (e.g. % of reduction in demand for air travel) performed with the help of widely simplified assumptions. Taking into account the market segmentation of the aviation sector and internal market dynamics, it is not possible to assess the environmental efficiency (e.g. how to translate the % of reduction in demand for air travel in a % of change in aircraft movements / aircraft emissions?) or the socio-economic impacts of policy options on the basis of such general data.

An in-depth market analysis is thus essential to be able to assess more realistically the impacts of policy options mainly because of the thought that policy options are closely related and even intertwined with evolutions in the aviation market.

7.10 Moreover, as regards the current European Commission proposal to include aviation in the EU-ETS, it is important to note that the bottom limit of 5.700 kg MTOW will not be able to cover the new "**very light jets**" that are predicted to enter the market in the coming years. Those aircrafts will not represent a major part of the emissions of the sector but they are expected to rapidly increase their market share as price competitive business jets and, what's new and important for this segment of the market, they will be able to fly at high altitude and will therefore increase the climate impacts due to non-CO_2 emissions. Modifications of the proposal or complementary policy tools are needed to tackle those aspects (very light jets, aviation non-CO_2 climate impacts), which are not part of the current proposal, in order to make sure that no market distortion occurs (e.g. competition within the business aviation between lighter and heavier aircrafts) and that all polluters contribute to the mitigation effort.

7.11 As regards the **database on aviation emissions**, there are many different aircraft models and engines. It was decided to work with aircraft families or type aircraft as in most of the aviation projects in Europe (AERO2k, EMEP/Corinair, etc.) and to use type engines (this last simplification has no real influence on CO_2 emissions because the fuel efficiency of engines are quite similar for economic reasons but concerning other emissions such as NO_x, it will be necessary to perform a sensitivity analysis or to implement some intervals of results because results might vary from one engine to the other.

7.12 The growing contribution of aviation should also be considered within the constraint of the **EU policy to limit global temperature rise below 2°C**. Unmitigated growth in aviation emissions would substantially reduce the emissions budget available to other sectors, especially when the climatic effects of ozone and cirrus clouds are considered.

7.13 As the ratio of the global climate impact of all aviation gases compared to CO_2 alone remains a key policy-relevant question, JCM was used to explore the sensitivity of this ratio to both scientific and policy choices. Although it can be misleading to use a single factor to compare the effect of gases whose distribution over both time and space differs so widely, nevertheless such indicators are often discussed. Some key results are that:

- the RFI is still in the range from 2 to 4, depending on whether cirrus clouds are included (which raise RFI substantially, but were excluded by some other studies due to high uncertainty) and whether efficacy factors are used (which tend to lower RFI)
- the RFI is scenario dependent, and will decrease over time, especially in stabilisation scenarios which include mitigation of aviation, as future emissions of short-lived gases will be lower relative to accumulated CO_2.

We are aware that the use of RFI (used in IPCC SRAGA) is inconsistent with the GWPs used to compare Kyoto gases, and that other potential indices, such as Global Temperature Potential[80], may be more appropriate. GTP could be derived by adapting the existing attribution module to work for sectors rather than countries (this module was developed for the ACCC/MATCH model inter-comparison regarding relative contributions of countries to climate change, taking into account several gases and non-linear cumulative cause-effect relationships)

Calculation of GTP should also take into account climate-carbon cycle feedback processes (for example warming increases soil respiration and wildfires, and alters the balance of ocean chemistry), which are already incorporated into JCM. This would show the extent to which emissions of short-lived gases such as aviation NO_x and contrails may indirectly lead to further emissions of long-lived CO_2, and thus a more prolonged warming impact.

7.14 In a stabilisation scenario in JCM, future aviation emissions may either be scaled down consistently with other sectors as described above, or left unmitigated to show the consequence of continuing to exempt this sector from the climate policy. In the latter case, since the total temperature rise is still constrained by the European policy to limit warming below 2°C, emissions from other sectors are reduced accordingly. Some preliminary model results:

- in a scenario limiting global temperature rise to 2°C (EU policy), but with unmitigated aviation (Fa1), aviation (including CO_2, ozone, cirrus etc.) adds about 15-20ppm CO_{2eq} in 2050
- to compensate for this unmitigated aviation forcing, CO_2 emissions from all other sectors must be about 30% lower in 2050, in order to reach the 2°C target.

Such numbers are, however, highly dependent on many uncertain factors, not only regarding aviation emissions and forcing, but also the time-profile of the emissions pathway, the carbon cycle, the climate sensitivity, etc. JCM can be used to explore these factors both in an interactive mode, and also to make a more systematic probabilistic analysis covering thousands of combinations.

7.15 Regarding the selection of stakeholders for the multi-criteria analysis in WP7, although the Belgian share of aviation climate impacts is larger than our share of aviation emissions, it is much harder to identify specific stakeholders to represent the effects of aviation-specific regional climate impacts (such as reduced sunlight) since these effects are widely dispersed among the population, and also poorly understood. Consequently it is left to researchers to also represent the climate viewpoint. It is noteworthy that considering the agreed EU policy to limit the global

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average temperature rise to 2°C, a growing share of emissions from the aviation sector requires further reductions in other sectors, which could also therefore be better represented in the future.

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