Towards a Global Market-Based Measure for the Aviation Industry

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TUDelft

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For once you have tasted flight you will walk the earth with your eyes turned skywards, for there you have been and there you will long to return.

Leonardo da Vinci

Preface

Today's developed world is a very materialistic one. For different reasons people buy new cars, televisions, smartphones, clothes, and much more. Nevertheless, over the past decade an abundance of psychological research has shown that experiential purchases provide more enduring happiness. The reason behind this is the accruing benefit before and the nostalgic longing afterwards. Besides, the fleetingness of the experience is actually what endears us to them. As James Hamblin, editor at *The Atlantic* phrases it: "*Either they're not around long enough to become imperfect, or they are imperfect, but our memories and stories of them get sweet with time. Even a bad experience becomes a good story*".

Personally, flying has enabled me to see things which I would not have seen otherwise. These experiences have opened my eyes and developed me as a person. However studying at the TU Delft has also shown me the environmental burden and challenges in solving this issue. As a solution, some environmental studies on aviation have suggested policies that significantly reduce demand in order to halt growth of the sector. However I am not an advocate of those policies for mainly two reasons. First, it is unlikely such a policy is politically feasible in the short-to-medium term. Second, affordable aviation is an enabler in broadening our perspective of the world, allowing us everlasting experiences.

In fact, I would rather see growth of the sector due to more affordable aviation, enabling people in developing countries to fly as well. I envision a world in which planes use solar power in combination with high-capacity batteries and advanced biofuels to power their engines. However the road towards sustainable aviation is long and requires effective global policies to stimulate that transition. I sincerely believe that a global market-based measure could be the first step towards this goal. It would be a significant milestone in international climate negotiations being the world's first global sectoral cap on carbon pollution. Reaching agreement on implementing this global policy would open the doors for future international policies in both the aviation sector and beyond.

For readers with in-depth knowledge it is recommended to certainly not skip chapters 6, 8, 9, and 10. For the hasty reader it may suffice to read chapters 6 and 9 combined with the executive summary.

Maurice Quintin Quant
- Delft, October 2015

Friends show their love in times of trouble, not in happiness.

Euripides

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In front of you lies a thesis which is the result of seven months of work concluding my Master of Science in Systems Engineering, Policy Analysis, and Management at the TU Delft. It has been a challenging time and I certainly would not have been able to make it without the support of many. Therefore I would like to extend my gratitude to a number of people – from the TU Delft, Ecofys, and personal circles - that have helped me during the process of writing this thesis.

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I also wish to extend my gratitude towards prof. dr. Kornelis Blok, who four years ago during the World Renewable Energy Congress in Sweden, opened my eyes about how to translate academic knowledge into work by introducing me to the world of energy-consulting. He has also shaped me towards being a more optimistic and constructive environmental researcher.

In addition, I am grateful to Wouter Bakker MA for making me feel at home at Ecofys, guiding me throughout the whole process, and showing me that there are certain things in life which are more important than everything else. I am wishing you and your family all the best with your soon to be born child.

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I dedicate this work to a former teacher of mine and first Dutch astronaut, the late Wubbo Ockels, who left the inspiring message: "*we all are astronauts of spaceship earth*".

Maurice Quintin Quant
- Delft, October 2015

We cannot solve our problems with the same thinking we used when we created them.

Albert Einstein

Executive summary

The aviation industry is vital for economic growth, world trade, and is a major employer. Nearly \$2.4 trillion in global GDP, 35% of world trade by value and 58.1 million jobs are supported by the industry. However, with these benefits comes an impact on the environment. In 2013, aviation produced 705 million tonnes of carbon dioxide, approximately 2% of anthropogenic CO_2-emissions. With air traffic projected to grow by 4-5% per annum in the coming decades, this raises the question of how sustainable growth can be achieved in the aviation sector and the need for regulatory measures.

In 2013 the International Civil Aviation Organization (ICAO) adopted a Resolution in which it was decided to develop a global market-based measure (MBM). From 2020 onwards this measure - a global levy, global emissions trading, or global mandatory offsetting - would regulate carbon dioxide emissions from international aviation. However whether the measure will in fact be implemented depends for a large share on ICAO's next General Assembly in 2016, where the 191 Member States will vote on adopting the measure. Their decision will greatly depend upon whether the global market-based measure matches their interests and agenda. Therefore the design of the global MBM is crucial in ensuring adoption and implementation. In order to reach political consensus by 2016, this thesis has focused on how a robust global market-based measure can be designed by showing the design process to arrive at the robust global market-based measure, and applying this design process. The following *four principles of robust design* were defined: (i) legal feasibility, (ii) political viability, (iii) purposefulness, and (iv) sturdiness.

THE DESIGN PROCESS
The *design process* towards a robust global market-based measure consists of four phases. During the *exploration phase* the design space is identified, and by means of a literature review criteria can be found on which aviation environmental policies are to be assessed. A legal and stakeholder analysis should then be used to demarcate the design space and redefine the criteria such that they are specific for assessing the global MBM. Subsequently, the *design phase* builds upon the demarcated design space and allows for the construction of different designs by varying in design elements that have not been decided upon by the policy-maker. During the *analysis phase* the constructed designs are then to be tested upon the redefined criteria. By means of a *marginal abatement cost curve in combination with a simulation model* the commensurable criteria can be assessed while accounting for uncertainty. Lastly, the *interpretation phase* concludes whether a robust design is achieved, and provides recommendations and a critical reflection upon the results.

THE FOUR GLOBAL MANDATORY OFFSETTING DESIGNS
By means of a legal and stakeholder analysis is found that only a global mandatory offsetting scheme satisfies the principles of *legal feasibility* and *political viability*. The Global Aviation Dialogues in April 2015 showed the initial design elements of a global mandatory offsetting

scheme in which a number of design elements seem decided. Based on a literature review and qualitative analysis this thesis has built upon the ICAO Strawman by adding the missing design elements; forming the first design in this thesis. Since stakeholders' preferences misalign with regard to reflection of the UN's *Common But Differentiated Responsibilities* principle and a revenue generation mechanism, these design elements were used to construct the consecutive three designs. As such, the three designs show below include either elements, or both.

I. Strawman
This design is an extension of ICAO's Strawman and is therefore based on maintaining carbon-neutral growth from 2020 onwards. The choice of pollutant is CO_2-emissions and the respective type of flights are those from the international passenger and cargo markets. Furthermore compliance and enforcement shall happen through an Assembly Resolution and standards. Based on a qualitative analysis a number of design elements were added to ICAO's Strawman. These include that the allocation of requirements shall occur through grandfathering based on a benchmarking approach, that the use of offsets is restricted to only those offsets which are of high-quality, additional, and permanent, and that administration and monitoring shall occur by means of a body under ICAO, ICAO Member States, and aircraft operators.

II. Differentiating Responsibilities
This design is an extension of the Strawman and includes a phased-in route-based approach. The differentiation criterion is the maturity of aviation markets and it is proposed to include three consecutive phases within the global MBM. Phase 1 (2020-2023) includes all ECAC Member States, plus the top 10 States ranked by international activity. Phase 2 (2024-2026) includes the next 10 States, after which Phase 3 (2027-2050) include all ICAO Member States.

III. Revenue Generation
This design is an extension of the Strawman and includes a revenue generation mechanism for the purpose of mitigating aviation's environmental impact. It is proposed to that aircraft operators pay a transaction fee for each purchased offset, starting from 1 USD/tonne CO_2 in 2021 and increasing by 50 dollar cents per year. It is suggested this revenue stream flows into an Aviation Innovation Fund. This fund can be used to financially support research that helps in mitigating aviation's climate impact.

IV. Synthesis
This design combines all design elements from the previous three designs.

GLOBAL MANDATORY OFFSETTING SCHEME BASED ON DIFFERENTIATING RESPONSIBILITIES
The four global mandatory offsetting designs described above have been analyzed using a multi-criteria decision analysis. Based on this analysis, it is recommended ICAO uses the Differentiating Responsibilities design in this thesis as a framework for the global market-based measure in order to increase the likelihood of reaching political consensus by 2016. The corresponding design elements are presented below.

i. The design's foundation is a global mandatory offsetting scheme.
ii. The design focuses on carbon-neutral growth from 2020 onwards.
iii. The design concerns the international passenger and cargo markets.
iv. The design incorporates allocation of requirements through grandfathering based on a benchmarking approach.
v. The design includes an offset standard that restricts the use of offsets which are of high-quality, additional, and permanent.

vi. The design includes administration and monitoring done by a combination of a body under ICAO, ICAO Member States, and aircraft operators.

vii. The design shall be legally enforced by an Assembly Resolution and standards.

viii. The design includes a phased-in route-based approach that consists of the following three phases: Phase 1 (2020-2023), Phase 2 (2024-2026), and Phase 3 (2027-2050). The differentiation criterion should be the maturity of aviation markets.

ix. The design is flexible in the sense that including a revenue generation mechanism during the negotiation process at ICAO or after the global MBM's implementation is be possible.

Based a Monte Carlo simulation it is found this design yields the mean results for the period 2020 until 2050 shown below. These numbers should however be interpreted with care due to high uncertainty with regard to the business-as-usual civil aviation emissions, offset price, marginal abatement costs of biofuels and the availability of biofuels.

i. A cumulative CO_2-abatement potential of *16.5 GtCO₂*

ii. The share of in-sector emission reductions through infrastructural, operational, and technological improvements equals *55%*, while the rest of the abatement occurs through the use of offsets, *45%*.

iii. The cumulative costs of the emission reductions equal *353 bln USD*.

iv. On the short-to-medium term the annual costs of the global market-based measure for the aviation sector equal:
   – By *2025*, the costs equal *0.5 bln USD*   (0.05% of forecasted revenue)
   – By *2030*, the costs equal *3.8 bln USD*   (0.35% of forecasted revenue)
   – By *2035*, the costs equal *8.7 bln USD*   (0.66% of forecasted revenue)

v. The market distortion effects imposed by the global MBM are minimal both on the passenger transportation and cargo market.

ADDITIONAL POLICY RECOMMENDATIONS FOR ICAO

In anticipation of the COP21 in Paris, December 2015, this thesis has reflected upon whether the proposed global mandatory offsetting scheme would be in line with limiting the global temperature increase to 2°C by 2050. The following additional policy recommendations are provided to further increase the climate integrity of the scheme.

i. Since the global MBM only covers international aviation emissions, the design should be compatible with regional or national market-based measures that cover aviation.

ii. The design should allow States to make voluntary commitments when it is based upon a phased-in route-based approach.

iii. Since carbon-neutral growth is not sufficient in reaching the 2°C-target, ICAO should, after adoption of the global MBM, try to find political support for the design alteration of annually decreasing the emission baseline from Phase 2 onwards (2024).

iv. ICAO should further investigate the climate impact of non CO_2-emissions and, after the global MBM's implementation, consider the design alteration of changing the objective towards *Climate-Neutral Growth* or *Zero-Climate Impact*.

Beyond the fork, down either path, is the end of the world as we have known it. One path beyond the fork continues us on our current trajectory. Presidential science adviser John Gibbons used to say with a wry smile that if we don't change direction, we'll end up where we're headed. And right now, we're headed toward a ruined planet. That is one way the world as we know it could end, down that path and into the abyss.

But there is the other path, and it leads to a bridge across the abyss. We have been examining this bridge at the edge of the world and what is required to cross it. Of course, where the path forks will be the site of another struggle, a struggle that must be won even though we cannot see clearly what lies beyond the bridge. Yet in that struggle and in the crossing that will follow, we are carried forward by hope, a radical hope, that a better world is possible and that we can build it. "Another world is not only possible. She is on her way," says Arundhati Roy. "On a quiet day, I can hear her breathing." [...]

- James Gustave Speth
The Bridge at the Edge of the World: Capitalism, the Environment, and Crossing from Crisis to Sustainability
(2008)

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Acronyms and abbreviations

ACF	Advisory Group on Climate Financing
ADP	Ad Hoc Working Group on the Durban Platform for Enhanced Action
AEA	Association of European Airlines
ATAG	Air Transport Action Group
BA	British Airways
BAU	Business-as-usual
BSA	Bilateral Air Service Agreement
CAEP	Committee on Aviation Environmental Protection
CBDR	Common But Differentiated Responsibilities
CDM	Clean Development Mechanism
CER	Certified Emissions Reductions
CNG	Carbon-neutral growth
COP	Conference of Parties
DIF	Differentiating Responsibilities
EAG	Environmental Advisory Group
EEA	European Economic Area
ETS	Emissions Trading Scheme
EU	European Union
EAU	European Union Emissions Allowance
ERU	Emission Reduction Units
FTK	Freight Tonne Kilometers
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Greenhouse gas
GLAD	Global Aviation Dialogue
GMTF	Global MBM Task Force
GWP	Global Warming Potential
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IETA	International Emissions Trading Association
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
LLAP	Law of the least ambitious program
MBM	Market-based measure
MCDA	Multi Criteria Decision Analysis
MRV	Monitoring, reporting and verification
MODTF	Modelling & Databases Task Force
NAMA	Nationally Appropriate Mitigation Action
NGO	Non-governmental organization
REV	Revenue Generation
RPK	Revenue Passenger Kilometers
SWM	Strawman
SYN	Synthesis
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States

I
Thesis definition

We are in danger of destroying ourselves by our greed and stupidity. We cannot remain looking inwards at ourselves on a small and increasingly polluted and overcrowded planet.

Stephen Hawking

1   Introduction

In recent decades the issue of climate change has gained increased attention. Already in 1972 when the Club of Rome published *The Limits to Growth* it was shown how a world with exponential economic and population growth but finite resources can cause unbalances in the Earth's system. In 2015, more than 40 years later, climate action has become one of the *Global Goals* – succeeding the *Millennium Development Goals* - showing that environmental progress is still necessary. One promising sector for significant progress is aviation.

1.1   THE CHALLENGE OF SUSTAINABLE AVIATION

Anthropogenically enhanced climate change is now largely accepted amongst the scientific community (IPCC, 2014). In the past 20 years considerable international policy efforts have been made to mitigate the impacts of climate change, most notably through the United Nations Framework Convention on Climate Change's (UNFCCC) Kyoto Protocol - the first global agreement to address climate change – and in the many meetings of Conference of Parties (to the Kyoto Protocol) in the years since its inception in 1998. Whilst concerted efforts have been made in many sectors by many actors, one sector that has until now received relatively limited regulatory attention is the aviation industry (Preston, Lee, & Hooper, 2012).

The aviation industry is a catalyst for world trade, an enabler of economic development, and a major global employer. Nearly $2.4 trillion in global GDP, 35% of world trade by value and 58.1 million jobs are supported by the industry (ATAG, 2013a). Social benefits include the broadening of people's leisure and cultural experiences via wide choice and affordable access to destinations across the globe, improved living standards and alleviation of poverty through tourism, and the facilitation of delivery of emergency and humanitarian aid relief.

However, with these benefits comes an impact on the environment. In 2013, aviation produced 705 million tonnes of CO_2, or around 2% of the global total (ATAG, 2014). The international fraction of aviation emissions is approximately 65% of total civil aviation. If this fraction of aviation emissions of CO_2 were 'a country', they would be the 17th largest emitter of CO_2 in 2013 (Boden et al., 2013). With air traffic projected to grow by 4-5% per annum in the period 2010-2050 (Airbus, 2010), the aviation industry is the fastest growing transport mode in the coming decades. This development raises the question of how sustainable growth can be achieved and the need for regulatory measures.

1.2 THE ENVIRONMENTAL IMPACT OF AVIATION

The environmental impact of aviation occurs because aircraft engines emit heat, noise, particulates and gases which contribute to climate change and global dimming. Atmospheric changes from aircraft result from three types of processes (Lee et al., 2009):

i. direct emission of radiative substances (e.g. CO_2 or water vapor)
ii. emission of chemical species that produce or destroy radiative substances (e.g. NO_x, which modifies O_3 concentration)
iii. emission of substances that trigger the generation of aerosol particles or lead to changes in natural clouds (e.g. contrails).

Besides direct emissions through combustion engines from aircrafts, the aviation industry also contributes to greenhouse gas emissions from ground airport vehicles and those used by passengers and staff to access airports, as well as through emissions generated by the production of energy used in airport buildings, the manufacture of aircrafts and the construction of airport infrastructure.

The first comprehensive assessment of aviation's climate impact was performed by the Intergovernmental Panel on Climate Change (IPCC) in 1999. In its report '*Aviation and the Global Atmosphere*' it used the climate metric 'radiative forcing' (RF) to include both CO_2 and non-CO_2 effects such as ozone and cloudiness. Radiative forcing is defined as the difference of insolation absorbed by the Earth and energy radiated back to space (IPCC, 1999). It is a backward-looking metric because it measures the RF of a greenhouse gas that has accumulated in the atmosphere over a period of time (Stockholm Environment Institute, 2011a). The IPCC estimated that the RF in 1992 was equal to +0.048 Wm^{-2}, which at that time constituted about 3.5% of total anthropogenic radiative forcing (IPCC, 1999).
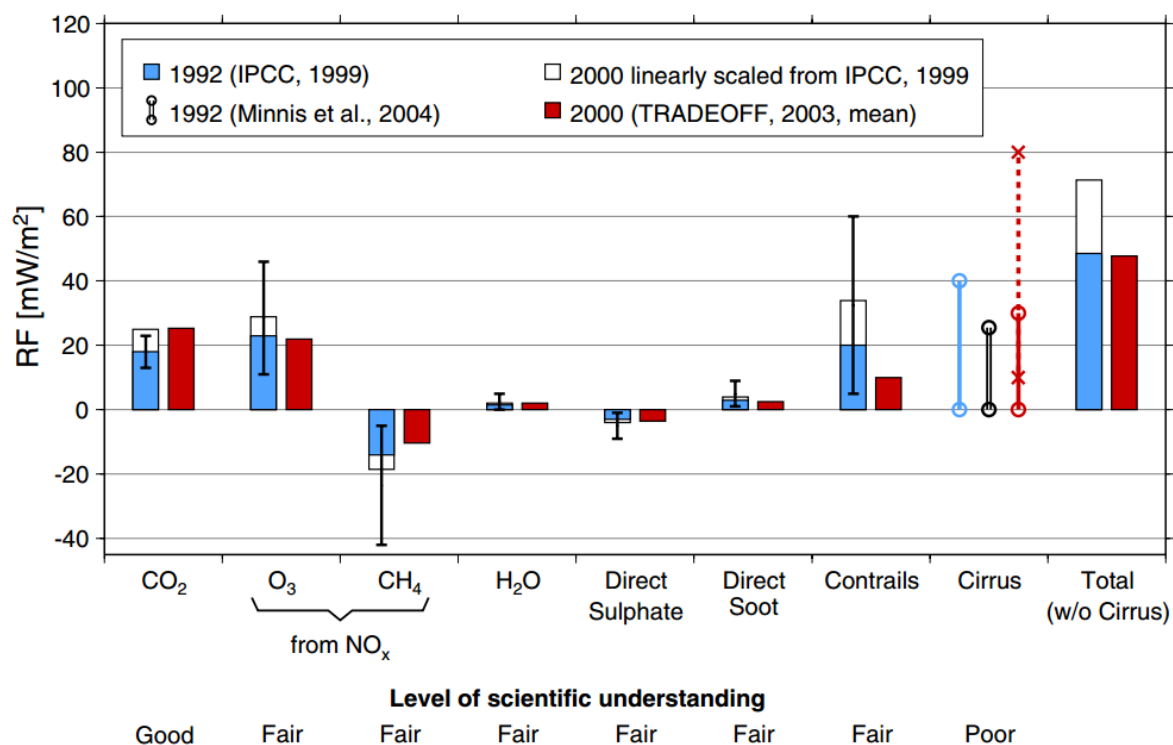
Figure 1 - Radiative forcing from aviation effects

In its assessment on aviation, the IPCC estimated that in the central case aviation's contribution could grow to 5% of the total contribution by 2050 if no action was taken in reducing greenhouse gas emissions, though the highest scenario is 15%, also depending upon significant cuts in other industries (IPCC, 1999). Later studies have re-evaluated the radiative forcing effects of aviation. In a study in 2005 by Sausen et al. (2005) the IPCC results were scaled to 2000 leading to a RF of +0.071 Wm^{-2}. Furthermore new observations about the non-CO_2 effects of aviation were taken into account leading to a new estimate which is represented by the 'TRADEOFF' scenario in Figure 1. According to this scenario, although there has been an increased fuel burn in the period 1992 to 2000, the lower estimate of radiative forcing from contrails compensates this increase leading to a RF similar to the IPCC estimate of 1992. Due to a lack of scientific knowledge, the effect from cirrus clouds was not included in the RF. The IPCC used these figures from Sausen et al. (2005) in its Fourth Assessment Report in which it estimated that aviation represented 3% of the total anthropogenic RF in 2005 (IPCC, 2007). However this study did not account for data regarding traffic growth and increased global aviation fuel usage between 2000 and 2005. In a newer study by Lee et al. (2009) this was accounted for to arrive at total radiative forcing of +0.055 Wm^{-2} for aviation in 2005, a 14% increase over the 2000 value assumed by the IPCC (2007).

Although there have been improvements in fuel efficiency through aircraft technology and operations, these improvements are continually being nullified by the increase in air traffic volume (Macintosh & Wallace, 2009). Furthermore, the tradeoff between CO_2 and NO_x emissions caused by aircraft combustion engines already cancels out some of the improvements made in reducing aviation's environmental impact. This tradeoff is related to the fact less fuel is consumed at higher temperatures and pressures, which reduces CO_2 emissions but increases NO_x emissions (KiM, 2010). Taking all these developments into account enables forecasting of radiative forcing until 2050, as is done by Lee et al. (2009), see Figure 2.
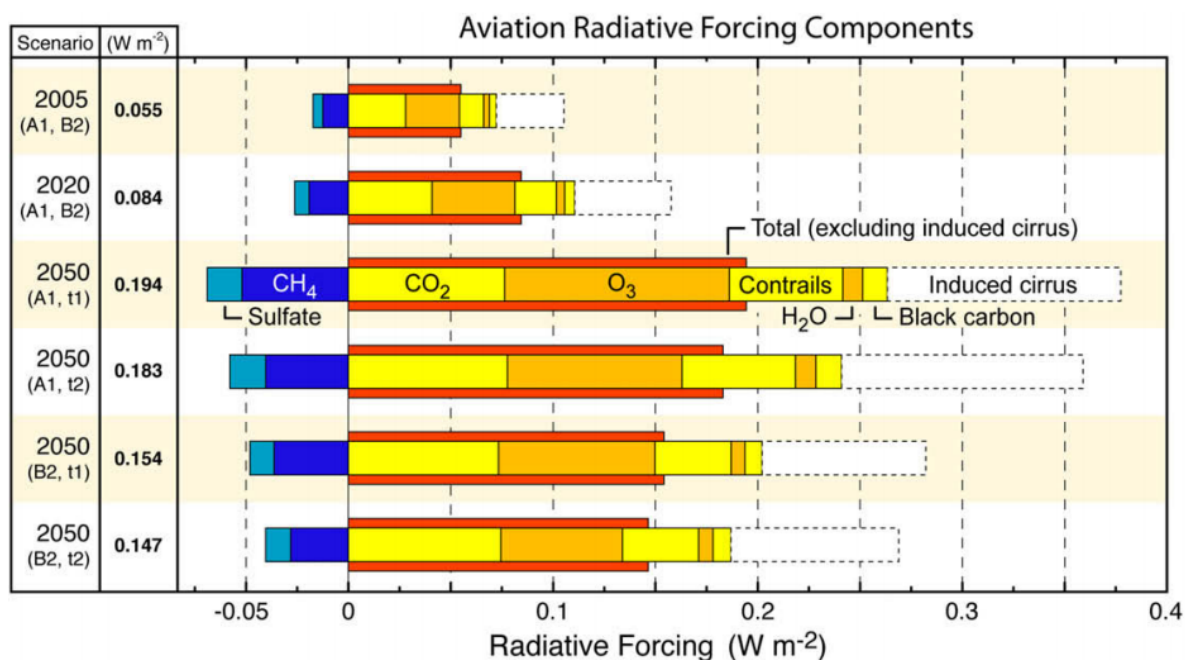
Figure 2 - Aviation Radiative Forcing Components

Figure 2 shows the radiative forcing for four different IPCC scenarios in 2050, excluding the uncertain climate effects induced cirrus clouds. In the best-case scenario the RF equals +0.147 Wm^{-2}, which is an increase of 167% compared to the 2005 level. In the worst-case scenario the RF equals +0.194 Wm^{-2}, which is an increase of 253% compared to the 2005 level. These results show an increased climate impact of aviation in the coming decades. The studies from Sausen et al. (2005) and Lee et al. (2009) provide the most up-to-date description of mechanisms with a critical review of information on the different forcing factors associated with aircraft flight (Murlis, 2014). However, as Figure 1 and Figure 2 and show, there still is uncertainty regarding the climate effect of induced cirrus clouds that could alter the total RF significantly.

In conclusion, the works from the IPCC (1999), Sausen et al. (2005), and Lee et al. (2009) show that aviation causes a larger radiative forcing than from CO_2 emissions alone. This factor is in the range of 2 to 4 due to the climate impact of NO_x-emissions, particulates and water vapor. The uncertainty is partially caused by a lack of scientific understanding about the climate impact of induced cirrus clouds.

1.3 INTERNATIONAL REGULATORY EFFORTS TO REDUCE AVIATION EMISSIONS

The international regime on climate change is built on the UN Framework Convention on Climate Change (UNFCCC). The convention established the regime by defining the principles that guide its development and its ultimate objective: to stabilize atmospheric concentrations of greenhouse gases "*at a level that would prevent dangerous anthropogenic interference with the climate system*" (UNFCCC, 1992). The convention was followed by a new international treaty - the Kyoto Protocol - which was adopted in 2007. However, during the Kyoto Protocol negotiations Parties were unable to reach consensus concerning legally binding targets for the aviation sector. The main breaking point during discussions was the question of how to address the '*Common But Differentiated Responsibilities and Respective Capabilities'* principle[1] central to the UNFCCC.

Acknowledging the environmental impact of the aviation industry, the UNFCCC Kyoto Protocol established in 1997 therefore agreed for developed States to address international aviation through ICAO. Together with the International Air Transport Association (IATA), representing 250 airlines or 84% of total air traffic, discussions were held about the introduction of a global aviation emissions reduction scheme. As requested in 2001, the UN agency explored policy options to reduce emissions including market-based measures stating that "such measures could achieve environmental goals at the lower costs and in a more flexible manner than traditional regulatory measures" (ICAO, 2001). However by 2005, no actions from an agreed measure were being put forward by ICAO. In conclusion, Parties meeting at the UNFCCC were unable to reach agreement on how to deal with the mitigation of aviation emissions after it was mandated by the Kyoto Protocol in 1997 (Preston et al., 2012).

The European Union, following the lack of progress by ICAO to reduce aviation's emissions with an international scheme, took action in 2005. Recognizing that direct emissions from aviation account for about 3% of the EU's total greenhouse gas emissions, the EU Council urged the Commission to come up with a legislative proposal to include the aviation sector into the EU ETS (IETA, 2012). The Commission published a draft Directive in 2006, which was adopted in December 2008, entered into force in 2009, and became effective as of

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[1] The principle of "common but differentiated responsibilities and respective capabilities" is the cornerstone of the United Nations Framework Convention on Climate Change (UNFCCC) that reflects the duty of States to share the burden of environmental protection according to their structural capacity to tackle global environmental problems.

January 1, 2012. Since then all flights from, to and within the European Economic Area (EEA) were included into the EU ETS (EC, 2015a).

However, though acknowledging the benefits of an emissions trading scheme for aviation, ICAO and IATA from 2010 onwards strongly disagreed with the inclusion of the sector into the EU ETS (IETA, 2012). Furthermore, the U.S. aviation industry showed fierce political opposition, China was threatening to withhold aircraft orders from the French aircraft manufacturer Airbus, and several powerful European nations including Britain, France and Germany, feared retaliation against their national carriers. Chinese and Indian airlines refused to submit emissions data, and U.S. lawmakers were preparing a law that could make it illegal to pay the tariff (Reuters, 2012).

At the same time, the International Air Transport Association (IATA) drafted a Resolution on Climate Change in 2010, setting out three targets for addressing carbon emissions (IATA, 2013a) *(Figure 3):*

- 1.5% average annual fuel efficiency improvement between 2010 and 2020
- Carbon neutral growth from 2020 onwards
- A reduction of 50% in net emissions by 2050 compared to 2005 levels

MAPPING OUT THE INDUSTRY COMMITMENTS
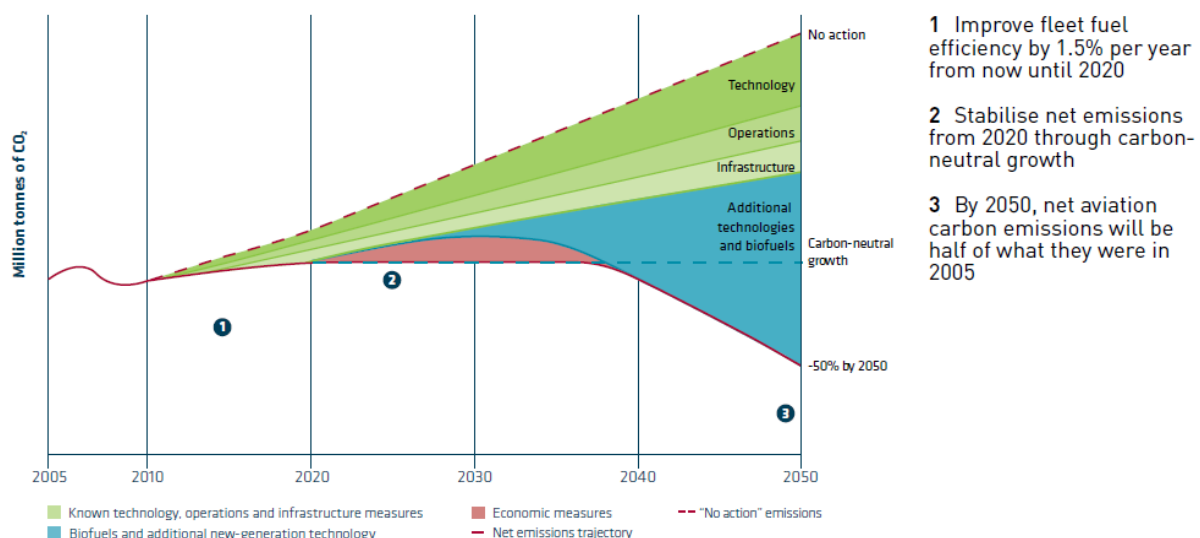
Figure 3 - Industry's commitments towards 2050 (ATAG, 2014)

Acknowledging the momentum of the industry to promote sustainable development, the 37th ICAO Assembly in 2010 adopted the Resolution from IATA. To achieve these short-, medium-, and long-term goals, ICAO plays a leading role in supporting stakeholders' collaboration, including governments and non-governmental organizations, towards implementing a four pillar strategy: improved technology, more efficient aircraft operations, infrastructure improvements, and a properly-designed market-based measure (MBM) to fill any remaining emissions gap (ATAG, 2013b). From 2010 to 2013, ICAO and member states have been analyzing and narrowing down options for a global MBM for aviation.

On 4 October 2013, the 38th ICAO Assembly adopted a resolution in which they decided to develop a global MBM for international aviation. The building blocks of the MBM are to be completed by the next Assembly in 2016, and implementation is scheduled by 2020. This

would be the first sector-wide global MBM, and would be a big step forwards towards sustainable aviation (ATAG, 2013b). Following from the fierce lobbying by both States and the industry, and the developments within ICAO to implement a global market-based measure to reduce aviation's emissions, the EU backed down and from April 2014 onwards, flights to and from the EU were exempted from its emissions trading scheme. Should ICAO fail to find a solution by 2016, EU legislation provides for the ETS to resume covering all flights to, from, and between EU airports.

1.4   A GLOBAL MARKET-BASED MEASURE FOR THE AVIATION INDUSTRY

ICAO is considering three types of MBMs in the context of aviation: (1) levies, (2) mandatory offsetting and (3) emissions trading. Their definitions are described below. At its 39th Assembly in October 2016, ICAO will propose a MBM design that is based on either one of these three policy options. Each of these have benefits and drawbacks that must be taken into account when deciding on which option to use as a building block for the global MBM.

1.4.1   GLOBAL LEVY

According to ICAO, a global levy is defined as follows:

> *"Levies can be divided into charges and taxes. A charge is designed and applied to specifically recover the costs of providing facilities and services for civil aviation. Examples include airport and navigation services. A tax is designed to raise national or local government revenues which are not applied to civil aviation in their entirety or on a cost-specific basis. Examples include a customs or fuel tax" ICAO (2015b).*

A global levy seems attractive for the sector because of its simplicity and familiarity with taxes and charges. An environmental charge or tax in the aviation sector can give a clear price signal that would help the industry towards more sustainable practices. However, previous work by ICAO has identified various challenges associated with this option. Firstly, a global levy does not provide any guarantee regarding the desired environmental outcome. Secondly, legal barriers might hinder implementation (ICAO, 2015b). An analysis of the legal feasibility of a global levy is provided later in this research, see paragraph 5.2.

1.4.2   GLOBAL MANDATORY OFFSETTING

According to ICAO, global mandatory offsetting is defined as follows:

> *"Greenhouse gases (GHG) can be offset through the reduction, removal or avoidance of emissions. An offset "cancels out" or "neutralizes" emissions from one sector through the reduction of emissions in a different sector or location. The standard measurement used is one tonne of CO_2, or CO_2-equivalent. Offsetting operates through the creation of emissions units, which quantify the reductions achieved. These emissions units, which would generally be created outside the international aviation sector, can be bought, sold or traded" (ICAO, 2013a).*

The underlying rationale behind this mechanism is that from a climate perspective, it does not matter in which sector the emissions reductions take place, as long as they do occur. This allows the sector to pursue emissions reductions within the sector itself when the price of abatement is lower than offsetting. In the case where abatement within the sector is more expensive than offsetting, the sector is allowed to compensate through other sectors. This

principle of compensation makes an offsetting scheme a cost-efficient tool to achieve emission reductions.

Though cost-efficiency is very important, there are questions that can be raised regarding an offsetting scheme. First of all opponents of such a system argue that at its best, an offsetting scheme is a zero-sum game – meaning that there are no emission reductions within the sector itself. Second, opponents question whether offsets used are of high quality[2] and additional[3]. Third, if an offset has a very low price there is little or no financial incentive for airlines to invest in technology, operational, and infrastructural improvements.

1.4.3 *GLOBAL EMISSIONS TRADING*
According to ICAO, global emissions trading is defined as follows:

> *"A global emissions trading scheme would use a cap-and-trade approach, where total international aviation emissions are capped at an agreed level for a specified compliance period. Specific aviation allowances (one allowance is equivalent to one tonne of CO_2) would be created under this scheme for all the emissions under the cap within the international aviation sector. These allowances would then be distributed for free, or auctioned, to participants using an agreed method. Revenues can be generated by auctioning aviation allowances rather than providing them to participants free of charge.*
>
> *At the end of each compliance period, participants would need to surrender allowances, or other emissions units, equal to the emissions they generated during that period. For participants with emissions above their initial allocation, allowances can be acquired from those who reduced emissions below their allocated amount and have surplus allowances available for sale or trade. Alternatively, other emissions units, such as offset credits can be used in combination with allowances. The participants' abilities to acquire and use these credits to meet their obligations under the scheme are established in the rules of the scheme"* (ICAO, 2013a).

Emissions trading places a cap on all emissions within the sector and allowances are created equal to the tonnes of CO_2 under the cap, which can then be traded by the emitters. The cap enables setting a maximum to the amount of emissions from the sector. The possibility of trading allows emitters that have high costs for carbon abatement to buy emission allowances from emitters that have lower abatement costs. Thus an ETS is argued to also allow for cost-efficiency within the aviation sector. A disadvantage regarding emissions trading is its greater administrative complexity.

1.5 THE INTERNATIONAL AVIATION POLICY WINDOW
To summarize the developments, as of ICAO's 38th Assembly in 2013 there is momentum within ICAO to implement a global market-based measure to limit aviation's emissions. This momentum is captured in Figure 4, which, by using Kingdon's *Multiple Streams theory*, is represented by the existence of a *Policy Window*. This *Policy Window* occurs due to the simultaneous existence of a (i) problem stream, (ii) political stream, (iii) policy stream.

---

[2] By quality it is meant that one offsets truly represents one tonne of CO_2-emission reductions.
[3] The principle of additionality refers to the requirement that these emissions reductions take place from new projects. Offsets from business-as-usual projects are not additional.
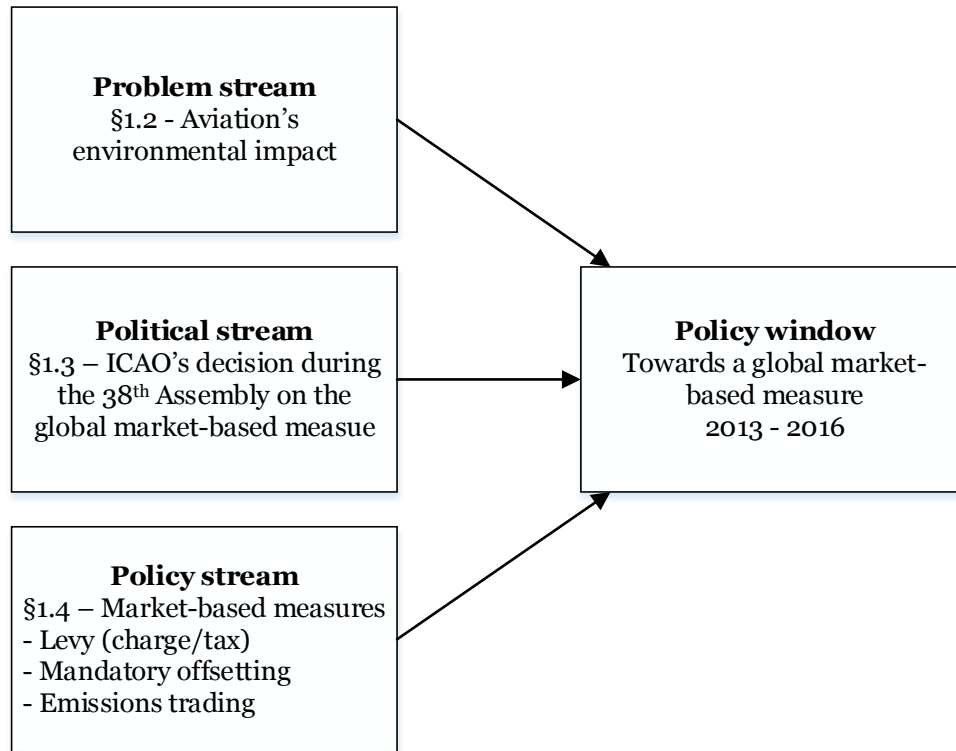
Figure 4 - The policy window towards a global market-based measure

1.6   READING AHEAD: THE STORYLINE

Although a more elaborate overview and discussion of the intended research is provided later in this thesis, this paragraph is intended to give the reader a brief glimpse into the structure of this document.

The thesis is structured according to five parts: (i) thesis definition, (ii) exploration, (iii) design, (iv) analysis, and (v) interpretation. This chapter is part of the thesis definition, which is followed by an overview on the intended research in the following chapter. Part I thus defines this research in terms of relevant background, scope, and methods. Part II commences research by zooming in from both an academic and practical perspective on the opportunities and boundaries in the aviation industry and demarcating the design space. Part III follows by constructing different global market-based measure designs and formalizing a simulation model. This model is then used in part IV to assess the designs. Part V concludes this thesis by providing conclusions, recommendations, limitations of the research, opportunities for future research, and a critical reflection of the performed research. A schematic overview of these phases is shown in Figure 5 below.

Figure 5 - Thesis' structure in five phases

*Research is to see what everybody else
has seen, and to think what nobody else
has thought.*

Albert Szent-Gyorgyi

2 Research definition

According to the Oxford Dictionary (2015) research is defined as "*the systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions*". This chapter aims at giving the reader insight into how this systematicness is achieved.

2.1 KNOWLEDGE GAP

The knowledge gap concerns designing the global market-based measure. Although as of ICAO's 38th Assembly in 2013 a policy window is existent, it should not be assumed that this global market-based measure will also be implemented by 2020. In fact, whether or not the global MBM will be implemented by 2020 depends for a large share on ICAO's next Assembly in 2016, where Member States will vote on adopting the measure or not. Their decision will greatly depend upon whether its design matches their interests and agenda. Therefore the design of the global MBM is crucial in ensuring adoption and implementation.

However, there are still many remaining questions with regard to the design of the global market-based measure for the aviation sector. For example, which of the three proposed types of market-based measures (levy, mandatory offsetting, emissions trading) has the most potential within the aviation sector? Are there any design variations possible within a certain type of market-based measure? How do different designs perform on reducing aviation's environmental impact and other important factors? These and other important questions should be answered before the next Assembly in 2016 such that political consensus can be reached and ICAO can move towards implementing the global market-based measure.

2.2 RESEARCH QUESTIONS

To assist ICAO in addressing the above described knowledge gap, this thesis has the following main research question:

*How can a robust global market-based measure
for the aviation industry be designed?*

In everyday language robustness is often meant to denote an entity that is "*strongly formed or constructed*" and "*strong and effective in all or most situations and conditions*" (Collins, 2001; Merriam Webster, 2015). According to the article of Arvidsson & Gremyr (2008) an important part of robustness is the "*insensitivity to noise factors*". This thesis uses these definitions as an inspiration, and based upon that defines the following *four principles of a robust design*:

>	*Legal feasibility*	The design obeys the law
>	*Political viability*	The design is accepted in the political arena
>	*Purposefulness*	The design satisfies the main goal of decreasing the climate impact of aviation
>	*Sturdiness*	The design is preferred under a wide range of conditions

It is argued that a design satisfying these four principles is by definition a robust design. In order to answer the main research question, several sub-questions shall be addressed. These are listed in Table 1 below.

Table 1 - List of sub-questions

Number	Sub-question
1	What is the design space for a global market-based measure?
2	What are the criteria needed to assess a global market-based measure?
3	Which designs for a global market-based are possible?
4	How do the global market-based measure designs score on the identified criteria?

2.3 METHODOLOGY

The research methodology used in this thesis is Systems Engineering. This is a rational, systematic, and structured research approach. Its purpose is to assist policymakers in choosing a course of action from among complex alternatives under uncertain conditions. Systems Engineering can be very helpful in assisting the judgment process of what policy measures to implement by clarifying the problem, presenting alternatives, and comparing their consequences (Haan, 2007; Walker, 2000).

In Systems Engineering, there are three "logical steps" that are central in examining systems: (i) formulation, (ii) analysis, and (iii) interpretation (Sage & Armstrong, 2000). The methodology in this thesis builds upon these steps. The first step 'formulation' is divided into 'thesis definition', 'exploration' and 'design' to arrive at the following five phases in this thesis: (i) thesis definition, (ii) exploration, (iii) design, (iv) analysis, and (v) interpretation. How these phases relate to the previously stated sub-questions (SQs) is described in Table 2 below.

Table 2 - Description of the research phases

Phase	Related SQs	Aspects to be covered
Thesis definition	none	> Problem description > Research definition
Exploration	1 & 2	> Describing underlying academic theory > Identification of assessment criteria > Identification of design elements > Demarcating the design space
Design	3	> Synthesis of design elements > Analysis on outstanding design elements > Formulation of a simulation model
Analysis	4	> Synthesis of designs and criteria > Qualitative and quantitative assessment of the designs
Interpretation	none	> Conclusions and recommendations for ICAO > Reflection

2.4 RESEARCH METHODS

Specific research methods shall be used to answer each sub-question. A list of methods is shown in Table 3. A detailed description of each method is given in paragraph 2.4.1 for the qualitative research methods, and paragraph 2.4.2 for the quantitative research methods.

Table 3 - List of research methods

SQ	Research method
1	> literature review > stakeholder analysis > legal analysis
2	> literature review > stakeholder analysis
3	> synthesis
4	> multi-criteria decision analysis > marginal abatement cost curve > Monte-Carlo simulation

2.4.1 QUALITATIVE RESEARCH METHODS

This paragraph describes the qualitative research methods used in this thesis: literature review, legal analysis, stakeholder analysis, and the interview with policy-makers.

LITERATURE REVIEW

Due to the explorative nature of sub-questions 1 and 2 – identifying related academic theory, design elements, assessment criteria – the *literature review* was chosen as the appropriate research method. This method allows for a fast but thorough search on "*what is already known on the topic*" and "*what theories and concepts have been applied to the topic*" (Bryman, 2012). It allows the user to define his or her own opinion based on existing knowledge, and equally important, it saves the user valuable time for more creative or analytical work (i.e. sub-questions 3 & 4). Demarcating the design space by doing interviews would take considerably longer due to the time needed to find promising respondents, and planning, executing and processing the interviews. Furthermore it would be questionable

whether a sufficient amount of respondents would be available due to the fact ICAO is working on the global market-based measure by itself and the confidential nature of the progress and discussions.

Academic databases that were used for the *literature review* include Scopus, Google Scholar, and ScienceDirect. By using keywords such as *"aviation"*, *"global market-based measure"*, *"emissions"*, *"tax"*, *"offsetting"*, *emissions trading"*, *"design elements"* and *"climate change"* a lot of interesting journal articles have been identified that allowed for gaining knowledge about the challenge at hand very quickly. Furthermore Google's search engine was used to scan for additional sources of information including reports from the aviation industry, consultancies, and non-governmental organizations. Lastly, the online platform on sustainable aviation *"Green Air Online"* was extensively used to stay up-to-date with regard to the latest developments on the global market-based measure.

LEGAL ANALYSIS

Part of demarcating the design space is identifying the legal barriers towards implementing a global market-based measure. For aviation the legal foundation for policy-making is defined in the *Convention on International Civil Aviation* - also known as the *Chicago Convention* (ICAO, 1944) – which was signed in 1944 and as of 2015 includes 191 States . During the legal analysis this Convention is analyzed to identify any legal barriers towards implementing a global market-based measure.

STAKEHOLDER ANALYSIS

Additional to the legal analysis is the stakeholder analysis. According to the work of Freeman (2001) a stakeholder is defined as *"any group or individual who can affect or is affected by the achievement of the organization's objectives"*. In theory, a stakeholder analysis is intended to achieve the five purposes as described below (Grimble & Wellard, 1997; Hermans & Thissen, 2009; Vilanova, 2007).

   i.   To enable the development of "socially-best" policies and interventions.
   ii. To allow decision makers and organizations to satisfy the interests of important stakeholders.
   iii. To improve the selection, efficiency, effectiveness, and evaluation of policies and projects
   iv. To improve the assessment of the distributional, social, and political impacts of policies and projects.
   v.   To facilitate stakeholder involvement in decision-making.

In this thesis the specific goal of the stakeholder analysis is to demarcate the design space. It is assumed that demarcation of the design space in an early phase of the research will ultimately lead to achieving these five purposes. There are many ways of how to perform a stakeholder analysis, see e.g. Bryson (2004), Grimble & Wellard (1997) or Hermans & Thissen (2009). Although there is a wide variety in the available methods, there are a number of important steps that appear in every method. These include the following three steps:

   i.   Identifying decision-makers and stakeholders
   ii. Investigating stakeholder interests and agendas
   iii. Investigating patterns of interaction and dependence

In this thesis these steps are used as a source of inspiration and a framework for the international aviation stakeholder analysis was designed that can specifically be used for demarcating the design space for the global market-based measure. This framework is shown in Figure 6.

This framework combines the above mentioned three steps and adds the important additions described below. A meta-framework showing how this stakeholder analysis fits in with other analyses in this thesis is shown in paragraph 2.6.

i. A distinction is made between decisive, influential, and affected stakeholders reflecting the different degree of power that can be used during the decision-making by each individual stakeholder.
ii. The decisive stakeholder with regard to the global market-based measure is ICAO.
iii. The stakeholder interests answered by the question - *what does the stakeholder value important?* – is translated into criteria. For example, if the analysis shows that a decisive/influential stakeholder or group of stakeholders attach great value to market distortion effects this criterion shall be used for assessing different global market-based measure designs.
iv. The stakeholder agenda answered by the question – *what does the stakeholder want?* – is translated into design elements. For example, if the analysis shows that a decisive/influential stakeholder or group of stakeholders want to *minimize* market distortion effects then a related design element should incorporate this.

Framework for the aviation global MBM stakeholder analysis
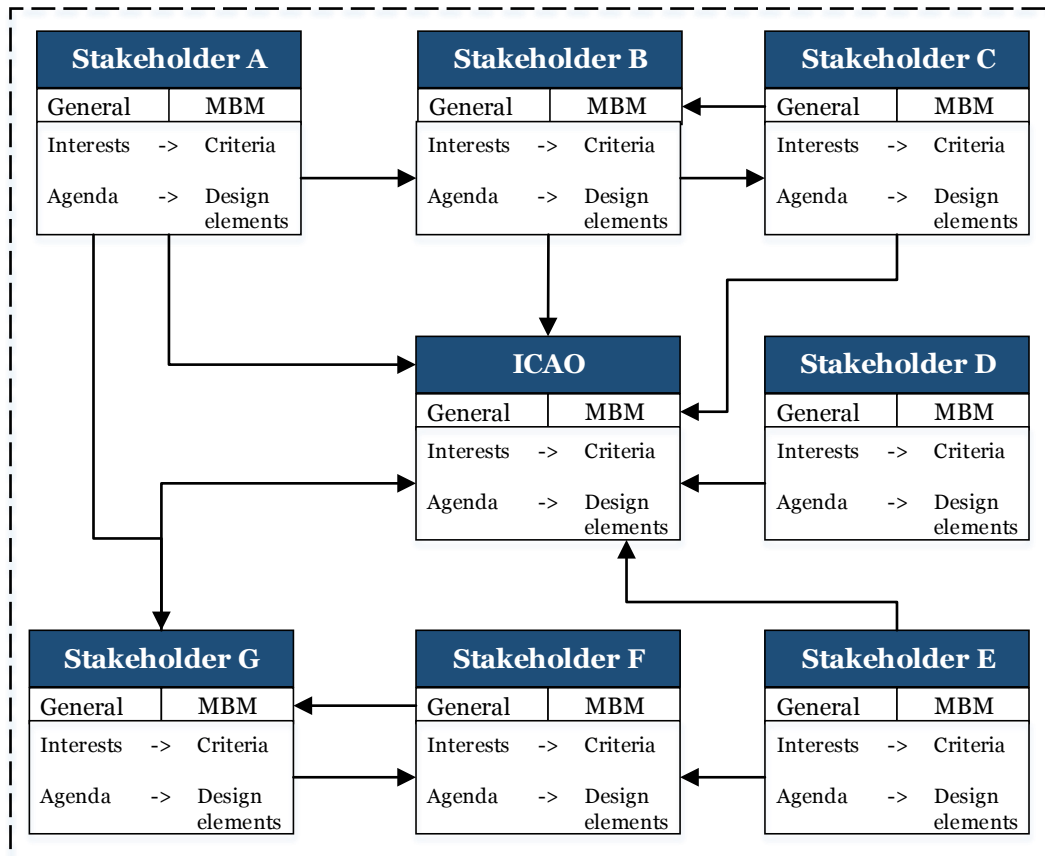
Figure 6 - Framework for the aviation global market-based measure stakeholder analysis

2.4.2 *QUANTITATIVE RESEARCH METHODS*
This paragraph describes the quantitative research methods used in this thesis: multi-criteria decision analysis, marginal abatement cost curve, and Monte-Carlo simulation. In addition cost-benefit analysis is discussed to provide the rationale for using the multi-criteria decision analysis.

In the past decades, a tool that has been frequently used in assessing climate change policies is cost-benefit analysis (Heinzerling & Ackerman, 2002). In order to compare the advantages and disadvantages of any particular regulatory standard, cost-benefit analysis seeks to translate all relevant considerations into monetary terms. Therefore in applying cost-benefit analysis to assessing the global market-based measures, the benefits of emission reductions should be presented in terms of dollars (or any other currency).

However, cost-and-benefit analyses used for the assessment of climate change policies have been critiqued for a variety of arguments. First, there is the belief that aspects such as life, health, and the natural world cannot be monetized, nullifying the underlying assumption of cost-benefit analysis that this is possible (Frank, 2000; Kelman, 1981; Turner, 1979). Second, cost-benefit analysis makes use of discounting to compare effects that happen in the present and in the future. Proponents argue that discounting cannot be reasonably used to make a choice between harms done to the current generation and future generations (Ackerman, 2008). In addition, by discounting long-term environmental risks tend to be underestimated. Third, cost-benefit analysis ignores the question of who suffers as a result of environmental problems and, therefore, threatens to reinforce existing patterns of economic and social inequality (Heinzerling & Ackerman, 2002).

Nonetheless, not doing anything in the aviation sector due to complexities in the decision-making process would place a huge burden on the environment. Thus, policy makers in the aviation domain need to agree on the global market-based measure in order to decrease the burden that the sector is placing on the environment. To facilitate the decision, policy makers need a tool that incorporates the complexity involved in an international environmental problem.

MULTI-CRITERIA DECISION ANALYSIS

In order to remediate the previously highlighted limitations of cost-benefit analysis, "*it is favorable to adopt a pluralist framework for environmental decision-making, within which a heterogeneous set of value-articulating and decision-making instruments are available to represent in a more comprehensive manner the multiple ways that people value and make decisions about the environment*" (Wegner & Pascual, 2011). The idea for a pluralist framework originates from the earlier work done by Norgaard (1989) and Ostrom (1998), and requires the recognition of plural values (both commensurable and incommensurable) and ethical attitudes (both consequentialist and deontological). It also needs to acknowledge the scientific uncertainty that is inherent to complex social-ecological systems (Wegner & Pascual, 2011).

An emerging tool in a pluralist framework for decision-making includes multi-criteria decision analysis (hereafter: MCDA). Whilst cost-benefit analysis has the sole objective of economic efficiency, MCDA evaluates policies in terms of multiple objectives that can be prioritized differently. Criteria indicate to what extent the objectives are achieved, and these criteria are measured through different units of measure that are not necessarily converted to a single monetary metric. Each alternative policy option is given a score for all criteria (Munda, 2004). In this thesis the Likert-scale[4] is used to assign scores to the criteria. The scores are relative to the business-as-usual (no global MBM), and can be categorized as follows:

---

[4] A five-points scale commonly used in surveys, incorporating symmetry and balance among the scores.

Table 4 - Normalization of scores

Score	Definition
++	Very good performance relative to the BAU
+	Good performance relative to the BAU
+/-	Neutral performance relative to the BAU
-	Poor performance relative to the BAU
- -	Very poor performance relative to the BAU

Besides allowing the prioritization of multiple objectives and the use of plural units, a MCDA is a transparent tool and can assist in making tradeoffs explicit and analyzing them (Solomon & Hughey, 2007). Transparency also allows for replicating the research for learning purposes, or for doing further research. Furthermore, a MCDA can help facilitate the deliberations of stakeholders by involving them in the process. Although multi-criteria decision analysis has benefits that may seem to make it superior to cost-benefit analysis, difficulties can still arise (Wegner & Pascual, 2011). Firstly, there is the risk of significant power asymmetries among participating stakeholders (Vatn, 2006). Dominant stakeholders can attempt to influence the outcome of the decision analysis by assigning greater weights to criteria most important to them.

Secondly, by its nature the outcome of the MCDA is sensitive to the criteria used. Although this may sound trivial at first, in the context of the aviation sector it is crucial. To illustrate, as the criteria (paragraph 2.2) and design elements (paragraph 2.5) show, one important aspect in designing and assessing aviation environmental policies is defining which pollutants are addressed by the policy. By including only carbon dioxide emissions, the outcome of the MCDA will be directed towards policy designs that result in lower CO_2-emissions as compared to policy designs with higher CO_2-emissions. As paragraph 1.2 has shown, one effective policy of achieving lower carbon dioxide emissions is by increasing fuel efficiency within the sector. However, the trade-off between CO_2 and NO_x cancels out some of the environmental improvements. This makes it questionable whether an increased fuel efficiency would still be a favorable policy option when the total aviation emissions are included in a MCDA. This example shows the sensitivity of the outcome of the MCDA to the criteria used. This sets focus to how criteria are defined. In some cases, criteria might be a result of delicate stakeholder engagement. Recall that in paragraph 2.2, the formulated criteria from Solomon & Hughey (2007) are a result of discussions with policy- and research-based experts. In the case of an open process, there is the risk of power asymmetries within stakeholders. In other cases the formulation of criteria could be more closed to the outside world, e.g. when the decision-making authority itself defines the criteria.

Besides originating from either an open or closed process, the addition of criteria also depends on scientific (un)certainty. Again, recall that the list with criteria in paragraph 2.2 does not contain the environmental effectiveness in terms of aircraft induced clouds. A reason behind this omission could be the perceived high scientific uncertainty (as expressed in paragraph 1.2) by the engaged stakeholders.

THE MARGINAL ABATEMENT COST CURVE
Though at this point of the analysis it is not precisely clear yet which criteria will be used for assessing the global MBM designs, it is clear that there will be a mixture of commensurable and incommensurable criteria. Assessing the impact of the global MBM designs on these different criteria thus requires a combination of qualitative and quantitative analysis. Whereas the former type of analysis relies on reasoning and argumentation, the latter relies on the interpretation of data with regard to carbon abatement and costs. To this end, a marginal abatement cost curve (hereafter: MAC curve) for the aviation sector will be used. A MAC curve is defined as a graph that indicates the marginal cost (the cost of the last unit) of

emission abatement for varying amounts of emission reduction. The measures are ranked according to their cost from cheapest to most expensive.

A MAC curve can give insights to policy makers concerning both the introduction of a CO_2-tax (price-based) and the introduction of a CO_2-permit or offset system (quantity-based) (Kesicki & Strachan, 2011), though the implications are somewhat different. Recall that for a carbon tax that there is uncertainty regarding the amount of emission reductions it would realize. A MAC curve can give an approximation of the reduction amount that will be associated with the introduction of a carbon tax at different levels. This is based on the logic that all abatement measures with costs up to the carbon tax will be implemented (Ekins, Kesicki, & Smith, 2011). Assuming full compliance and no interim regulatory changes, a CO_2-permit or offset system provides certainty regarding the emission reduction potential. However, there the question remains how these emission reductions will be realized. In other words, to what extent will they be achieved through technological, operational, and infrastructural improvements? And how many offsets are required to fill any remaining emissions gap? A MAC curve can provide insights into this question.

Despite the valuable insights a MAC curve can provide, there is also criticism. Firstly, there is the phenomenon of negative abatement costs that is considered to be incompatible with an efficient market, as is assumed in general equilibrium models (Ackerman & Bueno, 2011; Ekins et al., 2011). Assuming that all costs in the MAC curve are correctly estimated, the explanation might be one of insufficiently extensive cost definition, non-financial barriers to implementation, or inconsistent discount rates (Ekins et al., 2011). Secondly, MAC curves are a "*static snapshot of one period in time, usually one year*" (Kesicki & Strachan, 2011). The implication of this is that abatement costs are associated with abatement potentials for one year without giving information on what happened before or can be expected to happen afterwards. Nevertheless historic investments in low-carbon improvements and existing policies influence the abatement costs and potentials as well as future climate policies (Kesicki & Strachan, 2011). Thirdly, while in the energy sector technology learning, energy prices, discounting and demand development are all considered to be uncertain, MAC curves fail at sufficiently representing uncertainty (Kesicki & Strachan, 2011). In many studies only one curve is presented which does not give any insights into the uncertainties related to the abatement options and related costs (van Tilburg, Wurtenberger, & Tinoco, 2010).

MONTE CARLO SIMULATION

This thesis acknowledges the limitations of the marginal abatement cost curve. While solving the limitations of "*negative abatement costs*" and "*stasis*" requires research that is beyond this thesis[5], the point of "*insufficiently reflecting uncertainty*" is assumed crucial but solvable. To this end, instead of formulating a quantitative model that is primarily based on the marginal abatement cost curves, this thesis uses a Monte Carlo simulation model that also includes data with regard to uncertainty in marginal abatement costs and other input assumptions. A simplified overview is schematically shown in Figure 7.

Monte Carlo simulation performs risk analysis by building models of possible results by substituting a range of values—a probability distribution—for any factor that has inherent uncertainty. It then calculates results over and over, each time using a different set of random values from the probability functions. Depending upon the number of uncertainties and the ranges specified for them, a Monte Carlo simulation could involve thousands or tens of thousands of recalculations before it is complete. By using probability distributions, variables can have different probabilities of different outcomes occurring. Probability distributions are a much more realistic way of describing uncertainty in variables of a risk analysis. Common

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[5] The implications on modeling outcomes of not addressing these two points are addressed in the reflection (Chapter 10).

probability distributions include the normal, lognormal, uniform, triangular, and discrete distributions.
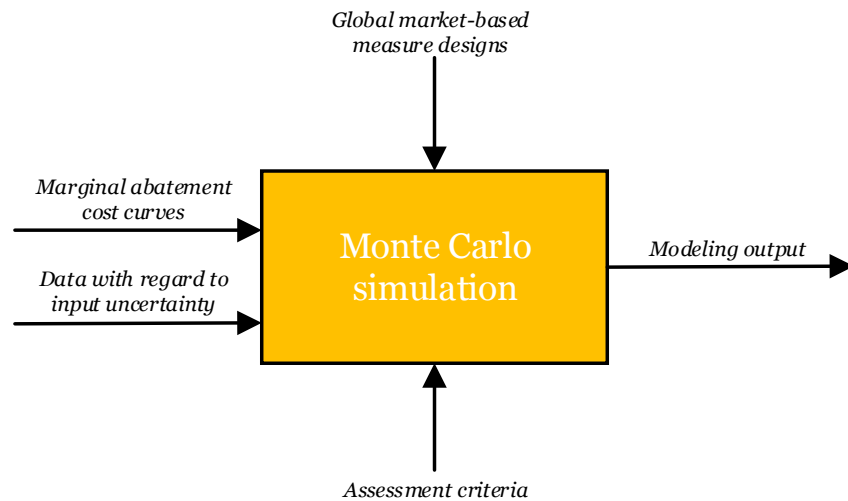
Figure 7 - Monte Carlo simulation

The advantages of doing Monte Carlo simulation over *deterministic* analysis includes:
– *Probabilistic results*: Monte Carlo simulation does not completely ignore uncertainty. Instead it allows for uncertainty w.r.t. the modelling input variables and the results. As such the simulation shows how certain or precise the outcomes are.
– *Sensitivity analysis*: Monte Carlo simulation allow the user to identify which variables cause most sensitivity in the modelling output.
– *Scenario analysis*: by doing thousands of runs Monte Carlo simulation allows the user to easily assess the range of potential scenarios.

2.5 SCIENTIFIC AND SOCIAL RELEVANCE

The goal of this thesis is to provide insights into designing a robust global market-based measure for the aviation industry in the two ways shown hereunder.

i. By showing the design process to arrive at the robust global market-based measure
ii. By applying this design process to determine the robust global market-based measure

The scientific relevance of this thesis is that it explains which phases – from thesis definition to exploration and interpretation - are needed to arrive at a robust global market-based measure for the aviation industry. Equally important, it shows how to perform each of these steps such that ideas generated in this thesis could provide insights for other market-based measures, whether they are on the sectoral, national, or individual level. In addition, this thesis provides an overview of design elements and criteria that are specific to the aviation global market-based measure.

The social relevance of this thesis lies more in the creative and analytical part of this thesis. This research will result in a number of global market-based measure designs that ICAO could implement by 2020. Besides an overview of options for ICAO, this thesis also provides a well-structured assessment of each of these designs showing its benefits and drawbacks while taking into account relevant uncertainties. In addition, the reflection at the end of this thesis takes a critical view on whether the global market-based measure aligns with international climate change goals.

In conclusion, the thesis will result in *recommendations* on *how to design a robust global market-based measure for the aviation industry*. These recommendations will precede ICAO's 39th Assembly in October 2016, where member states will decide upon adoption of a preliminary market-based measure design. Thus this thesis will provide well-founded argumentation and structured analyses about how to arrive at a robust design. This is schematically shown in Figure 8.
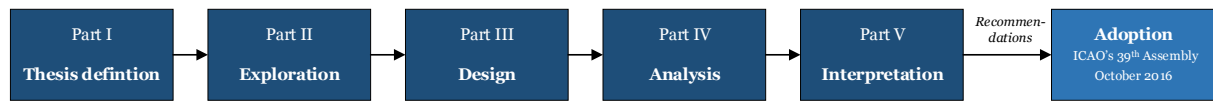
Figure 8 - Thesis preceding ICAO's next Assembly in 2016

2.6 RESEARCH PLAN

To summarize the intended research - including methodology and research methods – a research flow diagram has been constructed, see Figure 9. This figure is meant to give the reader a quick insight into the structure of the intended research, and can serve as a helpful reading guide.
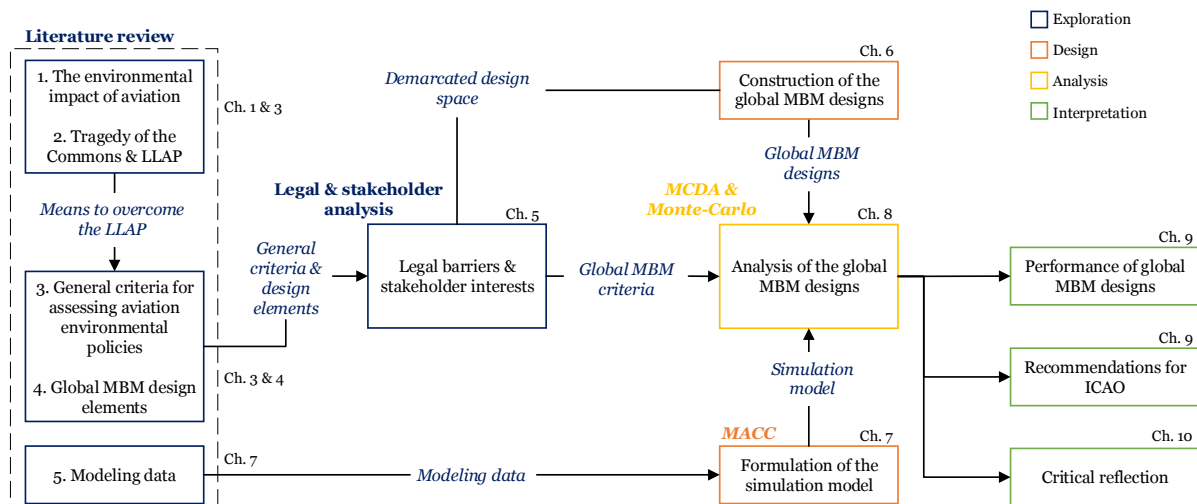
Figure 9 - Research flow diagram

II
Exploration

The central conservative truth is that culture, not politics, determines the success of a society. The central liberal truth is that politics can change a culture and save it from itself.

Daniel Patrick Moynihan

3 Aviation's environmental impact: a Tragedy of the Commons

The consequences in terms of atmospheric pollution are characterized as a *tragedy of the commons* (Vogler, 2000). This phenomenon can be characterized by the situation where individuals acting independently and rationally according to each's self-interest behave contrary to the best interest of the whole group by depleting some common resource (Hardin, 1968). Finding an effective policy for the aviation industry is difficult due to complexities, scientific uncertainties, and political sensitivities (Bardwell, 1991). Nevertheless, by means of a literature review, this chapter is intended to relate the current challenge in the aviation sector to existing academic theories, and to build upon those theories with the aim of finding ways to overcome barriers in implementing an effective global market-based measure.

3.1 NEGATIVE EXTERNALITIES AND MARKET IMPERFECTIONS

The essence of the phenomenon - *tragedy of the commons* - lies in insufficient and poorly protected property rights. The global commons are conventionally defined as areas and resources that do not fall within sovereign jurisdiction of states (Dauvergne, 2005). Examples include inter alia the oceans, outer space, polar regions, and the atmosphere.

The problem of a tragedy of the commons can lead to market failures – a situation where market forces lead to an allocatively inefficient or inequitable outcome (Gent, Bergeijk, & Heuten, 2004). Since no entity owns the atmosphere, consumers deciding to travel by air only consider their marginal private benefits and costs, ignoring the marginal external costs to the environment. Therefore, the marginal social cost is higher than the marginal private costs, resulting in an allocatively inefficient equilibrium, whereby there is an overconsumption of flights and hence a welfare loss (Riley, 2011). This phenomenon is known as *negative externalities*.

This inefficient allocation could in theory be addressed by *internalizing* the negative externalities. However in the aviation sector there has not been an effective way to relate the price of aviation to its externalities in terms of the costs of climate change. The most widely used aviation fuel, kerosene[6], bears no taxes and any national government implementing such a charge would be placed at a competitive disadvantage. Without any effective policies addressing these negative externalities this market failure will remain to exist. One of the most impactful reports on the economics of climate change – the *Stern Review* – stated the following:

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[6] A combustible hydrocarbon liquid, also known as 'paraffin'.

> *"Climate change is the greatest market failure the world has ever seen, and it interacts with other market imperfections. Three elements of policy are required for an effective global response. The first is the pricing of carbon, implemented through tax, trading or regulation. The second is policy to support innovation and the deployment of low-carbon technologies. And the third is action to remove barriers to energy efficiency, and to inform, educate and persuade individuals about what they can do to respond to climate change."*

> \- Stern Review on the Economics of Climate Change (2007)

Besides the existence of a market failure the *Stern Review* mentions the interaction between climate change and other *market imperfections*. These can be divided into *static* and *dynamic inefficiencies*, where the former can relate to *allocative* [7] and *technical* [8] *inefficiencies*. The latter refers to the phenomenon where companies are subject to insufficient incentives to invest in new technologies (Gent et al., 2004). This can inter alia be triggered by unfavorable national or international economic conditions, political uncertainty, and a highly competitive market. When designing new policies for the aviation sector the threat of market imperfections must be taken into account to avoid a lack of investments in innovation and deployment of low-carbon technologies.

However finding the right policy elements to address climate change is difficult, to put it mildly. Regarding the aviation sector, this is even more challenging due to its global nature. Issues with respect to the global commons fall into the scope of *international environmental problems* (Solomon & Hughey, 2007). By definition these problems are '*complex, plagued with scientific uncertainty, and extremely political*', and therefore are '*wicked*' by nature (Bardwell, 1991). These problems tend to be ill-structured because of the excessive ways of constructing the problem with many '*paths worth exploring and rarely one right solution*' (Bardwell, 1991). An effective policy requires not only an environmental fix, but a combination of social, economic, and institutional solutions (Bardwell, 1991). The next paragraph lists criteria that fit with these aspects.

3.2   CRITERIA FOR ASSESSING AVIATION ENVIRONMENTAL POLICIES

This paragraph provides an overview of the environmental, economic, social, and institutional criteria needed to assess the effects of aviation environmental policies. The criteria are derived from Solomon & Hughey (2007) who performed an extensive study on the matter. In their article "*a proposed Multi Criteria Analysis decision support tool for international environmental policy issues*" – in which they used the aviation sector as an example - international literature and contemporary policy developments were used to formulate a list with initial findings. Afterwards they applied the Delphi approach[9], in which a group of representative experts, both policy and research-based, were used to iteratively improve the list of criteria. The results of their analysis are shown below in Table 5.

---

[7] The situation where the supply of goods and services is insufficient to meet the needs of customers in terms of prices, quantities, and/or qualities (Gent, Bergeijk, & Heuten, 2004).

[8] The situation where there are inefficiencies during the production of goods and services (Gent et al., 2004).

[9] The Delphi method is a structured communication technique or method, originally developed as a systematic, interactive forecasting method which relies on a panel of experts.

Table 5 - Criteria for assessing aviation environmental policies

Category	Criteria	Sub-criteria
Environmental	Percentage of total emissions addressed	-
	Environmental effectiveness	a) carbon dioxide b) nitrogen oxide c) noise d) suspended particles and contrails
Economic	Economic growth consequences	a) impact on GDP of 'Northern' nations b) impact on GDP of 'Southern' nations c) impact on employment of 'Northern' nations d) impact on employment of 'Southern' nations e) impact on tourism earnings of 'Northern' nations f) impact on tourism earnings of 'Southern' nations
	Least cost way of reducing emissions	-
	Economic distortion effects	a) impact on trade (impact on imports and exports) b) impact on competition (air carriers)
Social	Equity considerations between nations	-
	Distributional impacts on society	a) accessibility of air travel b) affordability of air travel
	Impact on culture and other cultural considerations	-
Institutional	Political willingness	-
	Institutional feasibility	a) cost considerations b) administrative feasibility c) capacity and ability d) enforceability
	Legal and statutory considerations	a) international provisions b) domestic provisions
	Impact on technological innovation	-

The study done by Solomon & Hughey (2007) provides useful insights into criteria that can be used for the aviation sector. However, when using these criteria for the aviation global market-based measure, the following additional steps should be taken:

i. The criteria as defined by Solomon & Hughey (2007) should be assessed for relevance to the global market-based measure. A number of criteria might be considered irrelevant and removed; other criteria might be combined or separated.

> *As described in paragraph 2.4.1 this is done based on a stakeholder analysis. If the analysis shows that a decisive/influential stakeholder or group of stakeholders attach great value to market distortion effects this criterion shall be used for assessing different global market-based measure designs.*

ii. The criteria as defined by Solomon & Hughey (2007) should be operationalized, i.e. units should be added to the criteria in order to quantitatively evaluate the effects.

> *For time-efficiency reasons this will be done after stakeholder analysis, such that only the criteria considered relevant to the aviation global market-based measure shall be operationalized. The decision of units shall be based on what is common in the aviation sector (i.e. costs in US dollars versus euros), and what is easiest to interpret (i.e. 10.000 $MtCO_2$ versus 10 $GtCO_2$).*

The final list of relevant criteria for assessing the global market-based measure - taking into account interests within the sector – shall be presented at the end of the exploration phase of this thesis, see paragraph 5.5.

3.3 GLOBAL COMMON GOVERNANCE AND INTERNATIONAL POLITICS

The international regime on climate change is built on the UN Framework Convention on Climate Change – UNFCCC. The convention established the regime by defining the principles that guide its development and its ultimate objective: to stabilize atmospheric concentrations of greenhouse gases "at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC, 1992: Art. 2). As of May 2015, the Convention has 196 parties including developed and developing states. ICAO - being the UN specialized agency for aviation - works with the Convention's Member States to create and enforce legally-enforceable national civil aviation regulations (ICAO, 2015a). This institutional interaction can be characterized as interaction through commitment (Oberthür, 2003).

3.3.1 THE INSTITUTIONAL INTERACTION BETWEEN THE UNFCCC AND ICAO

Institutional interaction in this form occurs when commitments by certain members of a source institution affect the preferences of actors related to the target institution. It is based on the desire of member states to avoid mutually incompatible obligations and evolves in the following steps. "*First, members of the source institution agree on an obligation that might be relevant for the target institution. Second, this obligation actually commits one or more states that are members of both institutions. Third, the commitment accepted by these member states induces one or more of them to modify their preferences related to the target institution. Fourth, the modified preferences influence the collective decision-making process of the target institution and its output*" (Oberthür & Gehring, 2006, p.38). This interaction can stimulate coevolution of the norms when the output at the target institution triggers new obligations at the source institution. Other international organizations may also influence the preferences of relevant actors and the resulting preference constellation. This could happen in a scenario where they commit actors in the target institution in ways that influence the range of options acceptable to them (Oberthür & Gehring, 2006).

To determine to what extent the *interaction through commitment* actually leads to the effectiveness of governance institutions, three hierarchically levels can be observed. Firstly, a source institution can produce collectively agreed knowledge or norms "*prescribing, proscribing, or permitting*" behavior of the members of the target institution, as its immediate *output*. Secondly, to become effective, this output must generate a behavioral *outcome* within the target institution. Thirdly, the behavioral outcome must have a targeted *impact* upon the environment or other domain (Underdal & Young, 2004).

In the aviation sector, the Kyoto Protocol triggered action within ICAO to take effective action regarding greenhouse gas emissions. In 1999 it requested the Committee on Aviation Environmental Protection (CAEP) "*to study policy options to limit or reduce the greenhouse gas emissions from civil aviation*" (ICAO, 1999), taking into account the IPCC Special Report

on Aviation and the Global Atmosphere that it demanded from the IPCC two years before. Though considering measures including levies, voluntary measures, technical and operational measures, emission standards, and emissions trading, the adoption of legally binding regulations to tackle greenhouse gas emissions in the aviation industry has been lacking until now. Most progress has been made in introducing more stringent noise standards, NOx-emissions standards and drafting non-binding guidelines regarding greenhouse gas emissions (ICAO, 2015a).
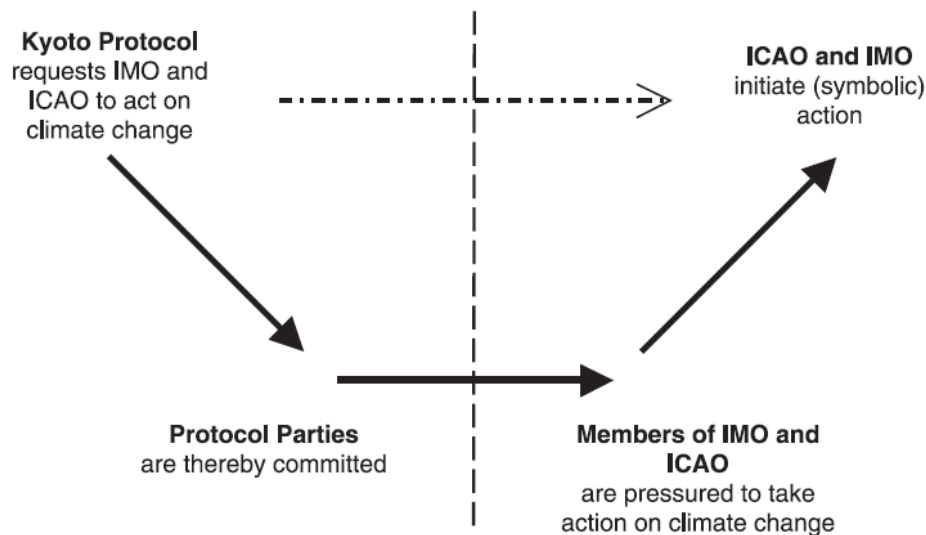
Figure 10 - Interaction through commitment, from Oberthür & Gehring (2006)

3.3.2 *LACK OF EFFECTIVENESS OF THE INSTITUTIONAL INTERACTION*

In terms of Underdal's levels of effectiveness, the case of the aviation industry shows that there has been change on both the level of *output* (the Kyoto Protocol mandating ICAO to tackle GHG-emissions within the aviation sector) and the level of *outcome* (ICAO increasing the priority of reducing GHG-emissions and CAEP studying policy options to reduce GHG-emissions). However until now, the *interaction through commitment* has been ineffective on the level of *impact*. Though several policy options to reduce GHG-emissions have been considered over the last two decades, none have been implemented so far and made legally binding for ICAO member states.

The lack of effectiveness on the *impact* level can be explained by a lack of translation from the *outcome* level (behavioral change) to the *impact* level (environmental effects). This stagnation can be explained by a limited behavioral change within ICAO as a whole – meaning across all member states. For ICAO to make amendments to the 1944 Chicago Convention it needs to reach agreement in its Assembly by a two-third majority vote (ICAO, 1944). Thus it would require a behavioral change within at least two-thirds of its member states upon a certain topic before it can effectively move forward as a whole.

Since ICAO consists of 196 members from both developed and developing countries, each having different perspectives on responsibilities in reducing GHG-emissions, it is very challenging for the source institution – the UNFCCC – to modify the behavior of (two-third of) ICAO member states in a similar direction. Another way for ICAO to reach an agreement would be then be when member states would make compromises in the decision-making process, and thus aim for consensus.

3.3.3 *Applying the law of the least ambitious program to ICAO decision-making*

However, aiming for consensus can have negative effects on the effectiveness on contemplated policies. According to Underdal's *"law of the least ambitious program"* (hereafter: LLAP) the effectiveness of an international agreement is limited by commitment level of the agreement's least interested party (Underdal, 1980). The LLAP is based on three fundamental assumptions. First, a decision usually requires the consent of all states to which the decision is intended to apply. Second, state behavior is assumed to be based upon their evaluations of the expected consequences of the alternatives in question. Third, states are assumed to be individualistically motivated – meaning that they are focused only on their own payoffs and derive neither positive nor negative utility from benefits contained by others (Hovi & Sprinz, 2006). Thus the LLAP implies that the result of international negotiations where reaching consensus is the main goal.

The outcome of the LLAP can be improved when the most reluctant party modifies its original position. When the aforementioned current *output* at the source institution is not sufficient, there are three ways to add pressure on the reluctant party. The first factor is the *threat of regulatory competition*. After the Kyoto Protocol addressed GHG-emissions from international transport for the first time, ICAO was mandated to take the responsibility for aviation emissions reductions. Until the Protocol's adoption in 2005, international transport had fallen off the UNFCCC's agenda for several years. Combined with failed initiatives from the EU and other institutions this resulted in a weak *threat of regulatory competition* (Oberthür & Gehring, 2006). More recently however, this threat has become more powerful with the EU including international aviation in their emissions trading scheme that will become effective again in 2017 if ICAO does not reach agreement on a global market-based measure.

The second factor is the *threat of unilateral action*. This occurs when domestic action is taken to internalize the environmental costs of aviation. Within the EU only the Netherlands introduced a fuel tax for domestic flights. Outside the EU it is the US, Japan, India, and Norway that have done the same (KiM, 2010). Though these cases show that some unilateral action has occurred, it is unlikely that this threat will cause a lot of pressure on ICAO. First, due to the 1944 Chicago Convention and hundreds of consecutive bilateral agreements between states that followed, states are exempted to pay fuel tax to one another. Thus implementing a domestic fuel tax could weaken the competitive position of national carrier's against foreign airlines. Second, it is impossible to take unilateral action to tax international aviation – constituting the greatest share in total aviation.

The third factor is an increase in the *output* at the source institution – the UNFCCC – which at the start of 2015 already seemed to occur. In advance of the next Conference of Parties that will be held in Paris, France in December 2015, states are developing the negotiating texts. The results from the Geneva Climate Change Conference in February 2015 show the increased political pressure from the UNFCCC on ICAO Parties and the role of *institutional interaction* in that perspective.

> *"In meeting the 2 °C objective, Parties agree on the need for a global sectoral emission reduction target for international aviation and on the need for all Parties to work through the International Civil Aviation Organization (ICAO) to develop global policy frameworks to achieve this target."*
>
> *- Geneva Climate Change Conference (2015)*

3.3.4 STRATEGIC BEHAVIOR BY ICAO AND THE AIRLINE INDUSTRY

Even though there is an increased threat of regulatory competition from the EU and increased pressure on norms of ICAO Parties from the UNFCCC Convention, it should be questioned whether that is sufficient to move ICAO towards effective climate change policies. The problem that still exists is the misalignment between the main objective of the Convention and ICAO. The Convention's primary focus is stabilizing greenhouse gas concentrations. Though ICAO includes addressing GHG emissions in their environmental goals (ICAO, 2015b), its main goal remains promoting aviation to stimulate further development. With key objectives misaligning, strategic behavior is bound to exist.

To illustrate the effect of strategic behavior on the decision-making process at ICAO, consider that from an environmental perspective it does not matter how emissions reductions are achieved. Instead it matters that they are realized to reach a certain environmental target, i.e. to stay below an increase of two-degrees Celsius by 2050 compared to pre-industrial levels. One effective way to achieve this is reducing emissions by lowering demand of air travel. Policies could be aimed at altering the preferences and thus behavior of travelers by making flying less attractive. As a result, travelers could switch to other modes of transport (*modal shift)* or decide to travel less (*transport demand loss*).

An effective policy option for ICAO to lower demand of air travel could be to implement a global fuel tax. This Pigouvian tax would then intend to correct the inefficient market outcome by being set equal to the social cost of negative externalities (GHG-emissions). Taking into account the high level of competition within the aviation industry and resulting low profit margins, it is reasonable to expect that airlines would at least partially pass through these costs to the consumer. Increased prices can then stimulate a *modal shift* or *transport demand loss*. For ICAO, having the main objective of 'promoting aviation', this policy option would then be highly undesirable. Instead it could behave strategically towards other options which affect air travel demand in a lesser way.

Furthermore, as was already shown in paragraph 2.2.1, other international organizations may also influence the preferences of relevant actors and the resulting preference constellation. This could happen in a scenario where they commit actors in the target institution in ways that influence the range of options acceptable to them. In the aviation sector, IATA - representing the airline industry - has a clear incentive to behave strategically towards ICAO to modify preferences their towards a policy option that is least costly to them.

3.4 SEARCHING FOR GREATER SOCIAL GAINS IN THE AVIATION INDUSTRY

The previous two paragraphs have shown that for the aviation sector to become more sustainable, it needs a policy that addresses each aspect – environmental, economic, political, and institutional – sufficiently. And even though this policy might already exist or be feasible to design, the law of the least ambitious program can hamper its development and implementation. This thesis attempts to find ways to tackle this challenge, such that a more purposeful aviation global market-based measure becomes feasible. To this end, a simplified and formalized rendition of the aviation sector is used in the following paragraphs.

3.4.1 FORMALIZING THE PROBLEM

Consider that the authority responsible to reduce greenhouse-gas emissions for the aviation sector, ICAO, finds itself three available policy options. These policy options would lead to environmental gains and economic losses - for now neglect other aspects such as political and institutional effects. The environmental gains incurred from each policy option are defined by the row:

$$G_p = G_{p-1} + 3 \ \textit{with } G_{p1} = 3$$

Also, consider that the economic losses are incurred by the aviation industry and are defined by the row:

$$L_p = L_{p-1} + 1 \ \textit{with } L_{p1} = 1$$

Furthermore, consider that the social gains are defined by the function:

$$S_p = G_p - L_p$$

If ICAO would implement neither of these policy options, the business-as-usual scenario would lead to a tenth of both the environmental gains and economics losses, resulting in a social gain of 0.2. All is summarized in
Table 6 below.

Table 6 - Formalization of the problem

	Policy 1	Policy 2	Policy 3	Defined by the row/function	BAU
Environmental gains	3	6	9	$G_p = G_{p-1} + 3 \ \textit{with } G_1 = 3$	0.3
Economic losses	1	2	3	$L_p = L_{p-1} + 1 \ \textit{with } L_1 = 1$	0.1
Social gains	2	4	6	$S_p = G_p - L_p$	0.2

From a social perspective, the objective is to maximize the social gains. Thus policy 3 would be the preferred choice, since it would result in the social optimum of 6. However, from the perspective of the airline industry, incurring the economic losses, the objective is to minimize losses. Thus the business-as-usual scenario would be the preferred choice.

The previous paragraph has shown that an increased *threat of regulatory competition* mainly from the EU and an increase in the *output* level at the UNFCCC has led to a behavioral change within ICAO, such that it has stated to work towards implementing a policy for the aviation sector. Assume that this pressure from other institutions is large and permanent, and that ICAO has no choice but to implement a policy. Thus the business-as-usual scenario can be neglected from this point onwards. Now also take into account that certain strategic factors can modify ICAO's preferences towards the least costly option for the airline industry, policy 1. The *law of the least ambitious program* applies and would lead to the lowest social gains. The resulting situation is schematically shown in Figure 11.
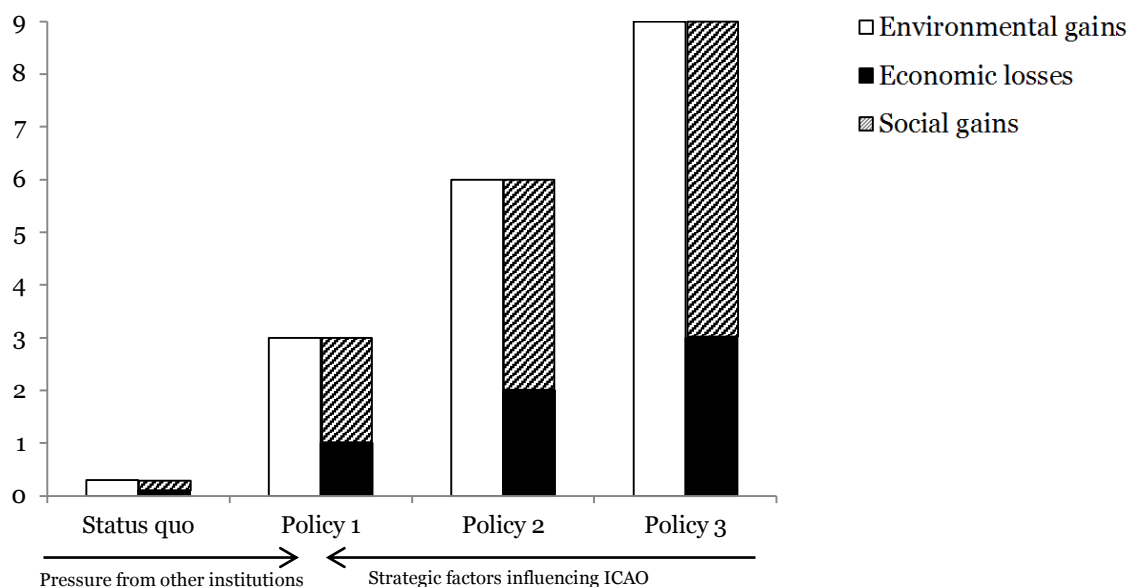
Figure 11 - The law of the least ambitious program

The important question here is how the preference of ICAO towards policy 1 can be shifted towards policies with higher social gains: policy 2 or 3. From the figure this can be achieved in two ways, either by improving pressure from other institutions or by less strategic behavior influencing ICAO. The next paragraph will provide four recommendations that affect these forces.

3.4.2 *MEANS TO OVERCOME THE LAW OF THE LEAST AMBITIOUS PROGRAM*

In Underdal's early work on the LLAP the tone was rather pessimistic in the sense that it showed how hard it can be to arrive at an effective international agreement (Underdal, 1980). Later work done by the International Institute for Applied Systems Analysis (hereafter: IIASA) focused on the implications of the LLAP. Work at IIASA focused especially on one means to overcome the LLAP: variable geometry (Victor, 2006). This paragraph will use that concept in the context of the aviation sector. Furthermore this paragraph introduces three newly defined means to overcome the LLAP.

APPLYING VARIABLE GEOMETRY SOLUTIONS

As paragraph 2.2.2 showed, the lack of effectiveness on the *impact* level can be explained by a limited behavioral change within ICAO as whole – meaning across all member states. This problem becomes even more challenging when taking into account that ICAO consists of 196 members from both developed and developing countries, each having different perspectives on responsibilities in reducing GHG-emissions.

One way to overcome this problem is by applying *variable geometry* solutions, which have been very successful in the formation of the European Union (Victor, 2006), and later in formalizing the emissions reduction targets in the Kyoto Protocol. The term is used to "*describe the idea of a method of differentiated integration which acknowledges that there are irreconcilable differences within the integration structure and therefore allows for a permanent separation between a group of Member States and a number of less developed integration units*" (EU, 2015). In other words, by incorporating the different structures of member states into the policy design for the overarching organization as a whole, variable geometry solutions can increase acceptance and compliance regarding that specific policy.

Relating this to the aviation sector, it was already shown before that the '*Common But Differentiated Responsibilities and Respective Capabilities*' principle of the UNFCCC

requires that ICAO should take into account the differences between developed and developing member states when designing the global market-based measure. Though ICAO's principle of '*non-discrimination*' seems to implicate the opposite, this conflict does not have to exist per se. ICAO could focus on designing a policy that does not discriminate between countries that are economically developed to a similar extent - e.g. the US, Japan, Australia, Canada and most northwestern European countries – to prevent competitive distortions among these states. At the same time, ICAO could differentiate between developed and developing countries according to their specific responsibilities and capabilities. By taking into account both principles a policy designed by ICAO could expect to encounter greater acceptance and compliance.

COMPENSATING LOSS INCURRING PARTIES

The example in paragraph 2.3 assumed that a certain policy leads to environmental gains and economic losses. By subtracting the latter from the former, the social gains can be calculated. The example also showed that the law of the least ambitious program leads to a weaker policy than would be desirable from a social perspective. One way to circumvent strategic behavior towards a weaker policy could be if the loss incurring parties are somehow compensated.

To illustrate, consider the example from the previous paragraph again. For every policy, the social gains are greater than the economic losses. If a mechanism would exist where the economic losses would be compensated by the social gains, there would still remain positive social gains after compensating for the economic losses. In fact, as Table 7 shows, these social gains after compensation can be defined by the row:

$$SC_p = SC_{p-1} + 1 \; with \; SC_{p1} = 1$$

Assuming full rationality, as a result of compensation the initially loss incurring parties would not have a preference anymore towards the relative weak policy option 1. In fact, it would be indifferent regarding all three policy options. Another important observation is that initially loss incurring parties would now also prefer a policy instead of the business-as-usual scenario, in which they would incur - albeit being minimal - a loss of 0.1. In other words, after compensation a Pareto improvement[10] is possible.

Thus, compensation for loss incurring parties has the potential to decrease strategic behavior towards a relatively weak policy and would allow the policy decision-maker to implement a more ambitious policy option that has the highest social gains.

Table 7 - Social gains after compensating for economic losses

	Policy 1	Policy 2	Policy 3	Defined by the row/function	BAU
Environmental gains	3	6	9	$G_p = G_{p-1} + 3 \; with \; G_1 = 3$	0.3
Economic losses	1	2	3	$L_p = L_{p-1} + 1 \; with \; L_1 = 1$	0.1
Social gains	2	4	6	$S_p = G_p - L_p$	0.2
Social gains *after compensating for economic losses*	1	2	3	$SC_p = S_p - L_p$	0.1

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[10] Given an initial allocation of goods among a set of individuals, a change to a different allocation that makes at least one individual better off without making any other individual worse off is called a Pareto improvement (Pang, Deng, & Chiu, 2015).

Another way to overcome the LLAP is to incorporate the risk of future economic losses. To illustrate, consider the example again given in the previous paragraph. It can be observed that the relationship between environmental gains and economic losses can be defined by the equation:

$$L_p = \frac{1}{3} \cdot G_p$$

Now consider that in the future the costs for achieving the same environmental gains are higher. This scenario can for instance unfold when a lack of earlier action results in increased costs for climate adaptation. Assume that the cost increase per one environmental gain can be described by the following formula:

$$L_{p,t} = \alpha_{p,t} \cdot G \ with$$

$$\alpha = \{\frac{1}{3}, \frac{1}{2}, 1, 2, 3, ...\} \, for \ t = \{1, 2, 3, 4, 5, ...\}$$

Furthermore, note that when policy option 3 is not chosen, the environmental gains are not maximal. In fact, policies 1 and 2 would lead to neglected environmental gains of 6 and 3, respectively. Now assume that e.g. in year 5 the scenario unfolds where a new policy has to be implemented to correct for earlier weak policies. This situation is described in Table 8.

The implications of this situation are as follows. If initially policy 3 is not chosen to be implemented, future economic losses to achieve the same environmental gains can be significantly higher than before. Thus by incorporating future economic losses into the decision-making process, parties that initially would strategically behave towards a relatively weak option should reconsider when they are fully rational. An important counterargument for this way of thinking is that very often in cost-benefit analyses - and especially in climate change decision-making *(see e.g. Stern's Review on Climate Change)* – discount rates are used to incorporate the time value of a certain utility. The initial loss incurring parties could argue that costs now are more important than in the future. However, whether a discount rate should be used or not depends on the situation. In a highly competitive industry where parties can already expect that extreme high future costs would be fatal to their existence the use of discount rates can be questionable.

Table 8 - Incorporating future economic losses

	Policy 1	Policy 2	Policy 3	Defined by the row/function
Environmental gains	3	6	9	$G_p = G_{p-1} + 3 \ with \ G_1 = 3$
Neglected environmental gains	6	3	0	$NG_p = G_{max} - G_p$
Economic losses at t=5	18	9	0	$L_{p,t=5} = \alpha_{p,t=5} \cdot NG$

INCREASING OUTSIDE PRESSURE THROUGH TRANSPARENCY

In his work on the effectiveness of environmental regimes, Oran Young stated that a "*sizable proportion of the success of environmental regimes is attributable to activities that are not regulatory in the ordinary sense. Often overlooked is the function of regimes in generating knowledge about the problems to be solved and contributing to a shared understanding of the issues at stake among participating actors*" (Young, 2011).

Translating these thoughts about environmental regimes towards policies that address the aviation sector it can be argued that besides the effect an aviation policy has on environmental, economic, social, and institutional aspects, it also has an effect upon the understanding the challenges in the sector as a whole. In most cases a set of available policies address multiple aspects of a problem differently. One policy might have a greater effect on the environmental aspects, while other policies might assign greater value to the economic, social or institutional aspects. Thus a set of policies can generate knowledge about what trade-offs exist with regard to the international environmental problem and can provide transparency in the policy decision-making process.

To illustrate, consider the example from the previous paragraph again. The three policies each address environmental and economic aspects differently such that gains and losses vary for each policy. Table 6 and Figure 11 both show that there is a trade-off between environmental gains and economic losses. Furthermore they show that even though there is a trade-off between the two aspects, greater social gains can be achieved by choosing either policy 2 or 3, as compared to choosing policy 1. By providing insight into the complexity of a problem policies can therefore increase awareness among actors that might not have been included in the decision-making process before. These 'new' actors then might have the possibility to influence preferences of already involved actors by exerting pressure.

3.5 CONCLUSIONS

To summarize, aviation's environmental impact is a tragedy of the commons resulting in negative externalities. An effective policy to solve this market failure requires not only an environmental fix, but a combination of social, economic, and institutional solutions (Bardwell, 1991). The study done by Solomon & Hughey (2007) provides useful insights into criteria that can be used to assess aviation environmental policies, and shall be used as a starting point for selecting and reshaping the criteria that can be used for the global market-based measure in Chapter 5. Whether an effective policy will be implemented at the ICAO level depends for a large share on whether the law of the least ambitious program can be overcome. This thesis had identified one from existing literature, and provided three newly defined means to overcome this barrier. Figure 12 provides a brief glimpse of how these four means relate to the rest of this thesis.
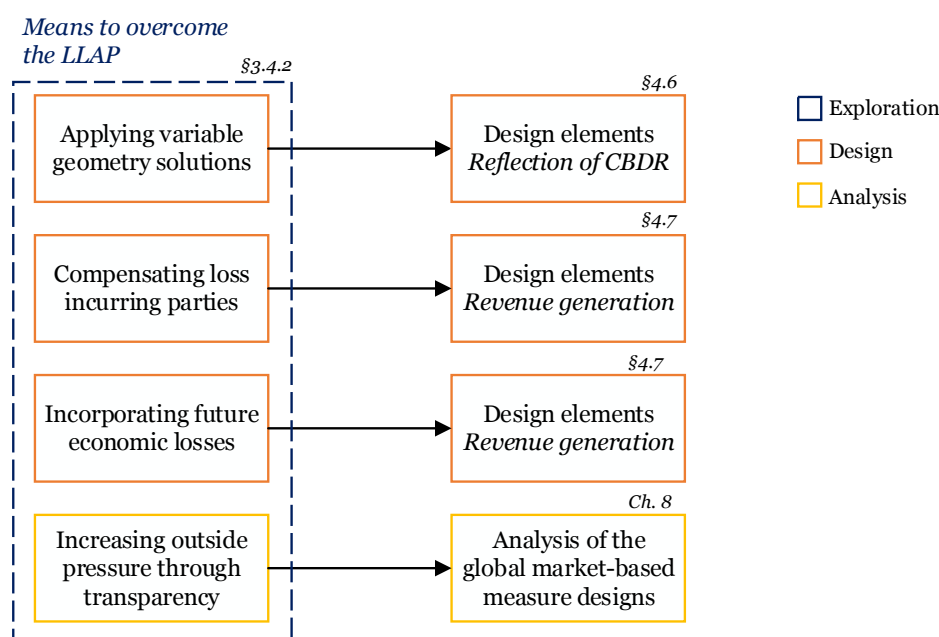
Figure 12 - Means to overcome the LLAP in relation to this thesis

To invent, you need a good imagination
and a pile of junk.

Thomas Edison

4 Design elements: an overview

Overcoming international environmental problems requires not only an environmental fix, but a combination of social, economic, and institutional solutions (Bardwell, 1991). A global market-based measure is a policy that addresses each of these aspects. This chapter provides an overview of design elements that have been identified by means of a literature review. Each paragraph describes a design element of which the interpretation is based upon findings in existing studies, new ideas following from these studies, and policy recommendations provided in paragraph 3.5. Since at this point of the analysis no decision has yet been made with regard to the type of market-based measure, a number of design elements are MBM-specific[11]. At the end of this chapter a summarized overview of design elements is given.

4.1 CHOICE OF POLLUTANT

Regarding the pollutant, paragraph 1.2 has shown that there is a variety of aviation emissions that have an effect on the environment, either direct or indirect. These include emissions such as CO_2, NO_x, aircraft particulates, and H_2O forming contrails and cirrus clouds. The global MBM could in theory regulate each of these emissions or a combination by converting the emissions to one scale. For example the non-CO_2 effects can be expressed in CO_2-equivalent emissions by taking into account the radiative forcing caused by those emissions.

4.2 TYPE OF FLIGHTS

The type of flights can be categorized differently. One distinction is whether the global MBM addresses only international flights or also domestic flights. Since ICAO was mandated by the UNFCCC to address only international aviation emissions (Oberthür & Gehring, 2006), the global MBM has the possibility to solely address international flights. Important to note here is that this amounts to approximately 65% of total aviation CO_2-emissions (Lee, Lim, & Owen, 2013). This means that although the global MBM implies a global nature, it does not cover worldwide aviation emissions. Another distinction in type of flights could be between passenger and dedicated cargo flights (FNI, 2014).

4.3 ACCOUNTABLE ENTITY

In the aviation sector there are many actors that can be held responsible for emissions (*for a detailed stakeholder analysis see Chapter 5*). These include passengers, airlines, airports, fuel suppliers, and individual States. Although the decision of which entity should be held accountable for reporting emissions does not have to influence other design elements, it does influence administrative complexity (Öko-Institut & CE, 2014). There are guiding principles that can be used to select which entity should be held accountable (Öko-Institut & CE, 2014):

---

[11] For example, the design element 'offset standards' is irrelevant in the case a global levy would be implemented.

i.   minimum administrative efforts by keeping the number of entities and number of information exchanges low.

ii. enhancement of the incentive to reduce emissions and alignment with the polluter pays principle.

4.4 OBJECTIVE

The objective states the target of emissions reductions that have to be achieved by the global MBM. Based on lessons drawn from already existing market-based measures (e.g. the EU ETS) these targets are normally set lower than the business as usual and moving towards a path consistent with an international climate target (Egenhofer, 2007). Setting initial targets close to the projected business as usual has sometimes led to problems with the oversupply of emission allowances, when emissions turned out to be lower than the level of the cap (IEA, 2010). A surplus of allowances can cause the price of allowances (in the case of ETS) or price of offset units (in the case of an offsetting scheme) to collapse, leading to a lack in carbon abatement investments (Anger, 2010; Lee et al., 2013). However setting highly ambitious environmental targets may harm the competitiveness of the industry (IATA, 2013a).

Considering the global MBM for the aviation industry a target could be carbon neutral growth from 2020 onwards. Emissions after 2020 are then capped at a specified level. This goal has already been adopted by ICAO and IATA and would fit in well with their current environmental strategy. Contrary to focusing on an initial point in time and capping emissions at that level, another way of looking at target-setting would be to focus on the end goal. In line with the *2010 IATA AGM Resolution on Climate Change* the target of the global MBM could also be set towards a 50% reduction of emissions by 2050 compared to 2005 levels. Another option would be to align the global market-based measure with the goal of limiting global temperature increase to 2°C by 2050.

4.5 EMISSION BASELINE

For both an offsetting scheme and emissions trading scheme there needs to be an emission baseline that serves as a reference point for the amount of emissions that are allowed, and the amount that has to be offset or traded (ICAO, 2015b; Öko-Institut & CE, 2014). If the objective of the global MBM would be to achieve carbon neutral growth from 2020 onwards, an emission baseline could be emissions in 2020. However, setting the baseline to emissions in a certain year would give accountable entities the perverse incentive to either delay or not report emission reductions in 2020 in order to acquire more emission allowances. Another option could then be to set the baseline to an average of emission in the period leading up to 2020, such as 2018 to 2020. In line with the objective proposed in the previous paragraph and other climate policies the emission baseline could also be set equal to emissions in 2005.

4.6 ALLOCATION OF REQUIREMENTS

In the case of implementation of an offsetting scheme or emissions trading scheme allocation of requirements can be done by auctioning or free allocation, or by a combination of the two (Svendsen & Vesterdal, 2003). In theory, the method of allowance allocation has no impact on the environmental outcome, i.e. it is the MBM's objective that determines total emission reductions (Stern, 2007). Allocation for free can assist affected parties (business and consumers) in the transition towards carbon pricing by decreasing the costs. Even if a firm receives more allowances than its total emissions, it would still see the theoretical incentive to reduce emissions since any surplus can be sold against the market price (IEA, 2010).

Free allocation can occur in three ways: (i) grandfathering based on a historic approach, (ii) grandfathering based on a benchmark approach, and (iii) with an 'output-based' allocation (Boemare & Quirion, 2002; Miola, Marra, & Ciuffo, 2011).

i. *Grandfathering based on a historic approach*
    Grandfathering based on a historic approach uses past emissions and is considered to be the simplest to implement (IEA, 2010). A disadvantage is that companies with the highest historical emission intensities receive larger allocations than more efficient competitors. In addition, carbon abatement investments that would have occurred as part of the business as usual operations can thus lead to windfall profits for these companies (IEA, 2010).

ii. *Grandfathering based on a benchmark approach*
    Another way of grandfathering is based on a benchmark approach, which is a process of determining the best practice and how all other practices relate to that best practice standard. With this approach, the emissions factor needs to be coupled with activity rate or output factors as a proxy for production (Egenhofer, 2007).

iii. *Output-based allocation*
     Free allocation on an 'output-based' level assigns allowances proportional to their current production, e.g. x permits per kWh for power plants or y permits per ton of aluminum (Boemare & Quirion, 2002). This allocation method thus taken into account efficiency within the sector and leads to less carbon leakage and damage to energy-intensive sectors (Takeda, Arimura, & Tamechi, 2011).

In practice there are downsides to free allocation including the decrease of market liquidity, the lack of a clear price signal towards investors, the incentive for new entrants to operate in high-emission activities, and windfall profits in case the allowance costs can be passed through to the consumer. Most importantly, if there is an overly generous free allocation of emission allowances the risk is created of preserving the status quo, whereas the objective of the MBM was to achieve change (IEA, 2010).

On the contrary to free allocation, auctioning enables governments to have a revenue stream that can be used to offset the impacts of the scheme on the affected parties and to fund e.g. energy efficiency, renewable energy, and climate adaptation for developing countries (IEA, 2010). In the case of a hybrid system with both grandfathering and auctioning, an additional advantage of auctioning arises when the objective of the MBM is set more ambitious, i.e. decreasing the emission baseline. Decreasing the amount of free allowances could lead to great resistance from the affected parties, while decreasing the amount of auctioned allowances might be considered easier (IEA, 2010).

4.7 REFLECTION OF CBDR

The UN's *Common But Differentiated Responsibilities and Respective Capabilities* principle has historically proven to be a hurdle in negotiations regarding aviation environmental policies. Since the Convention to the UNFCCC was unable to reach consensus on this matter, ICAO was mandated to address the environmental impact of aviation and to find solutions on how to address the UN's CBDR principle (see paragraph 1.3). One potential remedy as explained in paragraph 2.4.2 is to apply 'variable geometry solutions'. By incorporating the different structures of member states into the policy design for the overarching organization as a whole, variable geometry solutions can increase acceptance and compliance regarding that specific policy. Two basic approaches can be distinguished for distribution of obligations, both having a different impact on carbon leakage and international market distortion (Öko-Institut & CE, 2014):

i. *Aircraft operator-based*
Different aircraft operators would have different requirements based on the country in which they are registered.

ii. *Route-based*
Different routes would have different requirements based on the country of departure and/or arrival.

An aircraft operator-based differentiation would be administratively simpler because all flights of an operator would have the same requirements depending on the nationality of the aircraft operator. However it would distort the market since aircraft operators flying on the same route would have different requirements. Thus aircraft operators with lower requirements would be enabled to gain market share at the expense of operators with higher requirements (Öko-Institut & CE, 2014).

A route-based differentiation would imply that aircraft operators flying the same route would experience equal carbon requirements (Öko-Institut & CE, 2014). The differentiation would be based on the origin and destination country concerning that route. For direct flights this would not influence market competition. For indirect flights there is a possibility of market distortion when the passenger has a choice between hubs in countries with different requirements (Öko-Institut & CE, 2014; Piera, 2014a). The different requirements for routes can be implemented in two ways, by using:

i. *Stringency levels*
Stringency levels are applied as such that e.g. routes between two well industrialized countries are subject to stronger requirements than routes between two developing countries (Öko-Institut & CE, 2014).

ii. *Phased-in approach*
Routes to and from certain countries could initially even be exempted from requirements. This approach - which refers to as *incrementalism* - suggests a gradual expansion of the market-based measure's geographical scope to include all routes at a certain point in time (Piera, 2014a).

There are various differentiation criteria possible that could determine which routes will be covered and by when (Öko-Institut & CE, 2014), see below. In fact, the 2013 ICAO Resolution on the global MBM requests ICAO Council to analyze the exemption of flights from developing countries whose share in global aviation activities is below 1% - commonly referred to as the *de minimis rule* (ICAO, 2013b).

i. The share of routes in total aviation
ii. The maturity of aviation markets, e.g. expressed as the number of arriving or departing revenue tonne kilometer (RTK) per inhabitant
iii. Economic development, e.g. expressed as GDP per capita

In conclusion, although any kind of differentiation between States inherently influences market competition, the requirement to address the UN's CBDR principle urges ICAO to find a solution. The best way forward would then be to find a solution that satisfies the CBDR principle and minimizes market distortion. In fact, the last two ICAO Assemblies have recognized that *minimalizing* market distortions should be a principle when designing a global MBM, thus implicitly acknowledging that they are unavoidable (Piera, 2014a).

4.8 REVENUE GENERATION MECHANISM
Depending on the type of MBM (levy, offsetting, emissions trading) and the decision on allowance allocation there is a possibility of generating a revenue stream from the global

MBM. The easiest way of creating a revenue stream would be by imposing a levy on the accountable entity, e.g. $25 per emitted tonne of CO_2. In the case of an offsetting scheme one way to create a revenue stream could be by applying a transaction fee to each purchased offset unit. When implementing an emissions trading scheme, revenue can be generated when full or partial auctioning is used as an allocation method. The revenue stream from an aviation global market-based measure could be used a source for climate financing needed to limit the global temperature to 2°C by 2050 (ICAO, 2011). To achieve this objective, revenue streams from aviation can be applied in the following two ways: (i) mitigating the environmental impact of aircraft emissions, and (ii) supporting developing States with climate change mitigation and adaptation (ICAO, 2011).

i. *Revenues for mitigating the environmental impact of the sector*
The first option implies that the revenue stream collected from the global MBM flows back to the aviation sector. Revenues can be used to help aircraft operators with innovation in technology, operations, and infrastructure to enable more emissions reductions from the sector.
> This relates to the means described in chapter 3 that 'loss incurring parties should be compensated' to move towards a more ambitious policy and increase social gains.
> Innovation can lead to increased deployment and decreasing costs of in-sector emission reductions. Hence this revenue generation mechanism also relates to the means described in chapter 3 that 'future economic losses should be incorporated into decision-making'.
> A revenue generation mechanism is furthermore in line with Stern's recommendation of implementing policies that support innovation and the deployment of low-carbon technologies to overcome market imperfections.

ii. *Revenues for climate financing*
The second option means that the aviation sector is used as a source to assist developing countries in their attempt to deal with climate change. One way how this could be operationalized is when the revenue stream collected from the global MBM is used for the Green Climate Fund (GCF). This UNFCCC fund was a result of the UN Climate Conference in Cancun and was founded as a mechanism to redistribute money from the developed to the developing world in order to assist the developing countries in adaptation and mitigation practices to counter climate change. The UN's Advisory Group on Climate Change Financing (AGF) stated that international aviation could be a potential source of revenue through a fuel levy, passenger ticket tax or emissions trading system contributing up to up to $3 billion per year to long-term climate financing (AGF, 2010). By 2020, this revenue stream could even grow to $12 billion per year taking into account a carbon charge of $25 per tonne of CO_2 on international transport (IMF, 2011).

4.9 PRICE ESTABLISHMENT
For the three MBM options - global levy, offsetting, ETS - the establishment of a price is different.

i. *Marginal cost of the emission*
Regarding the global levy, ideally an optimal emission is equal to the marginal damage cost of the emission (Carlsson & Hammar, 2002). With such a charge a firm would reduce its emissions until the marginal abatement cost is equal to the marginal damage of the emission. A disadvantage of using a fuel tax is the uncertainty with regard to reaching a specific emission reduction objective. In order to define the adequate fuel tax level, information is necessary regarding abatement costs and price elasticities. Iterative steering by the regulator could increase the probability of reaching an environmental target (Carlsson & Hammar, 2002).

ii. *Via the market*

For both an offsetting scheme and emissions trading scheme, the price is determined by the market. In case of implementing an offsetting scheme, the price of offsets is determined by the supply by project operators and demand by the accountable entity. In case of implementing an ETS, the price is determined by supply and demand of allowances. Despite that in the end market dynamics determine the price of offsets or allowances, market design influences market dynamics. Setting targets close to the business as usual scenario can lead to an oversupply of offsets or allowances. This can then be followed by a price collapse and lack in carbon abatement investments (IEA, 2010). To avoid oversupply causing problems in the early stages of an emissions trading scheme, several strategies can be employed. Firstly, by using a transition phase with no banking to subsequent periods ensures that any allocation mistakes are not carried forward to future trading periods (IEA, 2010). Secondly, a price floor can be used to prevent a price collapse and to stimulate carbon abatement investments in case of an oversupply (Stranlund, Murphy, & Spraggon, 2014; Wood & Jotzo, 2011). Thirdly, by linking the ETS to other markets the market liquidity is enhanced, i.e. in case of an oversupply allowances could be sold to parties in other markets (IEA, 2010). Fourthly, policy fixes such as back-loading (short-term measure) or a market stability reserve (long-term measure) could be implemented, as is done for the EU ETS (EC, 2015b). With regard to an offsetting scheme less policy fixes are available to adjust the market price.

4.10 OFFSET STANDARDS

Key to using an offsetting or cap-and-trade scheme is the quality of offsets used to ensure the environmental integrity of the global MBM (Hemmings, 2015). In addition, as paragraph 1.4 explained, offsets should be additional, not double-counted, and permanent. These offsets are available on the following markets.

i. The *compliance market* that was created by the Kyoto Protocol, which established the *Clean Development Mechanism (CDM)* and *Joint Implementation (JI)*

ii. The *sectoral mechanisms* that are currently under negotiation at the UNFCCC, including the *New Market Mechanism (NMM)* and *Framework for Various Approaches (FVA)*

iii. The *voluntary market,* which can include many protocols. Examples are the *Gold Standard*, *Verified Carbon Standard (VCS)*, *VER+ Standards*, and *Plan Vivo*.

iv. The *allowance market,* by acquiring allowances from cap-and-trade schemes, such as European Allowances (EUAs) from the European Emissions Trading Scheme (EU ETS).

Besides differentiating offsets on their market origin (either the compliance), another distinction could be whether the offset has other benefits besides emission reductions. In the offset industry the distinction is made between 'minimum standard offsets' and 'gourmet offsets', of which in general the latter have a considerable higher price in the voluntary carbon market (Stockholm Environment Institute, 2011b).

i. *Minimum standard offsets*: offsets that are real, not-double counted, and permanent.

ii. *Gourmet offsets*: offsets originating from projects that in addition to additionality have strong social and environmental benefits.

4.11 ADMINISTRATION AND MONITORING

The administration of a global MBM could be done in different ways depending on the nature of the activity (ICAO, 2013c). Activities that are best harmonized across the global system can be undertaken by one or more international bodies such as ICAO, UNFCCC, World Bank. These activities could include e.g. the establishment of monitoring, reporting and verification processes and in case of an offsetting scheme or ETS, e.g. the types of offsets eligible for use in the global MBM and the calculations for the allocation of emissions. Other activities could fall more naturally to States, e.g. the regulation of aircraft operators (ICAO, 2013b).

Reliable and accurate monitoring of emissions will be essential both to track progress towards the global MBM objective as well as to administer the system (ICAO, 2013b). Monitoring should reflect all measures that aircraft operators can take to reduce emissions and should be harmonized globally (ICAO, 2013b). Aircraft operators are currently obliged to record the amount of fuel on board before take-off and after landing (Öko-Institut & CE, 2014). By taking into account the fuel used and plane type the emissions can be calculated. These should then be reported to the global MBM administration body which checks for compliance. In between the aircraft operator and administration body can be a third-party verifier and/or single state authority that for increased verification (ICAO, 2013b). This whole process is commonly referred to as the *monitoring, reporting and verification* (*MRV*) of emissions.

4.12 COMPLIANCE AND ENFORCEMENT

The enforcement of a market-based measure depends not only on the technical ability to detect violations (monitoring), but even so on the legal ability to deal with them once detected (Boemare & Quirion, 2002). In order to enforce compliance with the global MBM, an adequate *legal vehicle* is required. In his article "*The challenge of finding a legal vehicle to enforce compliance with a global aviation emissions scheme*" Piera (2014b) mentions several possibilities, each having their respective advantages and disadvantages:

i. *Standards*
The Chicago Convention entrusts ICAO with the mandate to develop *standards* addressing "matters concerned with the safety, regularity, and efficiency of air navigation" (Piera, 2014b). Provisions for the global MBM could be developed through standards that would form part of a new Annex to the Chicago Convention. Advantages are the relatively short implementation period and the ability to bypass national legislatures. Disadvantages are the non-binding character of standards and the simplicity to opt out enabling the possibility of free riding (Piera, 2014b).

ii. *Assembly resolution*
A global MBM could also be adopted through an ICAO *Assembly resolution*. Advantages are that similarly to standards, the implementation period is relatively short. Furthermore the non-binding nature of an Assembly resolution makes it a flexible legal vehicle. The main disadvantage of this instrument is the difficulty with enforcing the scheme (Piera, 2014b).

iii. *International convention*
Another possibility would be to adopt the global MBM by introducing a new *international convention*. Main advantages are the relative simplicity to address issues such as enforcement and sanctions with a treaty. In addition, a new convention has the ability to establish a legal personality to handle enforcement. Disadvantages are the high uncertainty with regard to approval by individual states and the long negotiation and adoption period for a new convention (Piera, 2014b).

iv. *Compliance through transparency*

Regardless of the legal vehicle chosen, *compliance through transparency* should be a cornerstone in designing a global MBM (Piera, 2014b). Information regarding emissions and solutions to overcome these emissions could be made explicit. The general public would then be able to identify non-compliant aircraft operators which may lead to harmful reputational losses within the industry. As such, transparency could serve as a *quasi-enforcement mechanism* (Piera, 2014b). This is in line with the argument in paragraph 2.4.2 that increasing outside pressure through transparency can lead to better system performance.

v. *External enforcers*

Besides enforcement by ICAO, actors outside ICAO can serve as *external enforcers*. Both industry stakeholders and States have historically induced compliance. With regard to the global MBM, IATA could make compliance to the global MBM mandatory for its members. States could also introduce amendments to their air services agreements to allow for operational bans with regard to non-compliant aircraft operators of other States (Piera, 2014b).

4.13 CONCLUSIONS

In this chapter the design elements of the global market-based measure have been identified and described based on a literature review. A summarized overview of design elements and their possible interpretation is given in Figure 13. In the next chapter a legal and stakeholder analysis shall be performed to demarcate the design space.

DESIGN ELEMENTS OF THE GLOBAL MBM
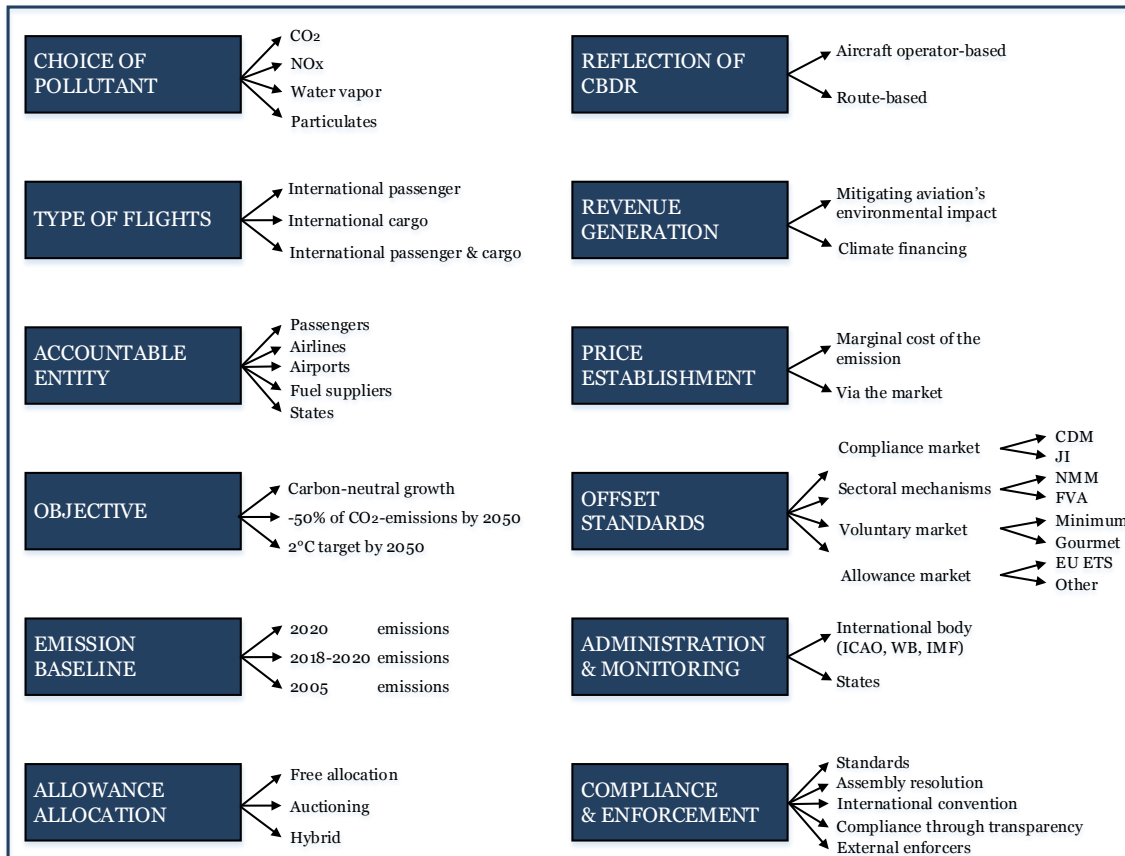
Figure 13 - Design elements of the global MBM

Coming together is a beginning; keeping together is progress; working together is success.

Henry Ford

5 Demarcation of the design space

In designing the global market-based measure there are endless possibilities. Besides the type of market-based measure - including a global levy, mandatory offsetting and emissions trading - the previous chapter has shown the wide variety of elements that constitute such a measure. Nevertheless there are legal and political boundaries that should be taken into account when designing the global MBM. This chapter identifies these boundaries with the purpose of demarcating the design space. In addition, the stakeholder analysis is used to redefine the criteria in order to make them specific to the aviation global MBM.

5.1 PROBLEM OWNER

The organization that is primarily responsible for addressing international aviation emissions is the International Civil Aviation Organization (ICAO). Thus ICAO is the leading organization in designing a global market-based measure for the aviation industry and is considered to be the *problem owner* towards which this thesis is mainly directed. The origin of ICAO is the signing of the Chicago Convention from 1944. Since then ICAO has been working with the convention's 191 Member States and aviation organizations to coordinate and regulate international air travel. The structure of ICAO is graphically shown in Figure 14.
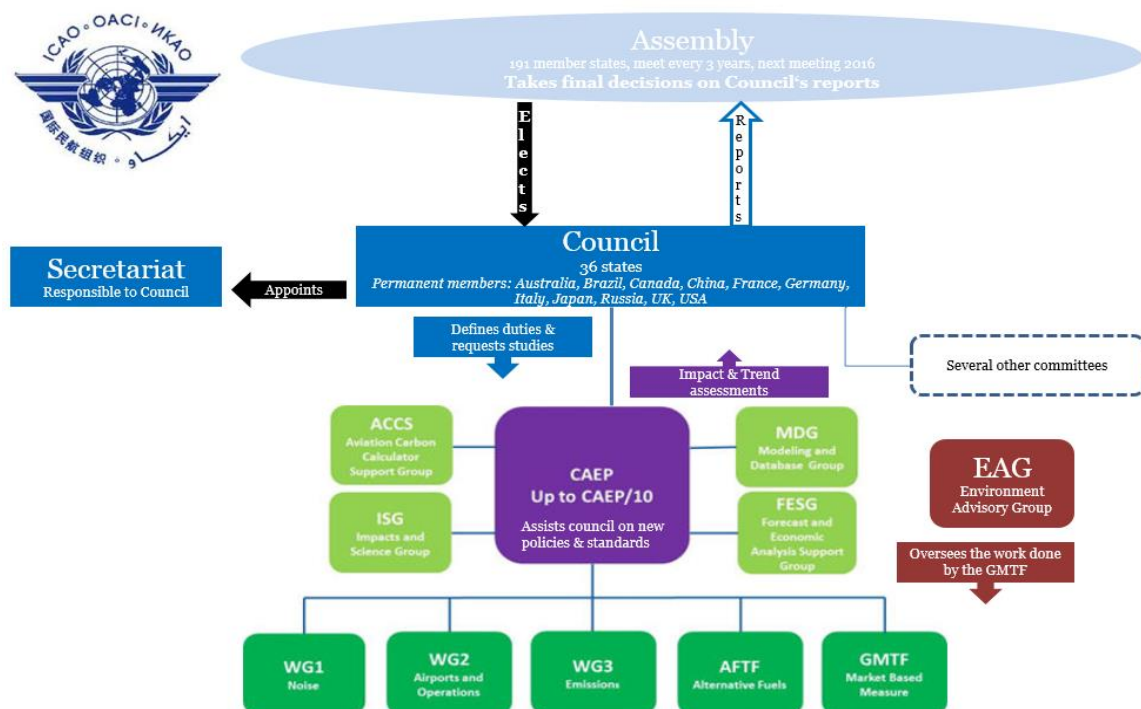
Figure 14 - The structure of the International Civil Aviation Organization

The ICAO Assembly meets every three years and provides general policy guidelines for the work of other ICAO bodies framed in the 'Assembly Resolution'. The ICAO Council governs the organization in each three years between the Assembly Resolutions. The Council passes resolutions and recommendations, and in addition adopts legally binding standards that are included in annexes to the ICAO Convention. This Convention also allows for the establishment of committees, of which several are into operation. Environmental matters are generally concerning the Committee on Aviation Environmental Protection (CAEP) that was established by the ICAO Council in 1983. CAEP prepares the Council's decisions on environmental matters (Oberthür, 2003). As a result of the 38th Assembly in 2013 ICAO set up two different working groups to focus on the global MBM:

i.   *Environment Advisory Group (EAG)*
     The EAG was established in 2014 to oversee and coordinate the work on developing proposals for a global MBM and to focus on the international policy aspects related to an MBM for aviation. The EAG comprises 17 ICAO member states with a great variety in geographical scope and level of development: Argentina, Brazil, Canada, China, Egypt, India, Italy, Japan, Mexico, Russian Federation, Singapore, South Africa, Spain, Tanzania, United Arab Emirates, United Kingdom and United States. Other Council members and non-Council representatives are also expected to be invited to participate in the group, along with observers from industry, non-governmental organizations and other bodies (Green Air Online, 2014a).

ii. *The Global MBM Task Force (GMTF)*
     The GMTF was enacted to tackle technical aspects regarding (1) monitoring, reporting and verification (MRV), and (2) criteria for the emissions units to be eligible under the global scheme. Furthermore, the GMTF is also conducting quantitative analysis (ATAG, 2015). Outside experts with relevant MBM experience are nominated by CAEP members and observers (Green Air Online, 2015b).

To facilitate the development of the global MBM, the ICAO Secretariat produced an outline proposal and key elements for a possible scheme. This proposal is continuously being refined by the EAG and GMTF and is referred to as the *Strawman*[12] (Green Air Online, 2015b). The ICAO Assembly resolution passed in 2013 requested regional workshops on the global market-based measure should be organized to invite officials and experts of ICAO member states and relevant organizations to discuss progress on the Strawman (Green Air Online, 2014a). These are referred to as Global Aviation Dialogues (GLADs). A roadmap towards the next ICAO Assembly in October 2016 – during which adoption of the global MBM is scheduled - is shown in Figure 15 (ICAO, 2015a).

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[12] A straw-man proposal is a brainstormed simple draft proposal intended to generate discussion of its disadvantages and to provoke the generation of new and better proposals.
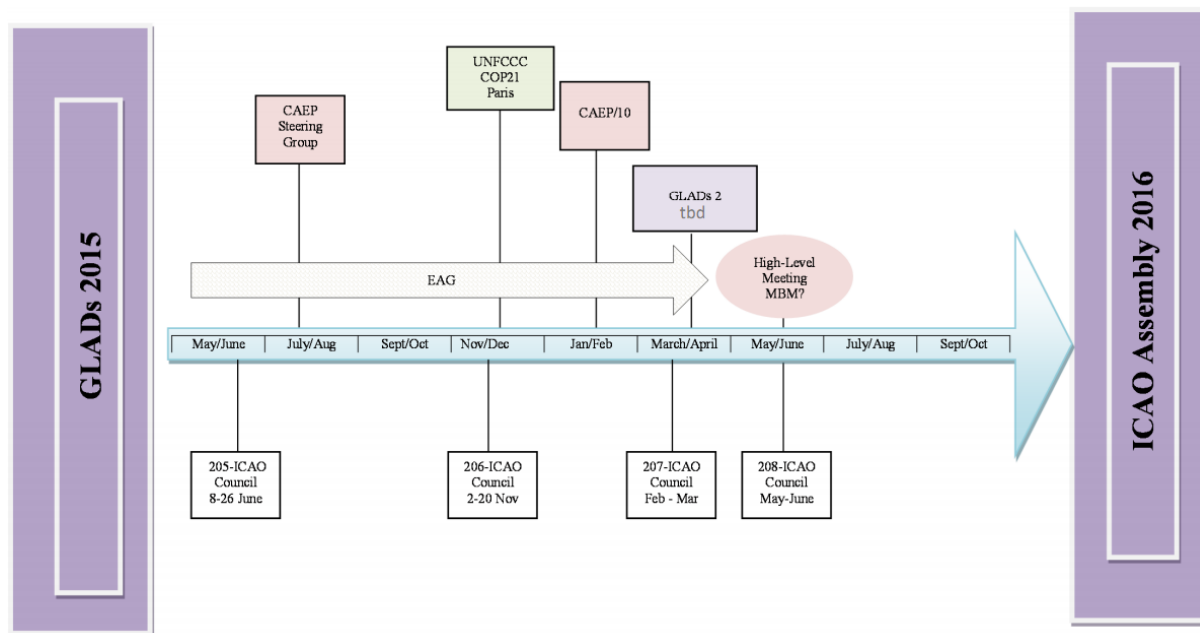
Figure 15 - Roadmap towards the ICAO 2016 Assembly

5.2 LEGAL OBSTACLES TO IMPLEMENTING A GLOBAL LEVY

Although taxation is an option to address climate change, such an alternative faces numerous hurdles in the international aviation context. An important hurdle is that fuel, which is commonly used in the aviation industry to measure emissions, has traditionally been exempted from taxes. This exemption derives mainly from two sources: the 1944 Chicago Convention and bilateral air service agreements (BSAs) (Piera, 2015).

i. *The 1944 Chicago Convention*
   This convention was established to coordinate and regulate international air travel (ICAO, 1944). It contained the basic principles that "*international civil aviation should be developed in a safe and orderly manner, and that international air transport services should be established on the basis of equality of opportunity and operated soundly and economically*" (ICAO, 2006). With regard to levies Articles 15 and 24 are relevant (KiM, 2010).

   > Article 15, referring to airport and similar charges: "*no fees, dues or other charges shall be imposed by any contracting State in respect solely of the right of transit over or entry into or exit from its territory of any aircraft of a contracting State or persons or proper ty thereon*" (ICAO, 1944).

   > Article 24, referring to customs duty: "*fuel on board the aircraft of a contracting State, on arrival in the territory of another contracting State and retained on board on leaving the territory of that State shall be exempt from customs duty, inspection fees or similar national or local duties and charges*" (ICAO, 1944).

ii. *Bilateral air service agreements*
   The BSAs were established for development of the aviation sector and expansion of international trade and travel (IMF, 2011). Despite the fact that the Chicago Convention does not prohibit the taxation of fuel that is added to the aircrafts' tank in a State itself, the existence of more than 4,000 existing bilateral air service agreements prohibits taxation of fuels used for international aviation (KiM, 2010).

Given the prime objective of ICAO to promote international aviation and emphasis on growth of the sector, it is unrealistic to expect any changes to the existing Chicago Convention that would permit the imposition of taxes on fuel since any aircraft fuel "*may [only] have an adverse economic and competitive effect on international air transport operations*" (Piera, 2015). Although in the context of the UNFCCC States have now again put forward the idea of taxing international aviation for climate change adaption purposes (see paragraph 3.3), imposing a global levy requires the support of many States. Making amendments to the Chicago Convention requires two-thirds majority (128 States), and would not be binding on States that did not ratify it. Amending the bilateral air service agreements would be more straightforward since any change can be made based on mutual consent (IMF, 2011), but it would be difficult to receive support from States to change more than 4,000 existing agreements (Piera, 2015).

5.3 RELEVANT STAKEHOLDERS AND THEIR OBJECTIVES

This paragraph contains an analysis of stakeholders to the MBM, their interests and agenda, and how that translates to relevant design elements and criteria. The view of ICAO – the problem owner in this thesis and decision-maker - is described in paragraph 5.3.1. A variety of ICAO Member States have openly expressed their interests with regard to the scheme, either individually or through an intergovernmental organization. These views will be presented in paragraph 5.3.2. Other important stakeholders are airline associations, of which the International Air Transport Association (IATA), representing 250 airlines or 84% of total air traffic, is probably the most influential. The Association of European Airlines (AEA) also has a great interest in the global MBM, because a global scheme might restore market distortion effects caused by the EU ETS. The views of these airline associations are presented in paragraph 5.3.3. Lastly, the views of non-governmental organizations are discussed in paragraph 5.3.4.

5.3.1 ICAO

To facilitate the development of the global MBM, the ICAO Secretariat produced an outline proposal and key elements for a possible scheme. From 2013 onwards this proposal has been refined by the EAG and GMTF and is referred to as the *Strawman*[13] (Green Air Online, 2015b). During the Global Aviation Dialogues (GLADs) in April 2015 ICAO showed it is working towards a *global mandatory offsetting scheme*. Whether this scheme should include a revenue generation mechanism or not has not been stated. Through the 38th Assembly though, ICAO expressed the concern that international aviation would be used as a source for climate financing (ICAO, 2014c). Furthermore ICAO stated during the GLADs a number of design elements and their interpretation that are included in the ICAO Strawman. These are shown in Table 9. Although these design elements and their interpretation are not official, they indicate towards what direction ICAO is heading. It is unlikely ICAO will alter these design elements since they are elementary and limited time after the first GLADs has to be spent on deciding upon the other design elements (Green Air Online, 2015b).

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[13] A straw-man proposal is a brainstormed simple draft proposal intended to generate discussion of its disadvantages and to provoke the generation of new and better proposals.

Table 9 - Design elements included in the ICAO Strawman

Design element	Interpretation
Choice of pollutant	CO_2 emissions
Type of flights	International passenger & cargo
Accountable entity	Aircraft operators
Objective	Carbon-neutral growth
Emission baseline	Emissions in 2020
Enforcement mechanism	Assembly resolution and standards

5.3.2 MEMBER STATES

UNFCCC

As paragraph 3.3 already described, the interaction between ICAO and the UNFCCC can be characterized as *interaction through commitment*, where certain members of a source institution (UNFCCC) affect the preferences of actors related to the target institution (ICAO). Due to this interaction, ICAO Member States are not only able to influence the progress with regard to the global MBM on the ICAO level, but also collectively through the UNFCCC. In fact, as was already stated before, Parties to the Convention have expressed the ambition with regard to the aviation sector that:

i. "*ICAO should develop a global policy framework in order to meet the 2 °C objective by 2050*" (ADP, 2015).
ii. "*ICAO should develop a levy scheme to provide financial support for the Adaptation Fund[14]*" (ADP, 2015).

Although these statements included in the negotiating texts towards COP21 in Paris, December 2015 do not provide any clarity with regard to whether such a "global policy framework" or "levy scheme" should be in the form of a market-based measure, it does show that the UNFCCC States attach significant value to the environmental performance of the aviation sector, and that the aviation sector should contribute to climate change action in developing countries. These preferences of States should thus be taken into account when designing the global market-based measure in order to increase stakeholder support. With regard to the first statement, it shows that the *environmental effectiveness* is a very important criterion to the UNFCCC States. An objective of the global MBM that would be in line with the first statement is to limit international aviation emissions such that the 2 °C target by 2050 can be met. With regard to the second statement, it shows that *equity considerations between nations* is an important criterion to the UNFCCC. In terms of design, the global MBM could include a revenue generation mechanism that is aimed towards climate financing. In fact, the UN Secretary General's climate finance report recommended using the revenues of a global market based measure to help the developing countries tackle climate change (Transport & Environment, 2012b). The above is summarized in Table 10.

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[14] The Adaptation Fund is a long-established UNFCCC fund set up to finance adaptation projects and programmes in developing countries particularly vulnerable to the adverse impacts of climate change. The fund is partly financed by a share of proceeds from the UN's clean development mechanism (CDM) project activities (Green Air Online, 2015a).

Table 10 - Preferences of the UNFCCC

UNFCCC	**Preferred MBM type**	**No clear preferences**	
	Important criteria	*Related design elements*	*Interpretation*
	Environmental performance	Objective	Target towards 2 °C by 2050
	Equity considerations between nations	Revenue generation mechanism	For climate financing (Adaptation Fund)

EUROPEAN UNION

Even though the EU included the aviation sector into its emissions trading scheme, the EU stated that a global approach remained the preferred option (Carbon Market Watch, 2013). With regard to the global MBM there are two important dilemmas that the EU might be facing.

Firstly, with its "stop-the-clock" the EU promised to amend its ETS if ICAO reaches agreement on a global market-based measure. However, the Strawman indicates that ICAO is moving towards an offsetting scheme, which in its design is very different than a global emissions trading scheme would be. If ICAO would propose an offsetting scheme by the next Assembly in October 2016, it will be harder for the EU and its Member States to satisfy its promise to amend the ETS if the global scheme does not have a similar ambition on reducing aviation emissions (Green Air Online, 2012). The argumentation behind this first dilemma is supported the statement from the European Commission's climate director Jos Delbeke, who argued that any system would have to deliver more emission reductions than the current EU system, and be non-discriminatory (Transport & Environment, 2012a).

Secondly, another dilemma facing the EU is what to do when ICAO is not able to reach consensus on the global MBM at the next Assembly. By law, all international flights arriving or departing the EU would be included again in the EU ETS from 2017 onwards. Similarly to 2013 when the EU decided to include international aviation in its EU ETS it could count on significant resistance from other countries. The above is summarized in Table 11.

Table 11 - Preferences of the EU

EU	**Preferred MBM type**	**Emissions trading**	
	Important criteria	*Related design elements*	*Interpretation*
	Percentage of total emissions addressed	Objective	More than the current EU ETS
	Economic distortion effects	Reflection of CBDR	Minimizing differentiation between States

INDIVIDUAL COUNTRIES

In this stage of the negotiations towards reaching consensus on the global MBM, a number of countries have expressed their opinions rather openly.

i. The United States have rejected the idea of CBDR within ICAO. In the shipping sector, the United States have blocked even the smallest progress towards multilateral solutions (Transport & Environment, 2012c).

ii. Emerging economic countries such as China and India, along with American countries such as Brazil and Argentina are not very content with a possible implementation of a global MBM for the aviation industry. These fast-developing countries are afraid of the additional costs a global MBM poses on their projected growth. As such they argue in favor of the CBDR principle, in which the responsibility for mitigating international emissions rests with the developed nations (Green Air Online, 2012).

iii. African States possibly even have a more negative feeling towards implementation of a global MBM for the aviation industry. During the last two ICAO Assemblies, in 2010 and 2013, African States have been strongly pushing for the inclusion of a *de minimis* threshold that would exempt them from the global MBM (Piera, 2014a).

iv. The Russian Federation has taken a totally different approach by not focusing on the CBDR discussion, but rather on the decision with regard to the type of market-based measure to be implemented by 2020. The Russian Federation had insisted on a global levy, and asked the ICAO Secretariat to include this option as well when working towards the next Assembly (Green Air Online, 2014b).

The interests of countries are in sharp contrast with one another, highlighting the conundrum that still exists within ICAO regarding the CBDR-principle, and the urge that the issue must be addressed in order to reach agreement by the 39th Assembly in 2016 (Green Air Online, 2012). The above is summarized in Table 12.

Table 12 - Preferences of individual countries

	Preferred MBM type	**Indifferent**, except Russia (global levy)	
Individual countries	*Important criteria*	*Related design elements*	*Interpretation*
	Economic distortion effects	Reflection of CBDR	Minimizing /maximizing differentiation between States

5.3.3 *AIRLINE ASSOCIATIONS*

INTERNATIONAL AIRLINE TRADE ASSOCIATION
While the ICAO Member States seem to be mainly focusing on environmental effectiveness of the global MBM and how responsibilities should be defined between countries, the aviation industry itself is mainly concerned with more economical and practical aspects of the global MBM. The International Air Transport Association (IATA), representing 250 airlines or 84% of total air traffic, is probably the most influential airline association. Its members have supported a resolution that recommends a set of principles that could be applied to the global MBM in a post-2020 carbon-neutral growth agreement (IATA, 2013a). This resolution is aimed to "*give governments momentum and set of tools as they continue their difficult deliberations*" (IATA, 2013b). At the Global Aviation Dialogues in April 2015, an IATA spokesperson said the industry wanted regulation through a global MBM for two reasons:

"Firstly, the global market-based measure will help us reach the climate goals we have set, which are closely aligned with those of ICAO, and as an industry that works to global standards, we also need one global measure instead of a patchwork of initiatives by States that in the end do not serve the environment or the aviation sector".

IATA's Senior Vice President Paul Steele
(Green Air Online, 2015a)

In IATA's plan towards carbon-neutral growth, an MBM is one of the four pillars of the aviation industry's strategy on climate change. Improvements in technology, operations and infrastructure are supposed to deliver the long-term solution for aviation's sustainability. A single MBM is considered critical in the short-term as a gap-filler until technology, operations and infrastructure solutions mature (IATA, 2013b). A global offsetting scheme is IATA's stated preference because it is a "*simple, easy-to-understand design, easy for airlines to comply with and easy to administrate, adaptable and responsive to specific needs, cost-efficient, and politically feasible*" (IATA, 2014). In other words, IATA would prefer a global MBM that would minimize the additional (administrative and financial) burden a global MBM would pose on its member airlines.

With regard to addressing the differences in responsibilities IATA differentiates not on the basis of countries per se, but rather on the basis of aircraft operators. IATA has opted for a flexible solution, based on mutual understanding, which bridges the different circumstances of fast growing airlines in emerging markets and those in mature markets (IATA, 2013b). On the subject of a revenue generation mechanism within an offsetting scheme, IATA's resolution states that any revenue generated by the MBM should not be used for climate financing (Carbon Market Watch, 2013; IATA, 2013a). Rather, if any revenue would be raised by the MBM, IATA prefers them to finance the greening of the sector by e.g. partially funding more fuel-efficient aircraft or other environmental upgrades (Transport & Environment, 2012b). The above is summarized in Table 13.

Table 13 - Preferences of IATA

	Preferred MBM type	Offsetting	
	Important criteria	*Related design elements*	*Interpretation*
IATA	Economic distortion effects	• Reflection of CBDR	• Include CBDR
	Administrative feasibility	• Administration & monitoring	• Minimize the administrative burden
	Impact on technological innovation	• Revenue generation	• For mitigating aviation's environmental impact

The Association of European Airlines (AEA), representing 24 European airlines, has the objective of sustainable growth of the European airline industry (AEA, 2015). The addition of aviation of the EU ETS has created market distortion effects, negatively affecting the market position of European Airlines. IATA's resolution, setting out principles for a global MBM, was therefore welcomed by the Association of European Airlines (Green Air Online, 2013).

The AEA has showed its support towards ICAO in developing a global mandatory offsetting scheme in order to reach the target of carbon-neutral growth from 2020 onwards. In its report "*Aviation's Impact on the Environment*" the AEA argued that an offsetting scheme has the "*biggest chance of being accepted at ICAO-level*" (AEA, 2014). Athar Hussain Khan, CEO of the Association of European Airlines, has argued that any market-based measure must be global and preserve fair competition, should take into account different levels of activity, must be transparent and easy to administer (Transport & Environment, 2014). Furthermore he argued that the global MBM must be as inclusive as possible, covering the widest possible number of aviation activities to prevent market distortion effects (Transport & Environment, 2014). In conclusion, the preferences of the AEA are very similar to those of IATA. The above is summarized in Table 14.

Table 14 - Preferences of the Association of European Airlines

	Preferred MBM type	Offsetting	
	Important criteria	*Related design elements*	*Interpretation*
AEA	Economic distortion effects	• Reflection of CBDR	• Minimize market distortion
	Administrative feasibility	• Administration & monitoring	• Minimize the administrative burden

Various individual airlines have also shared their preferences with regard to the development of a global market-based measure. KLM Royal Dutch Airlines stated in their 2013 Annual Report that "*KLM welcomed the landmark ICAO agreement that was reached by ICAO Member States to develop a global market-based measure (MBM) on aviation emissions*" (KLM, 2013). Furthermore in its report, KLM stated that it is working together with the Association of European Airlines to move towards a "*level, transparent, and easily verifiable playing field*" (KLM, 2013), implying that minimizing market distortion effects caused by any global MBM is very important to KLM.

Another airline that has openly stated its position with regard to the global MBM is Virgin Atlantic. For long, they have supported the addition of aviation in Europe's emissions trading scheme. Now that the global market-based measure is being developed by ICAO, Virgin Atlantic has stated a similar preference. They regard a global emissions trading scheme as the "*most carbon- and cost-effective solution*" (Virgin Atlantic, 2012). All of the above is summarized in Table 15.

Table 15 - Preferences of individual airlines

Individual airlines	**Preferred MBM type**		**Different per airline**
	Important criteria	*Related design elements*	*Interpretation*
	Economic distortion effects	• Reflection of CBDR	• Minimize market distortion
	Administrative feasibility	• Administration & monitoring	• Minimize the administrative burden

5.3.4 NON-GOVERNMENTAL ORGANIZATIONS

On the road towards designing a global market-based measure, various non-governmental organizations (NGOs) have also showed their interests and concerns. Some of these NGOs have been invited by ICAO to discuss progress on the global MBM, for example during the Global Aviation Dialogues in April 2015 (Green Air Online, 2015b).

In November 2012, shortly before ICAO's 38th Assembly in 2013, a consortium of 27 NGOs send an open letter to ICAO representatives, urging ICAO Council members to take action and agree on implementation of an MBM. The letter concluded with the concern that: "*failure to do so [implementing a global MBM] would be a tragedy for ICAO, for industry, and for the climate*" (Transport & Environment, Oxfam, & WWF International, 2012). Besides urging ICAO to take action, the consortium also set out principles for the design of a global MBM. In short, important criteria for these NGOs - including the WWF International, Oxfam, Transport & Environment, and CDM Watch – are the environmental effectiveness of the global MBM, equity considerations between nations and impact upon technological innovation. As such, they argue that a global MBM should allow only the use of offsets that are of high quality, that there must be a revenue generation mechanism for climate change action in developing countries and greening of the sector, and the CBDR-principle must be addressed. Similarly to the letter written by the 27 NGOs, an international group of 40 top economists, including 4 Nobel Prize winners, send out a letter to ICAO sharing their concerns with implementation of an offsetting scheme. In their letter they stated that:

> "*Unfortunately, all available evidence suggests that many countries within ICAO and the aviation industry support a type of market-based measure, which would allow airlines to buy emissions offsets in order to meet an already weak 2020 carbon neutrality target. If ICAO adopts this approach, it would not bend the aviation industry's total emissions downward and thus would fall short of being a meaningful policy. Such a market-based measure that fails to create appropriate incentives could set a bad precedent and would waste a significant opportunity to move the global climate response forward.*"

> *Maskin et al. (2014)*

This statement contains two important claims. Firstly, there is the claim of a "*weak 2020 carbon neutrality target*". Secondly, it is stated that it [a global mandatory offsetting scheme] "*would not bend the aviation industry's total emissions downward*". These claims are reflected upon in Chapter 10. All of the above is summarized in Table 16.

Table 16 - Preferences of NGOs

NGOs	Preferred MBM type		-
	Important criteria	*Related design elements*	*Interpretation*
	Environmental effectiveness	• Offset standards	• Offsets must be of high quality
	Equity considerations between nations	• Revenue generation mechanism • Reflection of CBDR	• For climate financing • Include CBDR
	Impact on technological innovation	• Revenue generation	• For mitigating aviation's environmental impact

5.4 DEMARCATING THE DESIGN SPACE

This paragraph answers the first research question: "*what is the design space for a global market-based measure?*" By means of a legal and stakeholder analysis the design space for the aviation global market-based measure has been demarcated. The demarcation occurs on two levels:

i. *Type of global MBM*
It is found that there are significant legal and political barriers when imposing a global levy to tax international aviation emissions. Therefore a global levy does not satisfy the principles of legal feasibility and political viability. In addition, the Strawman shows ICAO is aiming towards implementing a global mandatory offsetting scheme. Hence emissions trading is not satisfying the principle of political viability. This is schematically shown in Table 17.

Table 17 - Type of global MBM and legal and political principles

Type of MBM / Principle	Legal feasibility	Political viability
Global levy	X	X
Emissions trading	✓	X
Mandatory offsetting	✓	✓

ii. *Design elements*
The Global Aviation Dialogues in April 2015 showed the Strawman of a global mandatory offsetting scheme in which a number of design elements seem decided. From this point these elements are considered unalterable for design purposes. On the contrary, the interpretation of other elements remain unclear and are considered alterable. Since stakeholders' preferences misalign with regard to the inclusion of CBDR and a revenue generation mechanism, these design elements are used to construct different designs in the consecutive chapter. Figure 16 shows the demarcated design space.

DESIGN ELEMENTS
(global mandatory offsetting)

Unalterable
(included in Strawman)

DESIGN ELEMENT	ICAO INTERPRETATION
• Choice of pollutant	CO_2-emissions
• Type of flights	International passenger & cargo
• Accountable entity	Aircraft operators
• Objective	Carbon-neutral growth
• Emission baseline	2020 emissions
• Enforcement	Assembly resolution and standards
• Price establishment	Via the offsetting market

Alterable
(not decided yet by ICAO)

DESIGN ELEMENT	STAKEHOLDERS' INTERPRETATION	
• Allowance allocation	No clear stakeholder preferences	
• Reflection of CBDR	Airlines/developed States:	no reflection of CBDR
	NGOs & Developing States:	include CBDR
• Revenue generation	UNFCCC/Member States/NGOs:	climate financing
	ICAO & IATA:	no climate financing, rather mitigating aviation's environmental impact
• Offset standards	No clear stakeholder preferences	
• Administration & monitoring	No clear stakeholder preferences	

Figure 16 - Demarcated design space

5.5 REDEFINING THE CRITERIA FOR ASSESSING THE GLOBAL MBM

The stakeholder analysis has shown which criteria - from the list of criteria from Solomon & Hughey (2007), see Table 5 - are regarded as most important by stakeholders, including ICAO Member States, airline associations, and non-governmental organizations. Based on this analysis the list of criteria has been redefined such that the criteria are specific to the aviation global MBM, see Table 18. Furthermore, the criteria are operationalized, i.e. units are added. Thus this paragraph answers the second research question: "*what are the criteria needed to assess a global market-based measure?*"

5.5.1 ENVIRONMENTAL

The environmental performance of the global market-based measure is regarded as a key concern by many stakeholders, including the UNFCCC, EU, and NGOs. This criterion is crucial as the rationale of the global MBM is to "*support sustainable development of the international aviation sector*" (ICAO, 2014c). Environmental performance can be measured in different ways. With regard to the global market-based measure ICAO has stated that any MBM "*should be assessed in terms of CO_2-emissions reductions*" (ICAO, 2014c). This focus on carbon dioxide is in line with the Strawman. The corresponding criterion is phrased as *cumulative CO_2-abatement potential* and shall be measured in gigatonnes of CO_2. Furthermore the interest of IATA to include a revenue generation mechanism to fund more fuel-efficient aircraft or other environmental upgrades, combined with the interests of NGOs about "*bending the aviation industry's total emissions downward*" point to the direction that in-sector emissions reductions are considered important by a variety of stakeholders. Therefore the criterion "*in-sector emissions reductions*" is included, which is measured in [$GtCO_2$].

5.5.2 ECONOMIC

The economic impact is considered key to many stakeholders. Especially the airline industry represented through the associations IATA and AEA are concerned with costs that any global MBM shall impose on the industry. These concerns are twofold. One the one hand, the airline associations are concerned with the total costs for the industry. The criterion *costs of the emission reductions* will therefore be applied, measured in billion US dollars. On the other hand, the airline industry is concerned with potential *market distortion effects* that might arise from the implementation of a global MBM. These distortion effects can be distinguished into *passenger* and *cargo* market effects and shall be measured in percentage change in demand loss.

5.5.3 SOCIAL

Social considerations are considered crucial by a variety of stakeholders and non-governmental organizations. Especially emerging economic countries such as China and India, together with least-developed countries (LDCs), have argued for *differentiated responsibilities* within the global MBM. This criterion is therefore vital in reaching consensus on the ICAO level.

5.5.4 INSTITUTIONAL

The institutional feasibility of any global MBM is considered very important. Especially the airline associations IATA and AEA have argued that the MBM should minimize the *administrative burden* for airlines. These considerations shall be qualitatively assessed; hence no units are assigned to these criteria. Furthermore the *impact upon technological innovation* is considered important, which is measured in billion USD.

An overview of the redefined criteria for assessing the global MBM designs is provided in Table 18. It is recommended ICAO used this list of criteria when assessing the global market-based measure and future aviation environmental policies. Furthermore it could be used as inspiration for defining a list of criteria for assessing market-based measure in other industries.

Table 18 - Redefined criteria for assessing the global MBM designs

Category	Criteria	Unit
Environmental	Cumulative CO_2-abatement potential	[$GtCO_2$]
	In-sector emission reductions	[$GtCO_2$]
Economic	Costs of the emission reductions	[bln USD]
	Market distortion effects • Passenger • Cargo	[%]
Social	Equity between nations	[-]
Institutional	Administrative feasibility	[-]
	Impact on technological innovation	[bln USD]

5.6 CONCLUSIONS

By means of a legal and stakeholder analysis this chapter has demarcated the design space and redefined the criteria to assess the global market-based measure. It has shown ICAO is moving towards a global mandatory offsetting scheme in which carbon-neutral growth from 2020 onwards is central, and that a number of design elements remain open for interpretation. The next chapter builds upon the demarcated design space to construct four different global mandatory offsetting designs.

III

Design

The whole is greater than the sum of its parts.

Aristotle

6 Global mandatory offsetting designs

The process of designing can either follow a systematic or chaotic approach (Parnell, Driscoll, & Henderson, 2011). Whereas the former follows succeeding steps to arrive at a design, the latter is characterized by its lack of structure. This thesis follows the former approach and takes the ICAO Strawman as a starting point for designing. By means of a qualitative analysis alterable design elements with no clear stakeholder preferences (allowance allocation, offsets standards, and administration & monitoring) are filled in and the first design is constructed. The consecutive three designs are built upon the first design. Since stakeholders' preferences misalign with regard to reflection of CBDR and a revenue generation mechanism, these design elements are used to construct the consecutive three designs. As such, these designs involve the addition of either elements, or both. The structured process of designing is shown below, see Figure 17.
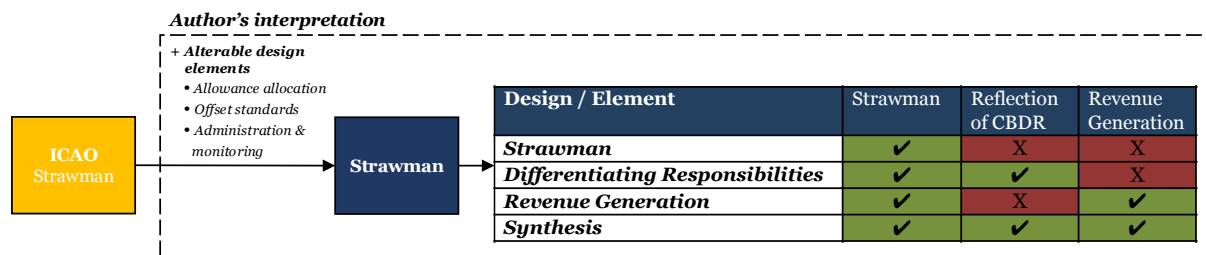
Figure 17 - Structured process of designing the mandatory offsetting schemes

6.1 STRAWMAN
This design extends the ICAO Strawman by adding the design elements of allowance allocation, offset standards, and administration & monitoring. The stakeholder analysis has shown these elements are not subject to stakeholders' preferences and are thus open for interpretation. By means of a qualitative analysis these three design elements are filled in. Together with the unalterable elements from the ICAO Strawman they form the first global mandatory offsetting design, which from now on shall be referred to as Strawman[15].

6.1.1 ALLOCATION OF REQUIREMENTS
Paragraph 4.6 described various ways of allocating requirements to responsible entities. These include (i) grandfathering based on a historic approach, (ii) grandfathering based on a benchmark approach, (iii) with an 'output-based' allocation, and (iv) auctioning. Although from a theoretical perspective auctioning is the preferred allocation method (IEA, 2010), it is questionable whether it would be politically feasible since one of ICAO's guiding principles is

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[15] Notice that ICAO is left out of the design's name, reflecting this Strawman is the author's own interpretation.

to "*not impose inappropriate economic burden on international aviation*" (ICAO, 2014c). Another guiding principle of the global MBM is to "*realize CO_2-emission reductions*" (ICAO, 2014c), implying the allocation of responsibilities to the amount of CO_2 is probably the most promising approach, thus also eliminating the third method where allocation is output-based. This leaves grandfathering based on a historic or benchmarking approach as potential methods for allocation.

i. *Grandfathering based on historic emissions*
Each aircraft operator receives the incentive to keep emissions below his base period emissions. The costs for emissions above the baseline are equal to the costs necessary to obtain the required offsets, making this approach relatively simple. Disadvantages are that any early action taken by aircraft operators to reduce their emissions is not rewarded. Furthermore there is the perverse incentive for aircraft operators to increase their emissions in 2020 when these are counted as the individual baseline. Also, fast-growing airlines would be hampered in their growth by allocating to historic emissions (Öko-Institut & CE, 2014).

ii. *Grandfathering based on a benchmarking approach*
The benchmark could be set equal to the globally aggregated aviation emissions divided by the global transport volume measured in RTK. The resulting emission factor (CO_2/RTK) would be the benchmark. The base period emission of an individual aircraft operator would then be determined by multiplying its individual carbon dioxide emissions with the emission factor. Aircraft operators with relatively good CO_2-performance would then have a relatively higher emission baseline, and would have to purchase less offsets. In this way, any early action by aircraft operators is rewarded. However, the problem of taking into account fast-growing airlines still exists (Öko-Institut & CE, 2014).

In conclusion, while both grandfathering approaches are sub-optimal and lead to challenges with regard to fast-growing aircraft operators, the benchmarking approach is considered to be the best option since it does not penalize early action taken by aircraft operators. In addition, the challenge of fast-growing aircraft operators can be partially solved by excluding certain developing countries from the global market-based measure (see the next design, paragraph 6.2). Therefore it is recommended ICAO uses **grandfathering based on a benchmarking approach** to determine offsetting requirements.

6.1.2 OFFSET STANDARDS
As paragraph 4.10 described, offsets might be available through different mechanisms including the compliance market, sectoral mechanisms, voluntary market, and allowance market. It is very difficult to predict which offsets are available after 2020, and which should be eligible under the global MBM (Öko-Institut & CE, 2014). This is mainly due to two reasons:

i. The dispute between developed and developing countries about the need for market-based approaches (World Bank, 2014).
ii. Past experiences with regard to units created under the CDM (Öko-Institut & CE, 2014).

The first point relates to the discussion on UNFCCC level between developed and developing countries. Developed countries regard market-based mechanisms as a key building block (Öko-Institut & CE, 2014). However, developing countries question the rationale behind market-based approaches since they consider market solutions rather the cause of climate change than the solution (Öko-Institut & CE, 2014). Furthermore, an increasing number of developing countries question the necessity of new mechanisms such as the NMM or FVA

until developed countries increase their level of ambition (World Bank, 2014). This has to do with the fact that weak ambition levels result in a relatively lower demand for offsets, hindering the establishment of a market price that is viable for project developers.

The second point relates to past experiences with the CDM. Although the CDM allows for international oversight, there have been questions raised with regard to the quality and additionality of the units generated. The quality of the units was undermined when industrial gas projects (e.g. HFC-23[16]) had the perverse incentive to increase emissions in order to generate more offset units (Öko-Institut & CE, 2014). The additionality of units generated under the CDM were questioned when the CDM Policy Dialogue in 2012 found that potentially two-thirds of all CDM credits expected between 2013 and 2020 could come from business-as-usual projects (Carbon Market Watch, 2013; CDM Policy Dialogue, 2012). The problem relates to *information asymmetries* between project developers and regulators, since the former usually have more detailed information (Öko-Institut & CE, 2014).

In conclusion, the uncertainty about the availability, quality, and additionality of offsets after 2020 make it difficult at this point to determine which units should be eligible under the global MBM. Instead, criteria for offsets should be agreed upon. Therefore it is recommended ***any eligible units should be of high quality, additional to the business-as-usual, and permanent***. Furthermore it is suggested ICAO – *should offset units from the voluntary carbon market become eligible under the global MBM* – supports the use of offsets with social and environmental benefits.

6.1.3 *ADMINISTRATION & MONITORING*

According to paragraph 4.11 the administration of a global MBM can be done in different ways depending on the nature of the activity. Reliable and accurate monitoring of emissions is essential both to track progress towards the global MBM objective as well as to administer the system (ICAO, 2013b). The following Monitoring, Reporting, and Verification scheme is proposed, which is an adapted version of the scheme proposed by Öko-Institut & CE (2014).
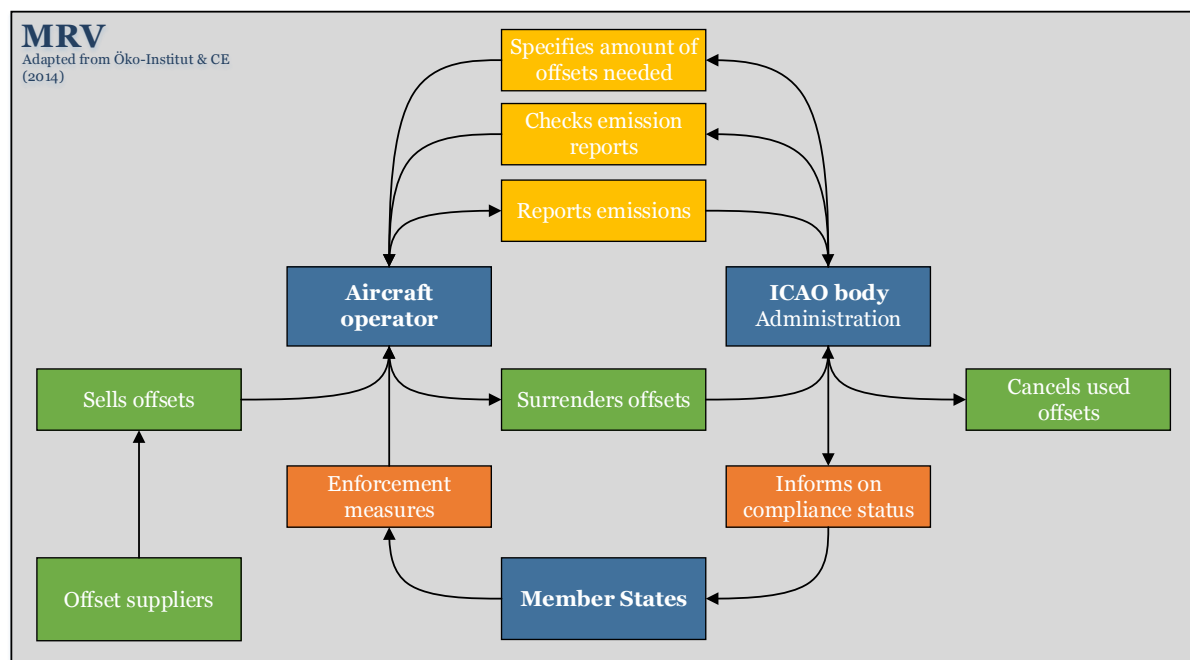

Figure 18 - MRV-scheme for a global mandatory offsetting scheme

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[16] HFC-23 is a sub-product resulting from the HCFC-22 refrigerant manufacturing process that has a powerful greenhouse effect (Noe21, 2015).

In this MRV-scheme aircraft operators calculate the CO_2-emissions based on fuel burn monitoring. They report emissions to a body under ICAO which then checks the emission reports and specifies the amount of offsets needed. This administering body informs ICAO Member States on the compliance status of individual aircraft operators. In the case of non-compliance States can impose enforcement measures on aircraft operators.

In conclusion, it is recommended monitoring and administration is performed by a combination of a **body under ICAO, aircraft operators, and Member States**, according to the MRV-scheme that is shown in Figure 18.

6.2 DIFFERENTIATING RESPONSIBILITIES

Reflecting the UN's CBDR-principle is regarded as a key design element by ICAO member states. Nevertheless no decision has yet been made about how to address this issue. This design uses the characteristics of the *Strawman*, and adds the reflection of the UN's *Common But Differentiated Responsibilities* principle. From here onwards, the second design will be referred to as *Differentiating Responsibilities*. In this paragraph the different design choices will consecutively be discussed.

6.2.1 AIRCRAFT OPERATOR-BASED VS. ROUTE-BASED APPROACH

From a theoretical perspective a route-based approach is preferred because of relative smaller market distortion effects. On the contrary, an aircraft operator-based differentiation would allow for market distortion on a single route enabling aircraft operators with lower requirements the possibility of gaining market share. Therefore it is recommended ICAO uses a **route-based approach** as the foundation for reflecting CBDR.

6.2.2 STRINGENCY LEVELS VS. PHASED-IN APPROACH

Both differentiation methods have the potential to take into account the different responsibilities and respective capabilities of countries, but in a slightly different way. The biggest difference is that with regard to stringency levels, all countries are included in the system from the start, while for a phased-in approach countries are gradually included in the system. Thus the selection of differentiation method might be most dependent on the political willingness of countries and the outcome of negotiations that are occurring prior to ICAO's next Assembly in 2016. Since the stakeholder analysis has shown resistance of emerging economic countries towards a global MBM for the aviation sector, it is assumed at this point of the analysis that a global MBM including a phased-in route-based approach has the highest potential of reaching political consensus in 2016. Therefore it is recommended ICAO uses a **phased-in approach** as differentiation method.

6.2.3 DIFFERENTIATION CRITERIA

Paragraph 4.7 showed the differentiation criteria that could determine which routes will be covered and by when, including:

 i.   The share of routes in total aviation
 ii. The maturity of aviation markets
 iii. Economic development

In his article "*Reconciling CBDR with non-discrimination: A fundamental requirement for ICAO's global MBM success*" Piera (2014a) illustrates possible implementations of phased-in route-based differentiation, making use of different criteria. His analysis shows that the selection of differentiation criterion has a high impact on the CO_2-emissions coverage of the global MBM. The criterion with the highest emissions coverage is the maturity of aviation markets (Piera, 2014a). In addition to covering most aviation emissions, this criterion also

ensures that the major aviation states are included in the system. A disadvantage of this criterion is that a number of Asian-Pacific and Middle-Eastern countries (e.g. China, Korea, and United Arab Emirates) are included in the system, threatening the political willingness of this option. However, it could be argued that any approach reflection CBDR could lead to resistance from a number of Member States. Since this design enables a wide coverage of CO_2-emissions and ensures that major aviation states are included in the system, it is recommended ICAO uses a ***phased-in route-based approach*** to reflect the UN's CBDR-principle, in which the differentiation criterion is the ***maturity of aviation markets***.

Based on Piera's second design (2014a) - which takes the maturity of aviation markets as a differentiation criterion - the following approach is recommended. A visualized overview is shown in Figure 19.

   i.   *Phase 1: 2020-2023, CO_2-emissions coverage = 80.5%*
        States covered: ECAC Member States, plus the top 10 States ranked by international RTKs, including Europe, US, China, UAE, Korea, Singapore, Japan, Qatar, Russian Federation, Australia, and Canada.

   ii. *Phase 2: 2024-2026, CO_2-emissions coverage = 90%*
        States covered: States in Phase 1 plus the next 10 States ranked by international RTKs, including Thailand, Malaysia, India, Saudi Arabia, Brazil, South-Africa, New Zealand, Chile, Ethiopia, and the Philippines.

   iii. *Phase 3: 2027-2050, CO_2-emissions coverage = 100%*
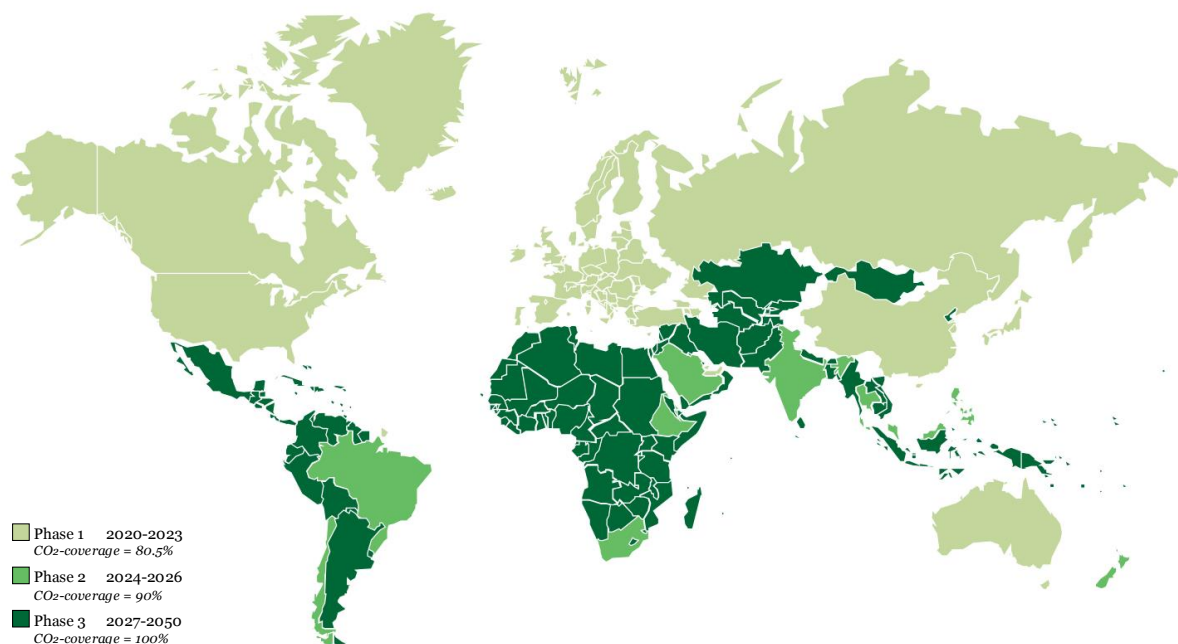   States covered: States in Phases 1 & 2 plus all other States.

Figure 19 - A phased-in route-based approach, adapted from Piera (2014a)

6.3 REVENUE GENERATION

This design is built upon the *Strawman* and adds the element of revenue generation. This paragraph discusses the complexity that is inherent to the revenue generation debate which has led to nondecision-making[17] within ICAO regarding this design element. This section describes the following three aspects and illustrates how a revenue generation mechanism can work. From here onwards, the third design will be referred to as *Revenue Generation*.

  i.   *Purpose of the revenue streams*
  ii. *Redistribution of the revenue streams*
  iii. *Determining the characteristics of the transaction fee*

6.3.1 *PURPOSE OF THE REVENUE STREAMS*

Referring to paragraph 4.8 the global MBM can be used to generate a revenue stream that can be applied to the following purposes: (i) mitigating the environmental impact of aircraft emissions, and (ii) supporting developing States with climate change mitigation and adaptation (ICAO, 2011).

The stakeholder analysis has shown that ICAO and IATA argue that any revenues created by a global MBM should be earmarked to mitigate the environmental impact of the aviation sector. On the contrary, States have expressed their preference through the UNFCCC that the aviation industry should contribute to climate financing for developing countries. Several NGOs seem to support this view. From a climate change perspective, funds should be used where it is more efficient to achieve environmental objectives. Given the sector's high abatement costs, funds should be used for climate financing purposes (Piera, 2015). However, without ICAO and IATA supporting the purpose of climate financing it is unlikely there is much political support. Therefore it is decided to use the revenue stream for the sole purpose of mitigating aviation's environmental impact.

6.3.2 *REDISTRIBUTION OF THE REVENUE STREAMS*

For the purpose of mitigating the environmental impact of aviation it is difficult to assign a destination to the generated revenues since the entities realizing emission reductions are individual aircraft operators. Therefore it is recommended at this point of the analysis that these revenue streams should flow into an *Aviation Innovation Fund* operated by ICAO. This fund can then be used to provide financial support to research performed by organizations such as knowledge institutes, aircraft manufacturers, and aircraft operators.

6.3.3 *DETERMINING THE CHARACTERISTICS OF THE TRANSACTION FEE*

ICAO has stated that one way an offsetting scheme can create a revenue stream could be by applying a transaction fee for the purchase of offsets (ICAO, 2013a). This increases the incentive for aircraft operators to reduce emissions if these are above the baseline. There are multiple dimensions to setting the height of the transaction fee. They are discussed consecutively below:

  i.   *The legal basis for a transaction fee*
       It is decided at this point of the analysis that the transaction fee is due for each tonne of CO_2 that is above the aircraft operators' emission baseline (ICAO, 2013a). This is in line with the suggestion of ICAO in their assessment on global market-based measures. Furthermore it eliminates the possibility for aircraft operators to buy all

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[17] "The practice of limiting the scope of actual decision-making to 'state' issues by manipulating the dominant community values, myths, and political institutions and procedures" (Bachrach & Baratz, 1963).

offsets at once in order to pay only one transaction fee (in the scenario that the legal basis for a transaction fee would be a transaction instead of a tonne of CO_2).

ii. *The height of the transaction fee*
The height of the transaction fee should be optimal in the sense that the fee is high enough that it significantly contributes to mitigating the emissions of aviation, and not too high such that the revenue generation mechanism does not impose disproportionate costs to the aviation sector. For now it is assumed that the height of the transaction fee in 2021 – the first year that aircraft operators have to reduce their emissions above carbon-neutral growth - is equal to 1 US dollar per tonne carbon dioxide that is emitted above the baseline.

iii. *Time-variability*
The height of the transaction fee can be constant or time-dependent. To increase the incentive of early emission reductions it is decided at this point of the analysis that from 2021 onwards each year the transaction fee is increased by 0.50 US dollar per tonne CO_2.

6.4 SYNTHESIS

The fourth design combines all elements of the former three designs. Thus it incorporates the design elements needed to achieve the aspirational goal of the ICAO Strawman (design 1), a phased-in route-based differentiation to reflect the UN's *Common But Differentiated and Respective Capabilities principle* (design 2), and a revenue generation for mitigating the environmental impact of aviation (design 3). From here onwards this design is referred to as *Synthesis*.

6.5 CONCLUSIONS

In this chapter four global mandatory offsetting designs have been constructed. The first design is an extension of the ICAO Strawman. The consecutive three designs are all variations of the first design by either adding the reflection of CBDR or a revenue generation mechanism, or both. A summarized overview of the four designs is given in Table 19.

Table 19 - Global mandatory offsetting designs

Offsetting designs	Design elements & interpretation	
Strawman	Choice of pollutant	CO_2-emissions
	Type of flights	International passenger & cargo
	Accountable entity	Aircraft operators
	Objective	Carbon-neutral growth
	Emission baseline	Emissions in 2020
	Allocation of requirements	Grandfathering (benchmarking)
	Reflection of CBDR	None
	Revenue generation mechanism	None
	Price establishment	Via the offsetting market
	Offset standards	*Criteria*: high-quality, additional, permanent
	Administration & monitoring	Body under ICAO, States, aircraft operators
	Compliance and enforcement	Assembly Resolution and standards
Differentiating responsibilities	All elements from Strawman	

	Reflection of CBDR	Phased-in route-based differentiation
		  i. Phase 1: 2020-2023
		     CO_2-emissions coverage = 80.5%
		  ii. Phase 2: 2024-2026
		     CO_2-emissions coverage = 90%
		  iii. Phase 3: 2027-2050
		     CO_2-emissions coverage = 100%

Revenue generation	All elements from Strawman	
	Revenue generation mechanism	Purpose and redistribution: • Mitigating the environmental impact of aviation (Aviation Innovation Fund) Characteristics of the transaction fee: • Legal basis is a tonne of CO_2 emitted above the aircraft operator's baseline • 1 USD/tCO_2 in 2021 • 0.50 USD/tCO_2 increase per year until 2050
Synthesis	All former three designs combined	

*We are all passengers on an aircraft we
must not only fly but redesign in flight.*

John Sterman

7 Developing the simulation model

Simulation is nothing but an imitation of reality. The act of simulation requires a model to be developed that represents the key characteristics of the selected system. Whereas the model represents the system itself, the simulation represents the operation of the system over time. It is very useful to show effects of alternative courses of action, and can be helpful when the real system is not accessible or simply does not exist. This chapter describes the development of the simulation model to assess the four global mandatory offsetting designs.

7.1 MODEL SPECIFICATION

The simulation model that is constructed consists of three parts: (i) model input, (ii) formalizing the global mandatory offsetting designs, (iii) calculations & model output. These parts are consecutively discussed below.

§7.1.2 – MBM designs

Global mandatory
offsetting designs

§7.1.1 – Model input

Business-as-usual civil
aviation emissions [GtCO2]

Distribution domestic vs.
international emissions [%]

Offset price [USD/tCO2]

Marginal abatement cost curve
costs [USD/tCO2] & potential [tCO2]

Simulation
model

Model output (CH8)

CO2-abatement
potential [GtCO2]

Costs of the emission
reductions [bln USD]

Market distortion
effects [%]

Impact on technological
innovation [bln USD]

7.1.1 MODEL INPUT

This paragraph describes the input for the simulation model which has been gathered by a literature review. This review has taken into account both scientific articles and reports from the aviation sector. The assumptions used for developing the model are highlighted. *Based on a sensitivity analysis and additional research later in this chapter uncertainty is added to a selection of them, see paragraph 7.3.*

BUSINESS-AS-USUAL CIVIL AVIATION EMISSIONS

To quantify the abatement potential of the global mandatory offsetting designs the business-as-usual CO_2-emissions have to be known. To this end ICAO's projections until 2050 are used, which were made by the Modelling & Databases Task Force (hereafter: MODTF) from the Committee on Aviation Environmental Protection. Different MODTF scenarios were

constructed, assuming different degrees of operational and technological improvements (MODTF, 2009). Their study provide the most up-to-date forecast of civil aviation emissions and have also been included in more recent modeling work by Lee, Ling, & Owen (2013).

In the business-as-usual scenario the forecasted CO_2-emissions in 2020 are equal to 1112 million tonnes. These emissions are projected to increase to reach 4531 million tonnes of CO_2 by 2050. By means of interpolation with a compound annual growth rate (hereafter: CAGR) the emissions in the years in between 2020 and 2050 are determined. The CAGR is defined by the formula:

$$CAGR(t_0, t_n) = (V(t_n) / V(t_0))^{\frac{1}{t_n - t_0}} - 1$$

In this formula $V(t_0)$ is the start value, $V(t_n)$ is the finish value, and $t_n - t_0$ is the number of years. The assumed resulting compound annual ***growth rate for civil aviation CO_2-emission for the years 2020 to 2050 is equal to 4.8%***.

DISTRIBUTION DOMESTIC AND INTERNATIONAL AVIATION
ICAO is mandated to solely address international aviation emissions. Thus the global MBM will not cover domestic CO_2-emissions. Therefore to determine how many emission reductions will be realized by the global MBM not only the total aviation emissions have to be known, but also the share of international aviation.

In their article "*Bridging the aviation CO_2-emissions gap: why emissions trading is needed*" Lee, Lim, & Owen (2013a) determined the share of international aviation in civil aviation emissions is equal to 62%. Recent analysis presented in the OECD/ITF Transport Outlook 2015 based on IATA data shows an equal share of international aviation (OECD & ITF, 2015). Furthermore, the OECD/ITF study shows historically this share has not changed significantly (OECD & ITF, 2015). Therefore this thesis assumes a ***constant share of international aviation emissions of 62%***.

OFFSET PRICE
As was pointed out in Chapter 4 it is very difficult to predict which offsets are available after 2020, and which should be eligible under the global MBM. Forecasting the price of these offsets would be even more cumbersome. However, to determine how emission reductions are realized by the global MBM and to what costs they are achieved, an estimate of the price of offsets is required.

In order to initially stay close to ICAO modelling and validation purposes, the first estimate of the offset price in the period 2020-2050 is taken from ICAO (2015b). In the Global Aviation Dialogues 2015, ICAO presented in a medium scenario that the ***price of offsets in 2020, 2030, and 2035 would be equal to respectively 8, 15, and 20 USD/tonne CO_2***. Similarly to the forecasted CO_2-emissions until 2050, interpolation with a CAGR is used to calculate the offset price in the periods 2021-2029 and 2031-2034. The offset price in the period 2036-2050 is then assumed to grow by the same CAGR as in the period 2030-2035. To this end extrapolation is used to arrive at an ***offset price of 47 USD/tonne CO_2 in 2050***.

In order to determine which type of mitigation options are used to realize the required emissions reductions and related costs it is necessary to identify the marginal abatement costs of each mitigation option. Although it is found that a limited number of studies have been performed on the marginal abatement costs for aviation, the existing studies are useful for this thesis. They are summarized below, see
Table 20.

Author(s) of study	Geographical scope	Analyzed years
Holland et al. (2011)	UK domestic aviation	2020, 2030, 2040, 2050
Morris et al. (2009)	UK domestic aviation	2007, 2012, 2020
	EU civil aviation	2007, 2012, 2025
Köhler (2010)	EU civil aviation	2020
IATA (2013c)	Global civil aviation	2020, 2030

Table 20 - Overview of studies on MAC curves

Since this thesis requires data regarding the global scale it uses IATA's marginal abatement cost curves as modeling input. The corresponding marginal abatement cost curves are shown in Figure 20 and Figure 21. A detailed description of these MAC curves and how they are included in the simulation model is described below.

Figure 20 - IATA's marginal abatement cost curve for 2020
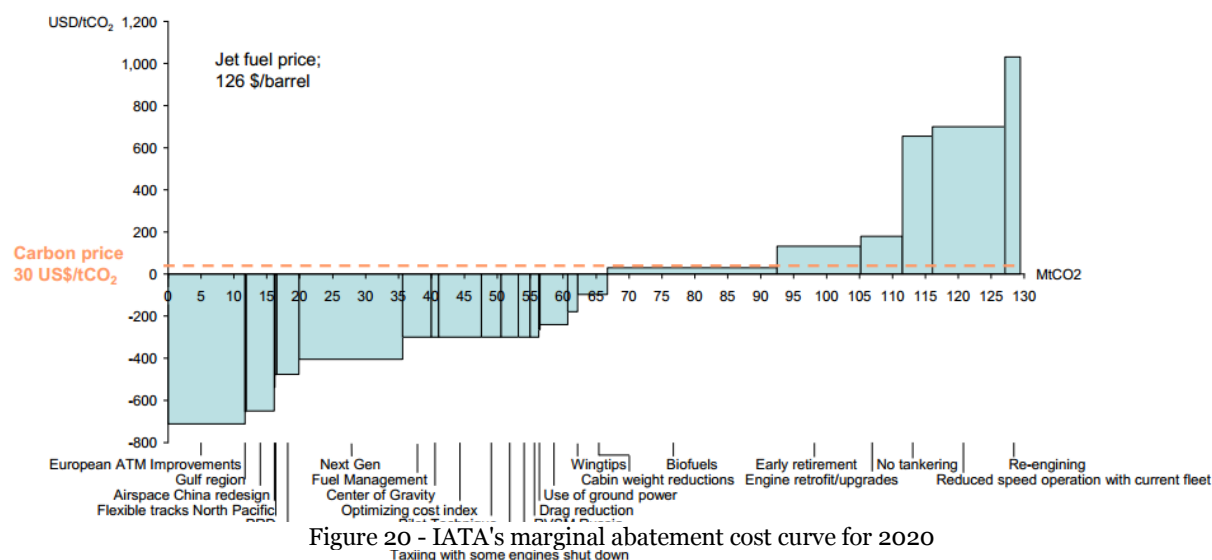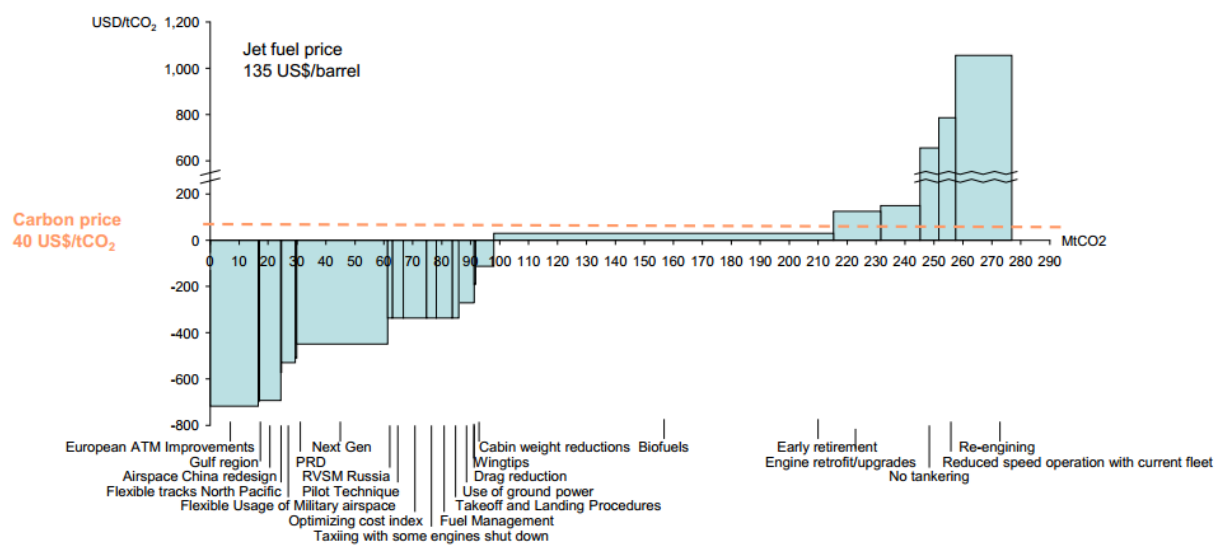
Figure 21 - IATA's marginal abatement cost curve for 2030

i. Description of the marginal abatement cost curves

In Figure 20 and Figure 21 each bar represents a single abatement option. The width of the bar represents the abatement potential relative to the business-as-usual. The height of the bar represents the abatement cost per year, relative to the business-as-usual. The costs are expressed in US dollars per tonne CO_2 avoided. The sum of the width of all bars shows the total carbon abatement potential. The total area of the bars indicates the marginal costs for choosing a low carbon pathway (van Tilburg et al., 2010).

ii. Differences between the two marginal abatement cost curves

The shape of the MAC curves in Figure 20 and Figure 21 show significant resemblance to each other. All costs except for biofuels are equal for both curves. The differences are more related to the abatement potential in 2030 compared to 2020. As the numbers corresponding to the x-axis show, the total abatement potential in 2030 is more than 2 times as large as in 2020. This is mostly caused by a significant increase in the abatement potential of NextGen [18] related ATM improvements, biofuels, and re-engining.

iii. Interpolation and extrapolation with a CAGR for 2020-2050

Since IATA has only made the marginal abatement cost curves for 2020 and 2030 available, interpolation with a CAGR is used to calculate the abatement potential and related costs of each option for the years 2021-2029. The same CAGR is then used for extrapolation until 2050.

iv. Modeling negative-cost abatement options

Furthermore, both figures show a great share of negative-cost abatement options, representing more than one-third of the cumulative abatement potential. From an economically rational perspective these findings are controversial, but as was explained in paragraph 2.4 there might be non-financial barriers to implementation. The negative-cost abatement options are problematic for modeling purposes: "*in any optimizing model, all negative-cost investments would be made immediately,*

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[18] NextGen proposes to transform America's air traffic control system from a ground-based system to a satellite-based system that will reduce aviation fuel consumption (NASA, 2015).

yielding a surge of additional capital available for other investments" (Ekins et al., 2011). However, reality often proves different and "*thus incorporating this feature would decrease the realism and policy relevance*" of climate modeling (Ekins et al., 2011). Similarly, van Tilburg et al. (2010) caution for combining options with negative and positive costs to arrive at cost-neutral implementation. In this thesis - to evade the illusion of cost-neutrality - a similar approach is taken as in climate modeling performed by Ekins et al. (2011) by assigning a near-zero but positive cost value to all reportedly negative-cost abatements. As such, there is no surge of additional capital released by those abatements.

v. Aggregation of improvements in infrastructure, operations, and technology

The MAC curves from IATA show a variety of abatement options available for the aviation sector. For legibility reasons these are aggregated to the type of abatement as defined by IATA: infrastructure, operations, and technology (IATA, 2013b), see Table 21.

Table 21 - Opportunities for carbon dioxide abatement in the aviation sector

Infrastructure	**Operations**	**Technology**
- NextGen related ATM improvements - European ATM improvements - Flexible tracks North Pacific - RVSM China (implemented 2007 but baseline emissions 2006) - Pearl River Delta ATM improvements - Chinese airspace redesign - Flexible use of military airspace - Gulf region airspace redesign	- Optimized flights using cost index - Use of ground power - Taxiing with some engines shut down - Improved fuel management - Cabin weight reductions - Improved pilot technique - Takeoff and landing procedures - Centre of gravity measures - No fuel tinkering - Reduced speed with existing fleet (no redesign)	- Wingtip devices - Engine upgrades - Re-engining - Early retirement of aircraft - Reduced speed with redesigned fleet - Algae oil-based biofuel

7.1.2 *FORMALIZING THE GLOBAL MANDATORY OFFSETTING DESIGNS*

To include the four global market-based measures from chapter 6 in the simulation model they have to be formalized. Since the Differentiating Responsibilities, Revenue Generation, and Synthesis designs are all variations of the Strawman design, only the differences in their formalization are described below. Table 22 provides an overview of used parameters.

Table 22 - Description of parameters

Parameter	Description
B_t	Business-as-usual emissions from civil aviation at time t
BI_t	Business-as-usual emissions from international aviation at time t
EB_t	Emission baseline at time t
ER_t	Required emissions reductions at time t
FI_t	Fraction of international aviation emissions over civil aviation emissions at time t
α_t	Partial coverage factor at time t
T_t	Height transaction fee at year t
TI	Yearly increase in height transaction fee
R_t	Revenue stream for mitigating aviation emissions at year t
O_t	Amount of offsets purchased at year t

STRAWMAN

For each year in the period 2020 to 2050 the value of these parameters has to be determined. They are interrelated as follows:

BAU emissions from international aviation
= BAU emissions from civil aviation * fraction of international aviation emissions over civil aviation emissions.

$$BI_t = B_t * FI_t$$

Emission baseline
= BAU emissions from international aviation in 2020

$$EB_t = BI_{2020}$$

Required emissions reductions
= BAU emissions from international aviation - emission baseline

$$ER_t = BI_t - EB_t$$

Differentiating Responsibilities

As explained in paragraph 6.2 this design differs from the first design because of differences in responsibility between ICAO member states in reducing aviation emissions. A phased-in route-based approach is followed, and as a result there is a partial coverage of the sector's emissions in the periods 2020 until 2023 and 2024 until 2026. Recall that for phase 1 (2020-2023), phase 2 (2024-2026), and phase 3 (2027-2050), the CO_2-emissions coverage is equal to respectively 80.5%, 90% and 100%. Formalized, this phased-in route-based approach can be written as below:

– *Required emission reductions*
= partial coverage factor * (BAU emissions from international aviation – emission

$$ER_t = \alpha_t * (BI_t - EB_t)$$

- *Required emissions reductions in the years 2020-2023*
  = 0.805 * (BAU emissions from international aviation - emission baseline)

$$\alpha_t = 0.805 \; for \; t = \{2021, 2022, 2023\}$$

- *Required emissions reductions in the years 2024-2026*
  = 0.9 * (BAU emissions from international aviation - emission baseline)

$$\alpha_t = 0.90 \; for \; t = \{2024, 2025, 2026\}$$

- *Required emissions reductions in the years 2027-2050*
  = BAU emissions from international aviation - emission baseline

$$\alpha_t = 1 \; for \; 2027 \leq t \leq 2050$$

Revenue Generation

As explained in paragraph 6.3 this design differs from the first design because a transaction fee is applied to each purchased offset unit. This is for the purpose of mitigating the environmental impact of aviation. The height of the transaction fee was assumed to be 1 US dollars per tonne CO_2 in 2021 with a yearly increase of 50 dollar cents until 2050. Formalized, the revenue generation mechanism is incorporated into the model as follows:

- Transaction fee in 2020
  = starting value (1 USD / tonne CO_2)

$$T_{2021} = 1$$

- Transaction fee in following years until 2050
  = transaction fee in previous year + yearly increase

$$T_t = T_{2021} + TI * (t - 2020)$$

- Revenue stream for mitigating aviation emissions in the period 2020-2050
  = amount of offsets purchased * transaction fee

$$R_{av,t} = O_t * T_t$$

Synthesis

As explained in paragraph 4.2 this design combines the design elements of all former three designs. As such, the Synthesis design is included in the simulation model by using all previously defined parameters.

7.1.3 MODEL LOGIC

The logical structure behind the simulation model is stepwise explained below. These nine steps have to be performed for each global mandatory offsetting design individually, and for every year in the period 2020 until 2050.

Stepwise explanation of the model logic

Step 1:	Determine the emissions reductions necessary in order to meet the emissions target.
Step 2:	For each abatement option calculate the cumulative CO_2-abatement until that option (starting from the cheapest abatement option).
Step 3:	For each abatement option calculate the cumulative costs until that option (starting from the cheapest abatement option).
Step 4:	Find the abatement option having a cumulative CO_2-abatement that is equal to the required emission reduction.
	> *If found, the abatement costs are equal to the cumulative costs of that specific option. Go to next year and repeat from step 1.*
	> *If not found, go to step 5.*
Step 5:	Find the abatement option having a cumulative CO_2-abatement that is the smaller closest value to the required emission reduction.
	> *All abatement options with costs equal and/or smaller to that specific option are used for abatement.*
	> *The related abatement costs are equal to the cumulative costs calculated for that specific option in step 3.*
Step 6:	Determine the difference between the emission reductions necessary and the cumulative abatement of the smaller closest abatement option.
Step 7:	Find the abatement option having a cumulative CO_2-abatement that is the higher closest value to the required emissions reduction.
	> *The abatement from that specific option is equal to the difference as calculated in step 6.*
	> *The related abatement costs are equal to the abatement from that specific option multiplied by its individual costs.*
Step 8:	Determine the total abatement costs by summing the costs as calculated in steps 5 and 7.
Step 9:	Go to next year and repeat from step 1.

To illustrate the model logic, assume that in 2030 the required emissions reductions equal 150 $MtCO_2$. From Figure 21 find that the abatement option with the smaller closest cumulative abatement value is 'cabin weight reductions'. All abatement options to the left of 'cabin weight reductions' on the MAC curve are used for emission reductions in 2030. The remaining required emission reductions are achieved by switching to biofuels. In the case where offsets are available to compensate emissions' growth they are purchased when their price is lower than biofuels.

7.2 VERIFICATION AND VALIDATION

This paragraph is concerned with testing the simulation model. Paragraph 7.2.1 describes the model verification to check whether the model is built correctly. During this process the model is tested to find and fix errors in the implementation of the model. Paragraph 7.2.2

describes the model validation to check the accuracy of the model's representation of the real system. Here the question is answered whether the constructed model is applicable to meet the study's objective.

7.2.1 Model verification

Verification checks whether no errors have been made in representing the model in the computer (van Daalen, Pruyt, Thissen, & Phaff, 2009). This is done below by testing for the following two purposes:

i. Consistency in logical structure
ii. Consistency in dimensions

Consistency in logical structure

The consistency test is the first verification method. Here it is checked whether the structure in the model is corresponding to the logical structure as defined in paragraph 5.1.3. In other words, is the translation from model conceptualization to specification correct?

The main part of the model is concerned with finding the cheapest abatement technologies to realize the required emission reductions. As such, for different years it is checked for a variety of input values with regard to the required emission reductions whether the cheapest abatement technologies are chosen by the model, and whether the realized emission reductions equal the required emission reductions. This is done by manually reading the smaller and higher closest values to the required emission reductions from the cumulated CO_2-abatement table in the model and checking these readings with the technologies that the model suggests.

The following conclusions can be drawn from this analysis:
> The model finds the correct smaller closest value to the required emission reductions.
> The model finds the correct higher closest value to the required emission reductions.
> The model finds the correct abatement technologies corresponding to the closest values as defined above.
> The cumulated abatement from these abatement technologies equals the required emission reductions.
> These findings hold for every year in the period 2020-2050.

As a result of this analysis it is concluded that the logical structure is correctly implemented into model.

Dimension check

A second verification test is checking whether the variables in the model have the correct unit. As such it is firstly checked whether the unit is representing a factual unit. In other words, are CO_2-emissions expressed in tonnes of CO_2 and are costs expressed in US dollars? Secondly, by testing the mathematical formulas it is checked whether the units match. For example, consider the following variables when calculating the annual costs of using offsets.

> Quantity of offsets used   (in $GtCO_2$)
> Cost of an offset unit   (in USD / tonne CO_2)
> Total abatement costs from using offsets   (in billion USD)

The logical formula for calculating the total abatement costs from offsets is by multiplying the quantity of offsets used with the unit price. However, the total abatement costs are expressed in billion USD, requiring the calculated costs to be divided by 10^3. Other formulas were tested similarly.

As a result of this dimension check it is concluded that the unit dimensions in the model are correct.

7.2.2 MODEL VALIDATION

Validation is used to refer to the entire range of tests conducted to check that the model meets the objective of the study (Forrester, 1968). This range of tests include the three described below.

    i.   Extreme values
    ii.   Comparing the model generated data with ICAO modeling results
    iii. Sensitivity analysis

EXTREME VALUES

The first test for model validation is checking model behavior when inserting extreme values into the model. When such extreme values (i.e. values equal to zero or extremely high compared to the actual values) are used it can be assessed whether the model is still showing logical behavior. The following examples show different extreme values used and the corresponding logical behavior that the model must show:

> If the business-as-usual growth factor in emissions equals 0, then the yearly abatement is constant.
> If offsets are priced at 0 USD/tonne CO_2 in the period 2020-2050, all abatement comes from 'free' abatement options, and the total abatements costs equal zero.
> If offsets are priced at 1500 USD/tonne CO_2 in the period 2020-2050, offsets would only be used when the cumulative abatement from all other options is less than what is required.
> If biofuels are priced at 0 USD/tonne CO_2 in the period 2020-2050, offsets would only be used to fill the emissions gap in case not enough biofuels are available.
> If biofuels are priced at 1500 USD/tonne CO_2 in the period 2020-2050, no abatement from biofuels takes place.

Under all of the above and other inserted extreme values the model behaved logically. As such, extreme value testing gives more confidence in that the model is accurate.

COMPARING THE MODEL GENERATED DATA WITH ICAO MODELING RESULTS

During the Global Aviation Dialogues in April 2015 ICAO has shown the results of modeling a global market-based measure based on carbon-neutral growth from 2020 onwards. Since the *carbon-neutral growth* design in this model is built upon that design, the modeling results from this thesis' design can be compared to the publically available figures from ICAO (2015b). However, it should be noted that the comparison is only possible to some extent, since most of the input that ICAO is using for its modeling is unknown. Therefore the comparison will only focus on the order of magnitude.

Table 23 shows the abatement costs for the international aviation sector from ICAO modeling and this thesis. Since ICAO uses different scenarios with regard to the offset price equal prices have been inserted into this thesis' simulation model to enable a fair comparison. The following scenarios were adopted:

> Under a low carbon price assumption, the offset price in 2025, 2030, and 2035 equals 6, 10, 12 USD/tonne CO_2 respectively.

> Under a medium carbon price assumption, the offset price in 2025, 2030, and 2035 equals 8, 15, 20 USD/tonne CO_2 respectively.
> Under a high carbon price assumption, the offset price in 2025, 2030, and 2035 equals 20, 33, 40 USD/tonne CO_2 respectively.

Table 23 - Comparing the model generated data with ICAO modeling results

Scenario [bln USD]	Low CO_2-price		Mid CO_2-price		High CO_2-price	
	Model	ICAO	Model	ICAO	Model	ICAO
Abatement costs in 2025	0.6	1.9	0.8	2.8	2.0	6.2
Abatement costs in 2030	3.1	3.8	4.7	5.6	12.7	12.4
Abatement costs in 2035	6.9	7.2	16.8	11.9	23.2	23.9

From Table 23 different observations can be made that are important. They are summarized hereunder.

> It can be observed that the abatement costs as calculated by the model are in the same order of magnitude as ICAO's results.
> The deviation in abatement costs is least under the high carbon price assumption.
> The deviation in abatement costs is least in the year 2030.
> Most deviation occurs in the year 2025 where the model shows lower costs under every scenario compared to ICAO's results.

The lower costs as calculated by the model could be a result of the abatement options that have net negative abatement costs that have been assigned a near-zero value. It could be that ICAO did not include these abatement options thus increasing the use of offsets, leading to higher abatement costs. In fact, excluding these options from the model yields results closer to the ICAO modeling results.

In conclusion, the comparison between the model generated output and ICAO modeling results gives confidence in that the right model is built.

SENSITIVITY ANALYSIS

The third method for validating the model is a sensitivity analysis. This is a technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions (van Daalen et al., 2009). It can be used to predict the outcome of a decision if a situation turns out to be different compared to the key predictions. As such, a variety of variables in the model have been adjusted by -10% and +10% of the original value to assess the sensitivity exhibited of the model. In other words, it is assessed which independent variables cause most deviation in the model output. After a scan of sensitivities in the model it is observed that the variables having most influence upon the model output are:

> Business-as-usual civil aviation emissions   [in $GtCO_2$]
> Offset price   [in USD/tCO_2]
> Marginal abatement costs of biofuels   [in USD/tCO_2]
> Abatement potential of biofuels   [in $GtCO_2$]

From the sensitivity analysis it is concluded that there is significant sensitivity in the model behavior. Small changes in the value of the four before mentioned independent variables result in considerable differences in modeling output.

Therefore based on this sensitivity analysis it is suggested to include uncertainty with regard to these four variables.

7.3 REFLECTING UNCERTAINTY

Until now different data sources have been used for constructing the model, including data from ICAO, IATA and the OECD/IMF. A number of sources have included uncertainty in their data. Examples include the forecasted aviation emissions including different MODTF scenarios (MODTF, 2009) and estimated offset prices including a low-, medium-, and high-carbon price assumption (ICAO, 2015b). Other data does not include uncertainty at all. For example, IATA's marginal abatement cost curves provide exact values for carbon abatement and related costs (IATA, 2013c).

Since the simulation model as defined in paragraph 7.1 is built by selecting scenarios – *MODTF Scenario 1 and a medium carbon price assumption* - and IATA's MAC curves, it does not include uncertainty. However, by not representing uncertainty there is the threat of the belief the model provides an exact representation of what would happen in reality, which can be harmful for policy-making (Ekins et al., 2011). Instead, "*it is important to place greater emphasis on the uncertainty, so that decision makers are more fully aware of them and can factor the uncertainty into their decisions*" (Ekins et al., 2011). Including uncertainty is especially relevant for those variables having most influence upon the model behavior and output. For each of the independent variables from paragraph 7.2.2 this is done below.

7.3.1 *INTERNATIONAL AVIATION EMISSIONS WITHOUT THE MBM*

As already explained in paragraph 7.1, ICAO has constructed six different scenarios with regard to the development of aviation emissions until 2050 without the MBM. In the static model MODTF Scenario 1 (*Do Nothing*) was chosen since it represents the business-as-usual emissions without any technological, infrastructural, and operational improvements. In this scenario, total aviation emissions in 2020 equal 1112 $MtCO_2$ and 4531 $MtCO_2$ in 2050 (MODTF, 2009). However it is imaginable that without the MBM there are improvements in reducing aviation's emissions. These improvements can be triggered by the goal of the industry to become more sustainable, and the goal of reducing costs (i.e. many carbon abatement measures can realize costs reductions (IATA, 2013c)). In fact, the industry already set a goal of achieving a fuel efficiency of 1.5% per annum from 2010 to 2020 and an aspirational goal of 2% per annum after 2020 (ATAG, 2013b). This goal aligns better with other MODTF scenarios that include carbon abatement measures.

The possibility of the aviation industry implementing technological, infrastructural, and operations improvements makes it difficult to forecast international aviation emissions without the MBM. Recent years have already shown an improvement in decoupling aviation emissions from international aviation activity (ATAG, 2013b). Furthermore, a temporary decrease in international aviation activity – as happened during the recent economic crisis (Macario & Van de Voorde, 2009) - can cut aviation emissions even more. In fact, global aviation emissions in 2012 equaled 689 $MtCO_2$, which is lower than the forecasted 2012 emissions from any scenario as calculated by MODTF.

In conclusion, including MODTF Scenario 1 (*Do Nothing*) in the model might overestimate the emission reduction potential of the global market-based measure. To include the possibility of carbon abatement measures occurring without a MBM the model is adjusted in such a way that there is an equal probability that either one of the six MODTF Scenarios would occur.

7.3.2 *OFFSET PRICE*

Since Chapter 4 pointed out that it is very difficult to predict the offsets available after 2020, it was assumed in the static model that the price of offsets would be equal to those as forecasted in ICAO's medium scenario (ICAO, 2015b). However, lessons drawn from existing

carbon pricing instruments show that these prices can be very volatile and unpredictable (World Bank, 2014). To reflect this volatility and uncertainty it is therefore decided to add ICAO's two other scenarios – *low carbon price* and *high carbon price* – to the model. According to the former scenario, the carbon price in 2020, 2030, and 2035 is equal to respectively 6, 10, 12 USD/tonne CO_2. According to the latter scenario, the carbon price in 2020, 2030, and 2035 is equal to respectively 20, 33, 40 USD/tonne CO_2. It is assumed that the probability of each of these three ICAO scenarios occurring is equal.

7.3.3 *MARGINAL ABATEMENT COSTS OF BIOFUELS*

According to a study on bioenergy done by the International Energy Agency (IEA) there is still a great degree of uncertainty over the production costs of aviation biofuels, mainly because they are currently not being produced on a commercial scale (IEA, 2012). In addition, since the price of jet fuel is almost perfectly correlated to the oil price (NREL, 2014), there is also a high degree of uncertainty with regard to the price of jet fuel. The high degree of uncertainty with regard to the production costs of aviation biofuels and price of jet fuel make it very difficult to estimate the marginal abatement costs of biofuels in the period 2020 until 2050. Nevertheless, an assessment of the marginal abatement costs as provided by IATA (IATA, 2013c) is possible when understanding (i) the range of available aviation biofuels production methods and (ii) their respective cost structure. Since estimating the oil price goes beyond the scope of this study, the oil price is assumed to be equal to the values as estimated by IATA.

AVIATION BIOFUELS PRODUCTION METHODS

There are different production pathways for fossil jet fuel alternatives. Table 24 summarizes studies studies from Faaij & van Dijk (2012) and ICAO (2014a) and shows that alternative fuels from three out of five aviation biofuels production technologies are currently approved as aviation drop-in fuels. In the future, biofuels from sugar conversion and direct liquefaction might become available. The use of farnesene from hydoproessing is still in its early phase (ICAO, 2014a). For now only the cost structure of the FT and HEFA fuels are described.

Table 24 - Production pathways for fossil jet fuel alternatives

Technology	Feedstock	Products	Approved as drop-in fuel
Fischer-Tropsch	Any material containing carbon (coal, gas, biomass, waste)	Straight alkenes	Yes
HEFA	Vegetable (waste) oils and animal fats	Straight alkenes	Yes
Hydroprocessing	Sugar crops, cereals, willow, switchgrass	Farnesene	Yes
Alcohol-to-jet	C6 sugars (from starch of cellulose)	Alcohols, alkanes and other hydrocarbons	No
Pyrolysis	Any solid material containing carbon	Mainly naphthenic compounds	No

COST STRUCTURE OF AVIATION BIOFUELS

The total costs of producing biofuels depend on mainly two factors: (i) raw material costs (i.e. the feedstock price), and (ii) the conversion costs (i.e. the capital costs). For FT-fuels, the conversion costs are the main cost factor, ranging from 35% to 50% (IEA, 2011). Lower total costs are achieved when the installed capacity is increased leading to economies of scale. For HEFA-fuels, the raw material costs are the main cost factor, ranging from 45% to 70% (IEA, 2011). Similarly to FT-fuels, lower total costs are achieved by economies of scale, although to a lesser extent (IEA, 2012). The availability of production capacity makes the HEFA

production technology the only realistic option to produce significant volumes of aviation biofuels on a commercial scale, although its price is still significantly higher than conventional jet fuel (Faaij & van Dijk, 2012). Therefore, the marginal abatement costs of biofuels depend to a great extent on the development of material costs (feedstock).

In its analysis on the development of conventional and alternative jet fuels prices, IATA shows a steady decline of alternative jet fuel prices derived from the HEFA production method. However, in an assessment performed by IEA (2012) on IATA's forecast it concluded that IATA's expectations were rather ambitious because feedstock prices do not have to decline as steadily as assumed.

Relating the above analysis to the model specification, uncertainty is added to reflect potential higher costs of biofuels.

7.3.4 ABATEMENT POTENTIAL OF BIOFUELS
The marginal abatement potential of biofuels is dependent upon the following three factors:

  i.   Eligibility of biofuels for aviation purposes (Faaij & van Dijk, 2012)
  ii. Availability of production capacity (Faaij & van Dijk, 2012)
  iii. Feedstock market competition (IEA, 2012)

Alternative jet fuel first has to be accepted as technically safe fuel before it can be used for commercial flights. This assessment is in general done by the American Society for Testing and Materials (ASTM). They have only approved fuels from FT and HEFA production methods in a 50% per cent blend with fossil kerosene (Faaij & van Dijk, 2012). However in the future, more technologies might become available when research shows sufficient safety with regard to these alternative jet fuels (IEA, 2011).

As was already mentioned in the previous paragraph '*marginal abatement costs of biofuels*' the current market situation shows that the availability of production capacity makes the HEFA technology the only production method to currently produce aviation biofuels on commercial scale (Faaij & van Dijk, 2012). More production capacity for HEFA and other technologies will be installed in the scenario of a more mature market, with higher feedstock availability and greater demand for biofuels (IEA, 2012).

With more biofuel production technologies and production capacity becoming available in the future, there is the prospect of increased potential for aviation biofuels in the period 2020 to 2050. However, this potential can to some extent be offset by feedstock market competition from other end uses. According to the IEA there are six competing factors (IEA, 2012):

  > Competition with other land use requirements for food, fodder, and other bioenergy applications
  > Competition with other renewable energy carriers at the end use (e.g. wind power)
  > Competition with other non-energy applications other than food (e.g. chemicals and natural products)
  > The competition for environmental use of land (i.e. biodiversity, carbon stocks in soil, sustainability standards)
  > Completion with fossil fuels in all the applications
  > For aviation biofuels in specific, competition with other bioenergy pathways (i.e. electricity, biofuels for transport)

This analysis shows that there are market developments which can have both a positive and negative effect on the abatement potential of aviation biofuels. Having said that, it is important to note that in IATA's marginal abatement cost curve only biofuels from algae are

included (IATA, 2013c). Even though there potential is very large, it is yet an unproven technology and the development time is expected to be long (Faaij & van Dijk, 2012). The International Energy Agency states that: "*it is clearly too early yet for any realistic assessment of the potential for algae production and large scale commercial exploitation; it is probably not possible before 2020*" (IEA, 2012). This raises questions with regard to the validity of the abatement potential of algae-based biofuels as estimated by IATA. Despite uncertainty with regard to the potential of algae-based biofuels, there are other feedstocks available that can be used in the HEFA production method. Other promising (non-food) feedstocks include jatropha curcas, camelina sativa, and salicornia bigelovii. However, their potential is similarly unpredictable (IEA, 2012).

In conclusion, this argumentation shows that on the one hand the abatement potential as estimated by IATA can be considered overoptimistic as analysis by the IEA shows that it is yet too early to forecast the potential of algae-based biofuels. On the other hand, IATA did not include other promising feedstocks. As such, it can be argued that IATA's forecast might underestimate the potential of aviation biofuels.

Relating the above analysis to the model specification, uncertainty is added to reflect both a lower and higher abatement potential of aviation biofuels. An overview of how uncertainty is added to the four described variables is shown in Table 25.

Table 25 - Reflecting uncertainty

Variable	Distribution	Range	Source & *assumptions*
BAU emissions	Discrete uniform	[1 – 6]	MODTF Scenarios (2009)
Offset price	Discrete uniform	[1 – 3]	ICAO Scenarios (2015)
Marginal cost biofuels in 2020 [USD/tCO$_2$]	Continuous uniform	[25 – 50]	Minimum: IATAs MAC curve *Maximum: twice the IATA estimate*
Cost growth factor [%]	Continuous uniform	[-2.2 – 0]	Minimum: IATA's MAC curve *Maximum: no decline in price biofuels*
Potential of aviation biofuels in 2020	Continuous uniform	[12.5 – 37.5]	*Minimum: -50% the IATA MAC curve estimate Maximum: +50% the IATA MAC curve estimate*
Potential growth factor	Continuous uniform	[0 – 18.3]	*Minimum: -50% the IATA MAC curve estimate Maximum: +50% the IATA MAC curve estimate*

7.4 MODELING SETTINGS

The simulation is run for the years 2020 until 2050 in which the interval is set to 1 year. This time period is taken since it has become the standard in assessing policies for ICAO, IATA, and other stakeholders, see e.g. ATAG (2013a), Green Air Online (2015b), IATA (2013b). The used sampling method is Monte Carlo, which is the traditional technique for using random or

pseudo-random numbers to sample from a probability distribution. Although Latin Hypercube is often considered a better method since it performs better with less trials (Palisade, 2015), it is found that running the model with the large amount of trials in this study does not deliver different results with the Latin Hypercube method. The random number generator is the Combined Multiple Recursive Generator (hereafter: CMRG), which is considered superior over other types of generators (Solver, 2015). For model testing purposes the simulation is run 1000 times, because it is found that doing 10.000 only slightly changes the modeling output. For the final analysis (see chapter 8) 100.000 trials are run. Doing more runs does not result in any changes in modeling output. A summarized overview of the modeling settings is shown in Table 26.

Table 26 - Modeling settings for the simulation

Modeling setting	Interpretation
Period	2020-2050
Interval	1 year
Sampling method	Monte Carlo
Random number generator	CMRG
Trials for testing purposes	1.000 (running time = ± 12 seconds)
Trials for final assessment	100.000 (running time = ± 20 minutes)
Software	Analytic Solver Platform V2015-R2 for Microsoft Excel

7.5 CONCLUSIONS

In this chapter it has been shown how the simulation model is built that shall be used to analyze the global mandatory offsetting designs. By means of a sensitivity analysis it was shown that four independent variables cause significant different model behavior. These include the business-as-usual civil aviation emissions, offset price, marginal abatement costs of biofuels, and abatement potential of biofuels. Based on a literature review changes have been made with regard to the input assumptions of these variables in order to reflect uncertainty. In the next chapter the simulation shall be used to analyze the global mandatory offsetting designs on the commensurable criteria.

IV
Analysis

All things are subject to interpretation, whichever interpretation prevails at a given time is a function of power and not truth.

Friedrich Nietzsche

8 Analysis of the designs

The four principles of a robust design require a design to be both purposeful and sturdy. As such, a design should satisfy the main goal of decreasing the climate impact of aviation and be the preferred design under a wide range of conditions. This chapter analyzes the four global mandatory offsetting designs based on the redefined criteria in order to assess for robustness.

8.1 CUMULATIVE CO_2-ABATEMENT POTENTIAL

In paragraph 5.5 it was mentioned that the environmental performance of the global market-based measure - as defined by the cumulative CO_2-abatement potential - is regarded as a key concern by many stakeholders, including the UNFCCC, EU, and NGOs. This criterion is crucial as the rationale of the global MBM is to "*support sustainable development of the international aviation sector*" (ICAO, 2014c).
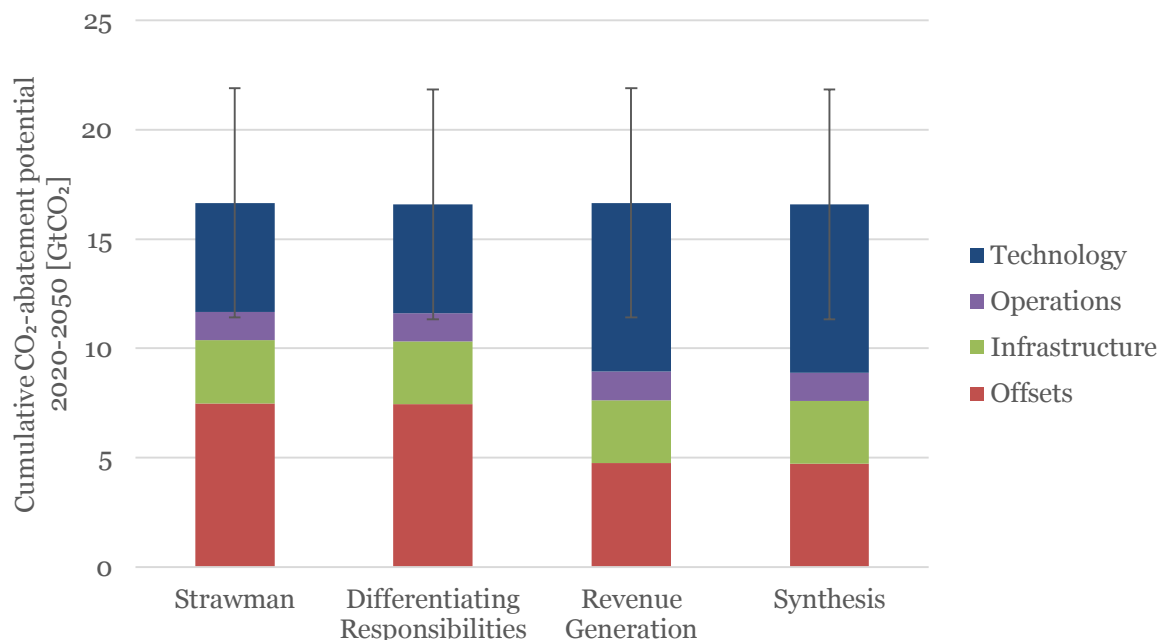

Figure 22 - Cumulative CO_2-abatement potential 2020-2050

Simulation results (see) show that for the Strawman and Revenue Generation designs the mean CO_2-abatement potential in the period 2020-2050 equals **16.6 $GtCO_2$** with a standard deviation of 5.2 $GtCO_2$. In ninety percent of the scenarios the carbon-dioxide abatement

potential lies between 11.3 and 26.9 Gt CO_2. The model shows similar results for the Differentiating Responsibilities and Synthesis designs. The mean cumulative amount of CO_2-emissions reductions equals ***16.5 GtCO₂*** with a standard deviation equaling 5.2 $GtCO_2$. In ninety percent of the scenarios modeled the carbon-dioxide abatement potential lies between 11.3 and 26.8 $GtCO_2$. Furthermore simulation results show the difference in cumulative CO_2-abatement potential between the four global mandatory offsetting designs is equal to ***65.8 MtCO₂*** with a standard deviation of 14.6 $MtCO_2$.

Based on the above described statistics, and additional modeling results, a number of important observations can be made that have implications for further analysis in thesis.

   i. ***The cumulative CO₂-abatement potential of all four global mandatory offsetting designs is substantial.***
   Modeling results show the large abatement potential is caused by the high growth of business-as-usual civil aviation emissions. In fact, by using the MODTF scenarios it is found that the compound annual growth rate of business-as-usual CO_2-emissions are in the range of 3-5%.
   > *An important implication of this finding is that all global mandatory offsetting designs satisfy the principle of purposefulness, i.e. all designs satisfy the main goal of decreasing the climate impact of aviation.*

   ii. ***There is only a small difference in the cumulative CO₂-abatement potential between the four designs.***
   The difference is caused by the temporary exclusion of certain developing States in the Differentiating Responsibilities and Synthesis designs. This exclusion leads to smaller amounts of CO_2-emission reductions in the years 2020-2023 and 2024-2026, when the CO_2-emissions coverage is 80.5% and 90% respectively. From 2027 onwards the carbon abatement is equal in all four designs.
   > *An important implication of this finding is that temporary excluding certain developing States to reflect the UN's Common But Differentiated Responsibilities principle does not lead to a significantly lower cumulative CO_2-abatement potential of the market-based measure.*

   iii. ***The difference between the four designs is more related to how emission reductions are realized.***
   Figure 22 shows that there is a significant difference between how emission reductions are realized in the Strawman and Differentiating Responsibilities design compared to the Revenue Generation and Synthesis design. A more extensive analysis of how emission reductions are realized is shown in paragraph 8.2.

   iv. ***There is a significant uncertainty with regard to the cumulative CO₂-abatement potential.***
   The uncertainty of the cumulative CO_2-abatement potential is caused by uncertainty with regard to business-as-usual civil aviation emissions. The six MODTF scenarios show great variety in possible emission pathways until 2050. To illustrate, according to MODTF (2009) in the worst-scenario the CO_2-

emissions in 2050 equal 4531 $MtCO_2$, while in the best-case scenario the emissions equal 2307 $MtCO_2$.

> *An important implication of this finding is that is impossible to state with certainty that the cumulative CO_2-abatement potential is exactly equal to 16.6 or 16.5 $GtCO_2$. Instead this number should be interpreted as an estimate that gives insight into the order of magnitude of the abatement potential for each global mandatory offsetting design.*

v. **The mean in cumulative CO_2-abatement potential is concentrated more towards the lower end of the range.**
The statistics show it is more probable that the cumulative CO_2-abatement potential is equal to somewhere between 11.3 to 16.6 $GtCO_2$ than 16.6 and 26.9 $GtCO_2$. This is caused by the unequal distribution of emissions in the MODTF Scenarios. For 5 out of 6 scenarios the CAGR lies in the range of 3-4%, while the remaining scenario includes a CAGR of 5%.

> *An important implication of this finding is that, when interpreting the CO_2-abatement potential estimate, it is more probable that the abatement potential is lower than the given estimate rather than higher.*

In conclusion, although there are small differences in cumulative CO_2-abatement potential between the global mandatory offsetting designs, all have a very good performance relative to the business-as-usual. Therefore the following scores have been assigned to each design, see Table 27.

Table 27 - Score on cumulative CO_2-abatement potential

	Strawman	Differentiating Responsibilities	Revenue Generation	Synthesis
Cumulative CO_2-abatement potential	++	++	++	++

8.2 IN-SECTOR EMISSION REDUCTIONS

The stakeholder analysis in chapter 5 showed that in the political debate regarding the global market-based measure there is a difference in the perception of in-sector emission reductions and the use of offsets. Simulation results shown in Figure 22 illustrated there is a significant difference in the amount of in-sector reductions and offsets used in the Strawman and Differentiating Responsibilities design compared to the Revenue Generation and Synthesis design. While the former two designs lead to a greater use of offsets than technology for CO_2-abatement purposes, the latter two designs show the opposite. Table 28 provides an overview of the mean share of in-sector reductions – the summation of infrastructural, operational, and technological abatement - per design.

Table 28 - Share of in-sector emission reductions

Design / Abatement	Offsets	Infrastructure	Operations	Technology	In-sector reductions
Strawman	44.5%	17.4%	7.9%	30.2%	55.5%
Differentiating Responsibilities	44.5%	17.4%	7.8%	30.3%	55.5%
Revenue Generation	31.9%	17.4%	7.9%	42.8%	68.1%
Synthesis	31.8%	17.4%	7.8%	43.0%	68.2%

Table 28 shows that the Strawman and Differentiating Responsibilities designs have a 55.5% share of in-sector emission reductions, while the Revenue Generation and Synthesis designs have a larger share, approximately 68%. The remaining emission reductions are realized by the use of offsets. While this analysis suffices for assigning scores to each design, additional analysis can provide insights into the underlying mechanisms that cause the difference between the designs. In other words, "*what is the story behind the numbers*"?

COST-PARITY BETWEEN OFFSETS AND BIOFUELS

In fact, the difference between the designs is caused by the marginal cost behavior of offsets and biofuels until 2050. Since (i) the abatement options with negative abatement costs (modeled as near-zero costs, see chapter 7) are always preferred over options with positive abatement costs, and (ii) the next abatement option after biofuels in the MAC curve is always more expensive than the use of biofuels (see Figure 20 and Figure 21 for the price difference in 2020 and 2030 respectively), either offsets or biofuels are used to realize the 'remaining' emission reductions. For each year, this decision is based on whether cost-parity has already been met, and whether the availability of biofuels is sufficient to realize the required emission reductions. Since there is no difference in the availability of biofuels between the four designs, the difference in the amount of in-sector emission reductions is caused by the cost-parity motive.

Figure 23 shows the simulation results of the mean price behaviour of aviation biofuels, the offset price, and the offset price including a transaction fee. It shows that when no transaction fee is applied, cost-parity between offsets and biofuels is reached around the year 2040. However, if a transaction fee is applied, cost-parity is reached approximately five years earlier, in the year 2035. Relating this finding to the global mandatory offsetting designs this means that for the Strawman and Differentiating Responsibilities designs offsets are cheaper than biofuels for a longer period than for the Revenue Generation and Synthesis designs. Combining this insight with Figure 22 (see paragraph 8.1) learns that the availability of biofuels is already sufficient to switch (partially) to biofuels in the year 2035 and that thus more biofuels are used in the latter two designs.
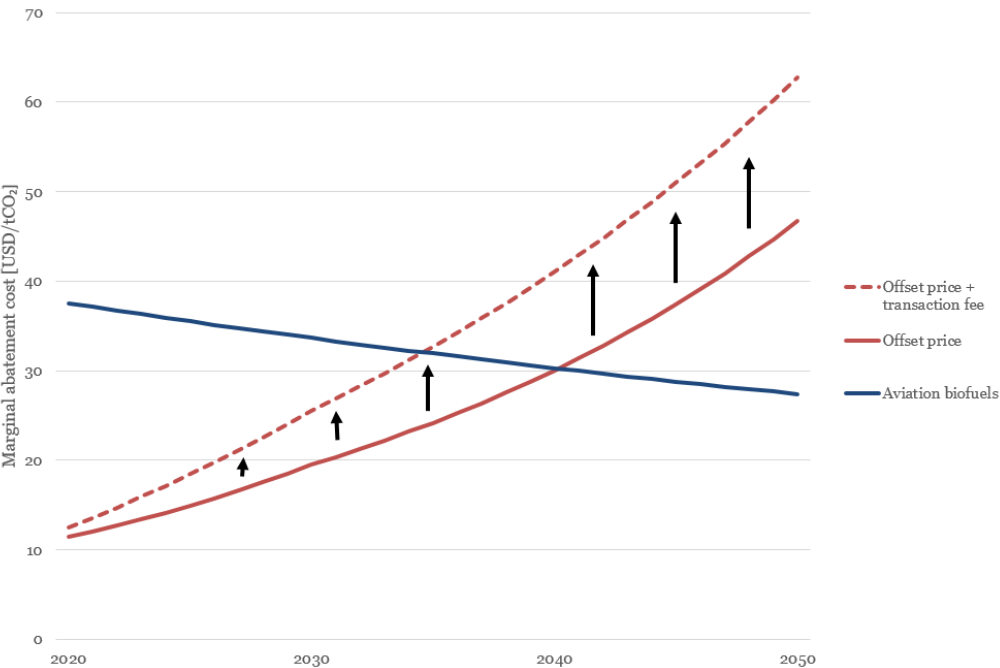

Figure 23 - Cost-parity between offsets and biofuels

Until this point of the analysis, the results have been presented in an aggregated way by cumulating the emission reductions over a period of 30 years. However, since the simulation model is specified to calculate the abatement per year, it allows the researcher to obtain insights into how emission reduction are realized *over time*. In fact, while analyzing a random sample of 100 model simulations runs four different abatement scenarios were discovered that could unfold until 2050. These are presented in Figure 24 and show *if* and *when* cost-parity is reached between offsets and biofuels. In this figure BAU represents the business-as-usual emissions, and CNG represents carbon-neutral growth. The coloured gap shows by which type of abatement the emission reductions are realized to maintain carbon-neutral growth.
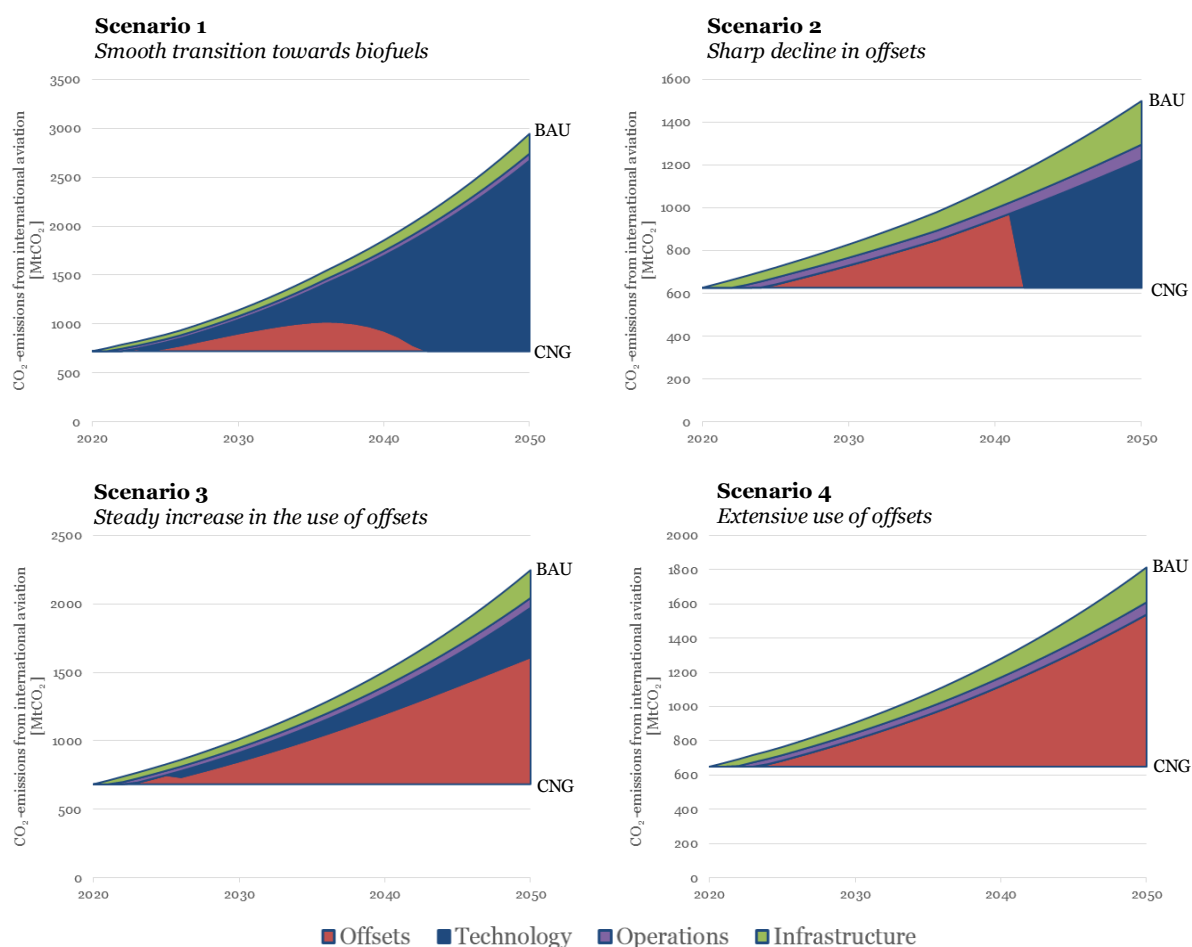
Figure 24 - The four abatement scenarios from 2020 until 2050

Smooth transition towards biofuels

This scenario is characterized by a gradual increase in the use of offsets followed by a gradual decline towards no offsets at some point in time. The bell-shaped area in Figure 24 graphically shows this and distinguishes this scenario from other scenarios. The gradual decline in the use of offsets is compensated by an increased use in technology, and in specific aviation biofuels. Note the resemblance between this scenario and Figure 3 showing the indicative industry's carbon abatement commitments towards 2050. In both cases the global market-based measure is merely a temporary measure to tackle international aviation emissions, after which biofuels are forecasted to deliver the necessary emission reductions. It is found the underlying mechanisms for this smooth transition are the following three events:

i.   At some point in time biofuels are cheaper than offsets. In this scenario parity is reached around 2035, when the bell-shape is at its highest point representing the maximum amount of offsets used in this scenario.

ii.   When parity is reached the carbon abatement potential of biofuels is not enough to realize all necessary emission reductions to realize carbon-neutral growth.

iii.   At some point in time before 2050 the carbon abatement potential from biofuels is greater than the required emission reductions to reach carbon-neutral growth. At this point no more offsets are used.

Sharp decline in the use of offsets

This scenario is depicted by a sharp decline in the use of offsets at some point in time. In Figure 24 this is shown by the steep red line downwards indicating the abrupt transition of offsets towards biofuels. It is found that the underlying mechanism for the sharp decline in offsets is the combination of the following events:

i.   Similarly to the first scenario, at some point in time biofuels are cheaper than offsets. In scenario 1 parity is reached around 2035, when the bell-shape is at its highest point representing the maximum amount of offsets used in this scenario.

ii.   When parity is reached between the offset and biofuel price the carbon abatement potential of biofuels is greater than the required emission reductions.

Steady increase in use of offsets

This scenario is depicted by a steady increase in the use of offsets until 2050. In Figure 24 this is shown by the steep red line representing the amount of offsets used. A fair amount of remaining emission reductions are realized by technology, operations, and infrastructure. This scenario differs significantly from the first scenario in the sense that there is no phasing-out of offsets. It is found the underlying mechanisms for the steady increase in the use of offsets are the following three events:

i.   Similarly to the first scenario, at some point in time biofuels are cheaper than offsets. In the first scenario parity is reached around 2035, when the bell-shape is at its highest point representing the maximum amount of offsets used in this scenario.

ii.   Similarly to the first scenario, when parity is reached the carbon abatement potential of biofuels is not enough to realize all necessary emission reductions to realize carbon-neutral growth.

iii.   The carbon abatement potential of biofuels is always smaller than the required emission reductions. This is caused by a lower growth factor of abatement potential than international aviation emission without the global market-based measure. For example, in the graph shown in Figure 24 the former growth factor is equal to 9.4%, while the latter equals 15.0%.

Extensive use of offsets

This scenario is characterized by an extensive use of offsets to realize the required emission reductions needed to maintain carbon-neutral growth. In Figure 24 this is shown by the large red area denoting the amount of offsets used. In contrast to the two previous scenarios there is no transition towards biofuels. It is found that the underlying mechanism is simply that in for this scenario the offset price is always smaller than the biofuel price. Hence, there is no phase-in of biofuels and all emission reductions are realized by the use of offsets.

At this point of the analysis the four different type of scenarios that could unfold from 2020 onwards have been identified. However, to relate the four abatement scenarios to how emission reductions are realized by each global mandatory offsetting design the proportional occurrence of each these scenarios is investigated. Therefore out of the 100,000 trials that are

run in each simulation a random sample of 100 trials [19] is analyzed to identify the proportional occurrence of each scenario. Since every global mandatory offsetting design is based on different modelling assumptions this is done for each design individually. The results of this analysis is shown in Table 29 below.

Table 29 - Proportional occurrence of scenarios

Global mandatory offsetting designs Sample (n=100)	Smooth transition	Sharp decline	Steady increase	Extensive use
Strawman	20%	**51%**	8%	21%
Differentiating Responsibilities	23%	**42%**	14%	21%
Revenue Generation	**42%**	**49%**	9%	1%
Synthesis	**37%**	**49%**	14%	0%

Based on the analysis on proportional occurrences a number of important observations can be drawn.

i. **Independent of the global mandatory offsetting design, the scenario that occurs most often is a sharp decline in the use of offsets.**
   > *Caution has to be taken when interpreting this conclusion. Even though modelling results show that a sharp decline in the use of offsets is the most probable scenario, non-financial barriers might impose an institutional or technological lock-in with regard to the status quo, or in fact smoothen the transition.*

ii. **The Strawman and Differentiating Responsibilities designs show a small proportional occurrence of a smooth transition towards biofuels.**
   > *An important implication of this finding is that, while the industry is foreseeing a pathway in which economic measures only make up a minor share of CO_2-emission reductions in relation to technologies (recall ATAG's display of mapping industry commitments, see Figure 3), that pathway only holds for a global mandatory offsetting scheme with an included revenue generation mechanism.*

iii. **The Revenue Generation and Synthesis designs show a large proportional occurrence of both the scenarios of smooth transition towards biofuels and a sharp decline in the use of offsets.**
   > *An important implication of this finding is that, when the global mandatory offsetting design includes a revenue generation mechanism, it is more likely that in-sector emission reductions will occur. This is in line with Figure 22.*

In conclusion, all global mandatory offsetting designs realize in-sector emissions reductions. While the Strawman and Differentiating Responsibilities designs enable a share of in-sector emission reductions of 55.5%, the Revenue Generation and Synthesis designs enable a share of approximately 68%. The difference is caused by the transaction fee that is applied in the latter two designs, leading to an advance of cost-parity between biofuels and offsets (approximately five years earlier). This results in a relatively smaller proportional occurrence of the scenario '*extensive use of offsets*' and a relatively larger proportional occurrence of the scenario '*smooth transition towards biofuels*'. Based on this analysis, the following scores have been assigned to each design.

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[19] It is found that taking more samples (e.g. 300 trials) from the simulation does not change the relative occurrence of the scenarios.

Table 30 - Score on in-sector emission reductions

	Strawman	Differentiating Responsibilities	Revenue Generation	Synthesis
In-sector emission reductions	+	+	++	++

8.3 COSTS OF THE EMISSION REDUCTIONS

8.3.1 *CUMULATIVE CO_2-ABATEMENT COSTS 2020-2050*

The economic impact of the global market-based measure is considered crucial to many stakeholders. Especially the airline industry, represented through ICAO and the associations IATA and AEA, are concerned with costs that any global MBM shall impose on the industry. One key concern for the industry is the total costs for the industry, measured in billion US dollars. By means of the marginal abatement cost curve in the simulation model, the cumulative abatement costs for the period 2020 to 2050 have been calculated. Simulation results show that there is a clear difference in costs between global market-based measure designs with and without a revenue generation mechanism.

For the period 2020 to 2050 the mean cumulative CO_2-abatement costs for the Strawman design equal **354 billion USD**. For the Differentiating Responsibilities design the costs are slightly lower, amounting to **353 billion USD**. The difference can be explained by the exclusion of certain States in the latter design. The other two designs have significantly higher mean cumulative CO_2-abatement costs. For the Revenue Generation design the costs equal **442 billion USD**. For the Synthesis design the costs are slightly lower, amounting to **441 billion USD**. These numbers are graphically shown in Figure 25. It is important to note that the standard deviation – as is indicated by the black line – is relatively large. This indicates significant uncertainty with regard to the cumulative CO_2-abatement costs.
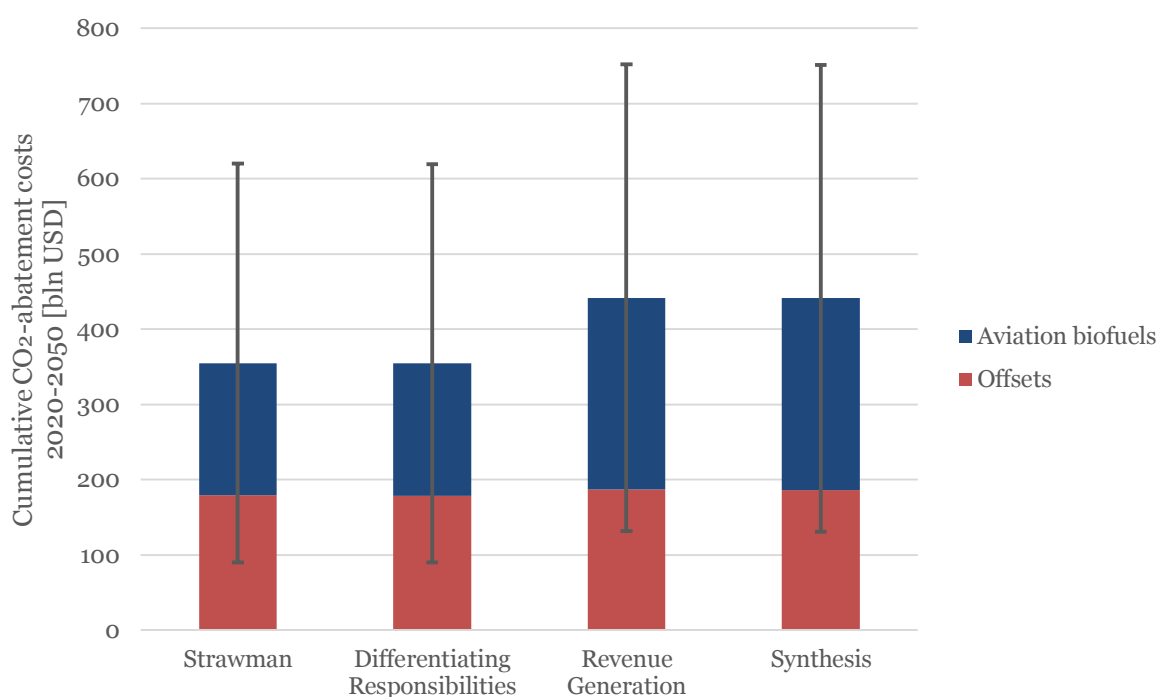
Figure 25 - Cumulative CO_2-abatement costs

8.3.2 *ANNUAL CO$_2$-ABATEMENT COSTS*

The above numbers have shown the related costs to the carbon abatement potential of each global market-based measure design. However, this does not indicate the development of annual abatement costs over time. For the airline industry it is especially relevant what the additional costs of the global market-based measure is to the business-as-usual on the short-to-medium term (ATAG, 2013b). Therefore this and the following paragraph zoom in upon the short-to-medium term. Figure 26 shows the mean annual CO$_2$-abatement costs for the years 2025, 2030, and 2035.

THE SHORT TERM: 2025

In the year 2025 the abatement costs are different for each global MBM design. Due to the exclusion of certain States the lowest costs are endured under the Differentiating Responsibilities design. These costs amount to 460 million USD. The Strawman and Synthesis design have higher abatement costs. Modeling results show that the former design leads to costs of 640 million USD, while the latter results in costs of 570 million USD. The highest costs are endured under the Revenue Generation design, with costs equaling 800 million USD. These relative high costs are caused by a combination of the additional fee for offsets and high price for aviation biofuels.

THE SHORT-TO-MEDIUM TERM: 2030

Since the model assumes that in the year 2030 no more States are excluded from the scheme, the costs for the Carbon-Neutral Growth and Differentiating Responsibilities designs converge. Due to a higher amount of emission reductions needed to maintain carbon-neutral growth the costs have increased substantially, reaching 3.8 billion USD for the total aviation industry. Since the other two designs incorporate an increased price of offsets the abatement costs are higher, amounting to 5.0 billion USD.

THE MEDIUM TERM: 2035

Modeling results show that compared to the year 2030, the carbon abatement costs in 2035 have grown considerably due to an even larger amount of required emission reductions. For the Strawman and Differentiating Responsibilities design the costs equal 8.7 billion USD. For the Revenue Generation and Synthesis design these amount to 11.5 billion USD.
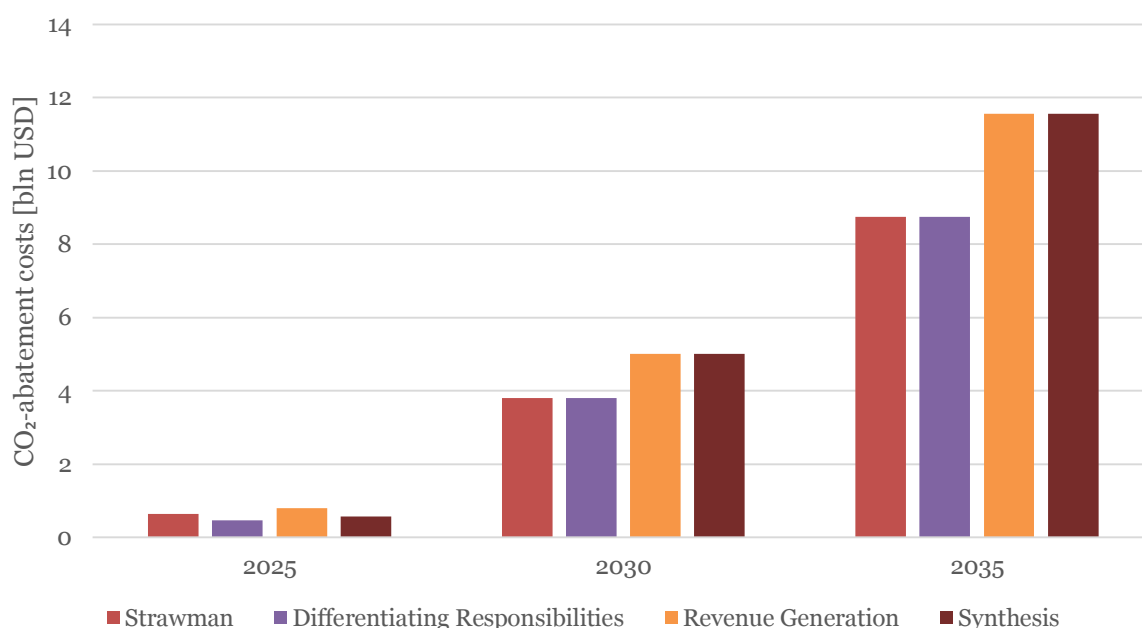

Figure 26 - Annual carbon dioxide abatement cost for 2025, 2030, and 2035

8.3.3 ABATEMENT COSTS RELATIVE TO FORECASTED REVENUE

The previous paragraph has given insights into the annual CO_2-abatement costs for several years on the short-to-medium term. However, the question that remains is whether costs imposed by the global market-based measure can be justified. In other words, can the aviation industry cope with the additional costs or are they exorbitantly high leading to the direct collapse of the industry?

In order to get insights into this question the annual CO_2-abatement costs have been compared to forecasted revenues. According to an ICAO forecast, the revenues in the years 2025, 2030, and 2035 are equal to 864, 1090, and 1330 billion USD respectively. Combining these numbers with costs calculated in the previous paragraph yields the annual CO_2-abatement costs relative to revenue. As Figure 27 shows the relative costs in 2025 are between 0.05-0.1% of forecasted revenue, depending on the global market-based measure design. For 2030 the relative costs are between 0.35-0.46% of forecasted revenue. For 2035 the relative costs are between 0.66-0.87%. From these statistics a number of important conclusions can be drawn:

1. In none of the examined years the annual CO_2-abatement costs are larger than 1% of forecasted revenue.
2. Even though revenues are forecasted to grow in the period 2025 to 2035, the growth rate of annual CO_2-abatement costs is larger. This leads to increasing relative CO_2-abatement costs.
3. Evidently, proportions between the global market-based measure designs are similar to the absolute costs calculated in the previous paragraph (as is indicated by the shape of Figure 26 and Figure 27).
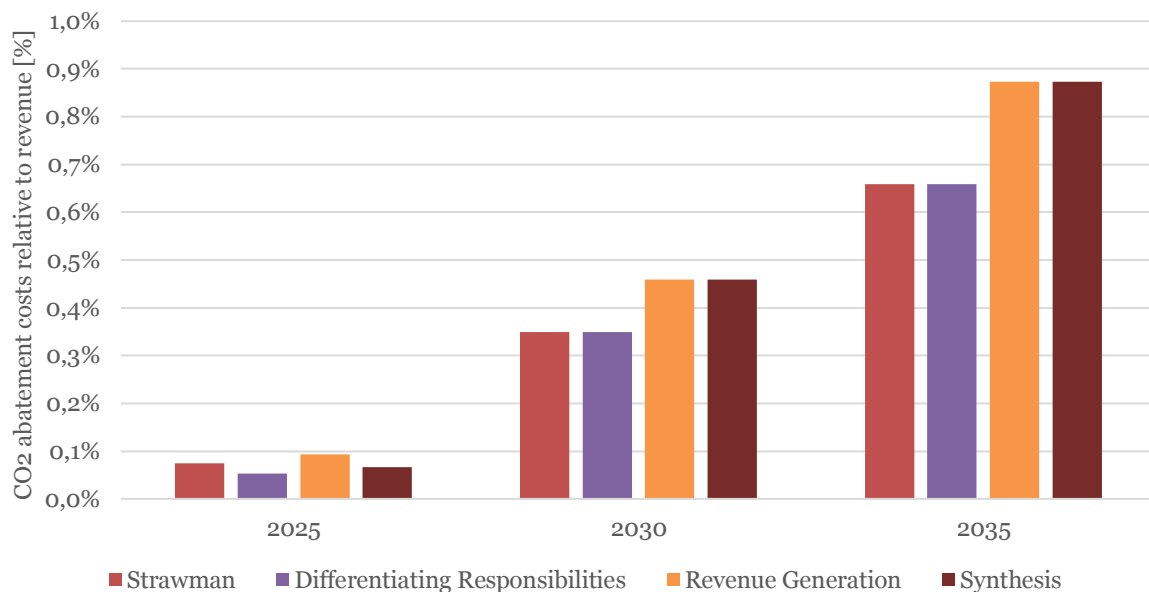
Figure 27 - Carbon dioxide abatement costs relative to revenue

To understand whether these costs exorbitantly harm the aviation industry it should be assessed whether industry's profits are high enough to compensate the additional costs. However, due to great uncertainties (e.g. fuel costs) profit margin forecasts are usually only made with regard to the near future[20]. Hence, for the years 2025 to 2035 no forecasted profit margins are available. Therefore historic industry averages are used to understand the size

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[20] For example, in April 2015 IATA first released a forecast with regard to aviation's 2015 net profits (IATA, 2015).

and development of aviation's profits. Table 31 below shows these statistics from IATA (2013c).

Table 31 - Industry's average profit margin

Year	Industry's average profit margin
2010	3.3%
2011	1.3%
2012	1.1%
2013	1.8%
2014	2.6%

These industry's average profit margins - combined with relative CO_2-abatement costs - show that *if future profit margins are similar to historic profit margins* the aviation industry could compensate for the additional costs imposed by any of the four global market-based measure designs. However, a number of remarks should be taken into account when interpreting this conclusion.

1. The conclusion is based upon the assumption - *"if future profit margins are similar to historic profit margins"* – which might not be true.
2. The conclusion is based upon no cost pass-through by the industry towards consumers. However, in reality individual airlines might pass-through the additional costs of the global MBM.
3. The relative CO_2-abatement costs have not been calculated for years after 2035. Nevertheless, previous years have shown a steady increase in these relative costs. This indicates that in the consecutive period 2035-2050 the relative costs will exceed 1% of revenue. Hence, at that point in time industry's profits might not be able to compensate for the additional costs imposed by the global MBM.
4. All the above used modeling results and statistics are industry averages. Since these are averages there are individual airlines with relatively higher/lower CO_2-abatement costs and profits. Even though on the industry-level it might seem that the global MBM might not exorbitantly harm the aviation industry, it could therefore push out individual airlines out of the industry.

8.3.4 CONCLUSION

In conclusion, the mean cumulative CO_2-abatement costs for the years 2020-2050 equal 354 and 353 billion USD for the Strawman and Differentiating Responsibilities designs respectively. Due to the additional fee for offsets in the other designs the mean cumulative CO_2-abatement costs for the Revenue Generation and Synthesis design equal 442 and 441 billion USD respectively. Furthermore, modelling results show that if future profit margins are similar to historic profit margins the aviation industry could compensate for the additional costs imposed by any of the four global market-based measure designs.
Table 32 summarizes the scores for each global market-based measure design.

Table 32 - Score on carbon dioxide abatement costs

	Strawman	Differentiating Responsibilities	Revenue Generation	Synthesis
Costs of the emission reductions	-	-	- -	- -

8.4 MARKET DISTORTION EFFECTS

The previous paragraph has focused on the CO_2-abatement costs for the collective aviation industry. Furthermore it has assumed no pass-through of costs towards the consumer. The focus of this paragraph is on market distortion effects. These are bound to occur either when (i) entities are affected differently by a policy or (ii) entities operate differently due to a policy. By excluding certain States until 2026, both the Differentiating Responsibilities and Synthesis design create an uneven level playing field in the aviation industry favoring airlines from countries with the least mature aviation markets. Since these airlines will not have to compensate for their emissions a temporary economic advantage is given to these airlines. Market distortion effects can also occur when a selection of airlines pass-through the additional costs of the global market-based measure towards the consumer and other airlines choose not to or only partially pass-through costs. In that case, there can be market distortion effects on both the airline-level and modal-level.

To assess these effects the analysis will be split into the two major markets in which the aviation industry is playing a role: (i) passenger transport, and (ii) cargo. Route-level elasticities are used to determine the demand effects for airlines which pass-through the global MBM costs to the consumer. In the analysis the following assumptions are used:

1. In the case of cost pass-through to consumers, 100% is passed-through.
2. For every route at least one substitute is available, i.e. a competitive[21] airline which does not pass through these costs.

8.4.1 EFFECTS ON THE PASSENGER TRANSPORTATION MARKET

To understand the passenger transportation demand effects which a cost passing-through airline could incur under the global MBM, a calculation scheme was created, see Figure 28. Note that in Figure 28 the white boxes contain either modeling results or are obtained from external sources. The blue boxes contain variables which are specifically computed to calculate the demand effects.
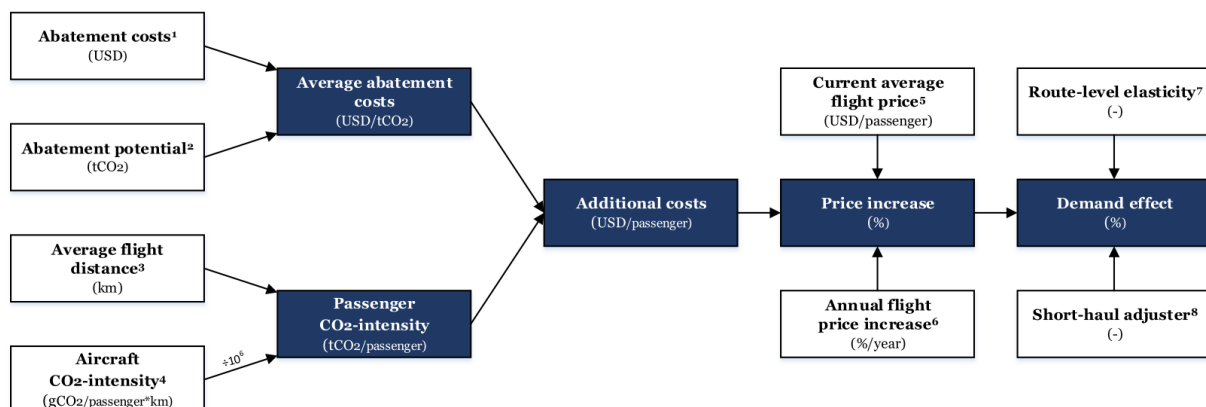

Figure 28 - Demand effects on the passenger transportation market

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[21] In this analysis a competitive airline is assumed to be one that operates in the same price category as the airline that passes through its costs.

A number of remarks and assumptions have to be made with regard to the above scheme:

1. The abatement costs are taken from modeling results in paragraph 8.2.
2. The abatement potential is taken from modeling results in paragraph 8.1.
3. Since the CO_2-emissions per passenger are dependent upon the flight distance, the scheme is re-calculated for short-, medium-, and long-haul flights. The average flight distance for short-, medium-, and long-haul flights is assumed to equal 463, 1108, 6482 kilometers. These statistics are derived from DEFRA (2013).
4. For short- and medium-haul flights the amount of emissions equal 115 gCO_2 per passenger-kilometer (Carbon Independent, 2015). For long-haul flights the amount of emissions equal 101 gCO_2 per passenger-kilometer (Carbon Independent, 2015).
5. The average price for short-, medium-, and long-haul flights in 2015 is assumed to equal 80, 125, and 500 USD/flight. These statistics are derived from Rome2Rio, a multi-modal search technology database (Rome2Rio, 2015).
6. The annual flight price increase is assumed to be 1.5%. This statistic is derived from the Air Travel Price Index from the U.S. Department of Transportation Statistics (2011).
7. Route-level elasticity is equal to -1.4. This elasticity estimate is applicable to a situation where the price of an individual route changes. It is derived from air travel demand analysis done by IATA (2008).
8. Due to the greater opportunity for inter-modal substitution an elasticity multiplier of 1.1 is used to adjust air travel price elasticities for short-haul markets. This multiplier is derived from air travel demand analysis done by IATA (2008).

Tables Table 33 to Table 35 show the effects of the different global MBM designs on the additional cost per passenger (in USD), the price increase (in %), and the related demand (in %). This is consecutively done for short-, medium-, and long-haul flights.

Table 33 - Short haul demand effects on the passenger transportation market

Short haul (463 km)	2025			2030			2035		
	USD /pass.	Price increase	Demand effect	USD / pass.	Price increase	Demand effect	USD / pass.	Price increase	Demand effect
Strawman	0.26	0.3%	-0.4%	0.69	0.7%	-1.1%	0.95	0.9%	-1.4%
Differentiating responsibilities	0.20	0.2%	-0.3%	0.69	0.7%	-1.1%	0.95	0.9%	-1.4%
Revenue generation	0.32	0.3%	-0.5%	0.90	0.9%	-1.4%	1.25	1.2%	-1.8%
Synthesis	0.24	0.3%	-0.4%	0.90	0.9%	-1.4%	1.25	1.2%	-1.8%

Table 34 - Medium haul demand effects on the passenger transportation market

Medium haul (1108 km)	2025			2030			2035		
	USD / pass.	Price increase	Demand effect	USD / pass.	Price increase	Demand effect	USD / pass.	Price increase	Demand effect
Strawman	0.62	0.4%	-0.6%	1.64	1.0%	-1.5%	2.27	1.3%	-1.9%
Differentiating responsibilities	0.47	0.3%	-0.5%	1.64	1.0%	-1.5%	2.27	1.3%	-1.9%
Revenue generation	0.76	0.5%	-0.7%	2.15	1.4%	-1.9%	2.98	1.8%	-2.5%
Synthesis	0.58	0.4%	-0.6%	2.15	1.4%	-1.9%	2.98	1.8%	-2.5%

Table 35 - Long haul demand effects on the passenger transportation market

Long haul (6482 km)	2025			2030			2035		
	USD / pass.	Price increase	Demand effect	USD / pass.	Price increase	Demand effect	USD / pass.	Price increase	Demand effect
Strawman	3.18	0.5%	-0.8%	8.43	1.3%	-1.9%	11.64	1.7%	-2.4%
Differentiating responsibilities	2.44	0.4%	-0.6%	8.43	1.3%	-1.9%	11.64	1.7%	-2.4%
Revenue generation	3.93	0.7%	-0.9%	11.05	1.8%	-2.5%	15.33	2.3%	-3.2%
Synthesis	3.00	0.5%	-0.7%	11.05	1.8%	-2.5%	15.33	2.3%	-3.2%

There are a number of important conclusions than can be drawn from the above analyses.

1. ***Passengers are more likely to switch (between airlines) on medium to long-haul flights than short-haul flights.***
   Even though more inter-modal substitution is available for short-haul flights and aircraft are more CO_2-efficient during long international flights, the price increase and thus demand effects on short haul flights is greater than medium and long haul flights. Using Table 33 together with the modeling results show that this is mostly caused by the fact that the average flight prices are not directly proportional to the flight distance.

2. ***The long-term demand effects are greater than the short-term demand effects.***
   Regardless of the global market-based measure design the long-term effects are relatively greater. Modeling results show that this is a result of a greater growth rate in average abatement costs than average flight prices. In fact, the former CAGR amounts to 4.2-8.6%, depending upon the global MBM design. The latter CAGR is equal to 1.5% for every design, i.e. the annual flight price increase.

3. ***By 2025 the demand effects are smallest for the Differentiating Responsibilities design and highest for the Revenue Generation design.***
   From Figure 28 it can be observed that the input variables - represented by the white boxes - which are affected by the global market-based measure are the abatement potential and related costs. Thus the computed average abatement costs is the most important factor when analyzing performance of the different designs. Similarly to paragraph 6.2 the Differentiating Responsibilities design scores best due to the exclusion of certain States until 2026. The Revenue Generation design scores worst due to the additional fee for offsets.

4. ***By 2030 and 2035 the demand effects are smallest for the Strawman and Differentiating Responsibilities designs and highest for the Revenue Generation and Synthesis design.***
   Similar argumentation holds as for point 3. Since no more States are excluded from 2027 onwards the average abatement costs are equal for the Strawman and Differentiating Responsibilities designs. Similarly the average abatement costs are equal for the Revenue Generation and Synthesis. The additional fee for offsets makes the latter designs more expensive, leading to relatively greater demand effects.

8.4.2 *EFFECTS ON THE CARGO MARKET*

To understand the cargo market demand effects which a cost passing-through airline could incur under the global MBM, a similar calculation scheme is used as in the previous paragraph, see Figure 29.
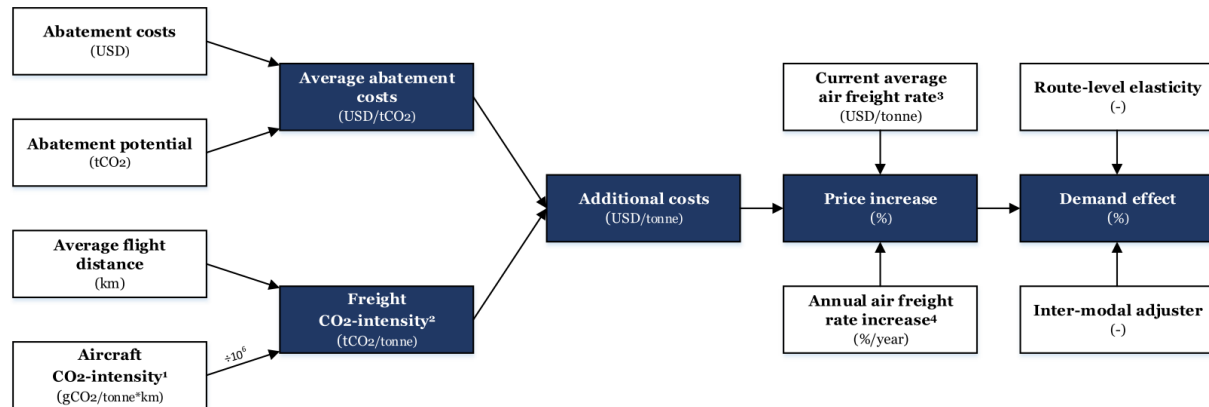
Figure 29 - Demand effects on the cargo market

The important differences between the calculation schemes in Figure 28 and Figure 29 are listed below:

1. Aircraft CO_2-intensity is measured in gCO2 per tonne-kilometer. According to Fluglaerm (2015) this equals approximately 500 gCO2 per tonne-kilometer for dedicated cargo aircraft.
2. Freight CO_2-intensity is used to calculate the additional costs for each tonne of freight that is transported by air.
3. Current air freight rates generally range from \$1.50–\$4.50 per kilogram. For this analysis it is assumed that the air freight rate in 2015 equals the mean of this range, i.e. \$3 per kilogram, or \$3000 per tonne.
4. The annual air freight rate increase is assumed similar to the inflation in the passenger transport market, i.e. 1.5% per annum.
5. The short-haul adjuster is replaced by the inter-modal adjuster which is added to reflect smaller possibilities of intermodal-substitution in the cargo market (w.r.t. the passenger transportation market). It is assumed that the route-level elasticity is 0.9 times as high as in the passenger transportation market. This point is further explained below.

An important note to the above concerns route-level elasticity. While for the passenger transportation market this elasticity number covers both competition (i) between airlines, and (ii) between airlines with other modes of transport, it is less likely that the global MBM will cause more competition between airlines with other transportation modes in the cargo market.

Already, air freight rate are 4-5 times of road transport, and 12-16 times of maritime transport. Therefore it is reasonable to assume that shippers decide to use transportation by air for other reasons than price. According to World Bank (2015) commodities usually shipped by air have high values per unit (i.e. shipping costs are relatively small percentage of total costs for product) or are very time-sensitive (i.e. no alternative that is just as fast). Therefore, to reflect the lack of intermodal-substitution an adjuster is used.

Table 36 shows the effects of the different global MBM designs on the additional cost per tonne freight (in USD), the price increase (in %), and the related demand (in %). Note that this is only shown for long-haul flights. Modeling results show minimal demand effects for short- and medium-haul cargo flights.

Table 36 - Long haul demand effects on the cargo market

Long haul (6482 km)	2025			2030			2035		
	USD/kg	Price increase	Demand effect	USD/kg	Price increase	Demand effect	USD/kg	Price increase	Demand effect
Strawman	0.02	0.5%	-0.6%	0.04	1.1%	-1.4%	0.06	1.4%	-1.8%
Differentiating responsibilities	0.01	0.3%	-0.4%	0.04	1.1%	-1.4%	0.06	1.4%	-1.8%
Revenue generation	0.02	0.6%	-0.7%	0.05	1.5%	-1.8%	0.08	1.9%	-2.4%
Synthesis	0.01	0.4%	-0.5%	0.05	1.5%	-1.8%	0.08	1.9%	-2.4%

There are a number of important conclusions than can be drawn from the above analyses.

i. **_Lower probability of intermodal-substitution in the cargo market_**
As previously explained, air freight rates are already many times higher than transport by other modes of transport. Instead air cargo is used for its speed and reliability.

ii. **_Minimal demand effects for short- and medium-haul cargo flights_**
Modeling results show a less than 0.01% change in demand for short- and medium-haul flights. This is caused by the relatively high air freight rates, resulting in very small prices increases (in %) and thus insignificant demand effects.

iii. **_Similar differences in performances between the global MBM designs_**
In 2025 the Differentiating Responsibilities design scores best due to the exclusion of certain States until 2026. The Revenue Generation design scores worst due to the additional fee for offsets. By 2030 and 2035 the demand effects are smallest for the Strawman and Differentiating Responsibilities designs and highest for the Revenue Generation and Synthesis design.

iv. **_In absolute terms the demand effects are greater in the passenger transportation market than the cargo market._**
While in the passenger transportation market the demand effects on the short- and medium-haul flights were significant, point 2 concludes the opposite for the cargo market. For long haul flights the demand effects in the cargo markets are approximately 75% as large as in the passenger transportation market (in absolute terms).

8.4.3 CONCLUSION

In conclusion, by excluding certain States until 2026, both the Differentiating Responsibilities and Synthesis designs create an uneven level playing field in the aviation industry favoring airlines from countries with the least mature aviation markets. Since these airlines will not have to compensate for their emissions a temporary economic advantage is given to these airlines. However, the analysis in paragraph 8.2 has shown that - in the case of not passing through costs of the global MBM – on average aircraft operators are able to cope with the additional costs. In addition, the analysis presented in this paragraph has showed

that –in case of 100% pass-through – the demand effects are only minimal. Nevertheless, for both the passenger transportation and cargo market it is found that the Strawman and Differentiating Responsibilities designs result in smaller market distortions than the Revenue Generation and Synthesis designs. Based on this analysis the following scores have been assigned to the criterion of market distortion effects, see Table 37.

Table 37 - Score on the market distortion effects

	Strawman	Differentiating Responsibilities	Revenue Generation	Synthesis
Market distortion effects	-	-	- -	- -

8.5 EQUITY BETWEEN NATIONS

A global market-based measure can realize equity between nations by adhering to the UN's Common But Differentiated Responsibilities principle and temporarily excluding certain developing countries from the market-based measure. In Chapter 6 it was described on what basis the Differentiating Responsibilities and Synthesis designs temporarily exclude certain States. It was argued that a phased-in route-based approach should be used, and that the differentiation criterion should be the maturity of aviation markets. This criterion covers most aviation emissions (as compared to other differentiation criteria) and thus ensures that major aviation States are included in the system. To recap, the following three phases were suggested.

  i. *Phase 1: 2020-2023, CO_2-emissions coverage = 80.5%*
     States covered: ECAC Member States, plus the top 10 States ranked by international RTKs, including Europe, US, China, UAE, Korea, Singapore, Japan, Qatar, Russian Federation, Australia, and Canada.

 ii. *Phase 2: 2024-2026, CO_2-emissions coverage = 90%*
     States covered: States in Phase 1 plus the next 10 States ranked by international RTKs, including Thailand, Malaysia, India, Saudi Arabia, Brazil, South-Africa, New Zealand, Chile, Ethiopia, and the Philippines.

iii. *Phase 3: 2027-2050, CO_2-emissions coverage = 100%*
     States covered: States in Phases 1 & 2 plus all other States.

This phased-in route-based approach is applied in both the Differentiating Responsibilities and Synthesis designs. Therefore it is argued these designs score very good compared to the business-as-usual. The Strawman and Revenue Generation designs lack this temporary exclusion for developing countries, and therefore score poor compared to the business-as-usual. In addition, the Revenue Generation does not exclude aircraft operators from developing countries to pay an additional transaction fee. Therefore it is argued this design scores very poor compared to the business-as-usual. The scores have been summarized in Table 38.

Table 38 - Score on equity between nations

	Strawman	Differentiating Responsibilities	Revenue Generation	Synthesis
Equity between nations	-	++	- -	++

8.6 ADMINISTRATIVE FEASIBILITY

The institutional feasibility of the global MBM is considered very important. Especially the airline associations IATA and AEA have argued that the MBM should minimize the *administrative burden* for airlines. According to Figure 18 - showing the administrative scheme of the global MBM - airlines will not be posed to great administrative burdens under any of the four global MBM designs. In fact, since already airlines have to report emissions and already invest in operational, infrastructural, and technological improvements, the only additional task an airline has is the purchase of offsets. Therefore it is reasonable to assume that the administrative burden lies mostly with ICAO. The separate administration body under ICAO has tasks including the establishment of monitoring, reporting and verification processes, the calculations for the allocation of emissions, and defining the types of offsets eligible for use in the global MBM.

In the case of the Differentiating Responsibilities and Synthesis designs the administering body under ICAO decides on the route-obligations. It should assess the maturity of aviation markets and define which countries are excluded when from the global MBM. In the case of the Revenue Generation and Synthesis designs the administering body under ICAO has the additional task of transferring the transaction fees from offsets to the Aviation Innovation Fund, operated by a another separate ICAO body. This ICAO body should then decide on how to distribute the funds for research. An adaptation to the original scheme is shown in Figure 30.
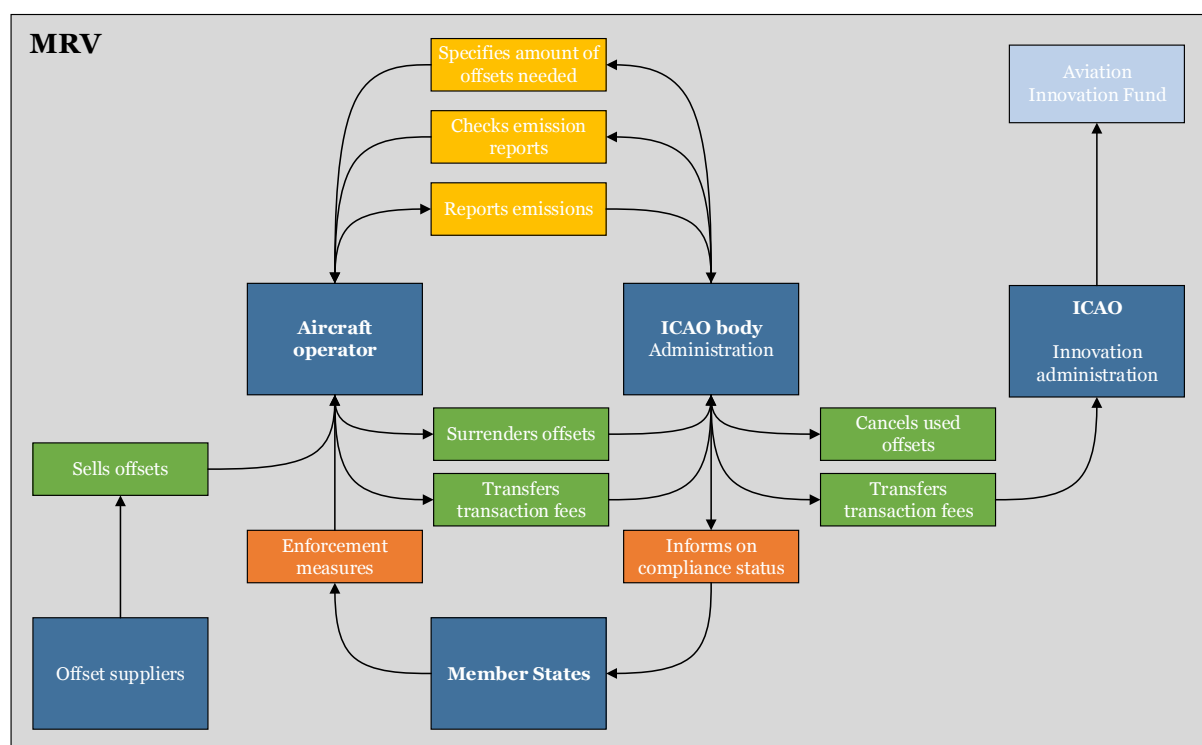
Figure 30 - Schematic overview of the MRV including revenue generation

In conclusion, the global market-based measure does not pose a lot of additional administrative burden on aircraft operators. Instead it provides ICAO more administrative tasks, especially in the case of the existence of a revenue generation mechanism. It is argued that defining the exclusion of States under a route-based global MBM poses only a negligible administrative burden. The following scores have been assigned to each different design, see Table 39.

Table 39 - Score on administrative feasibility

	Strawman	Differentiating Responsibilities	Revenue Generation	Synthesis
Administrative feasibility	+/-	+/-	-	-

8.7 IMPACT ON TECHNOLOGICAL INNOVATION

The global market-based measure can have an impact on technological innovation when any revenue from the global MBM is used as a source for the Aviation Innovation Fund. The simulation results show the following development of the proposed revenue stream, see Figure 31. Considering the period 2020 until 2050, the cumulated revenue for the Aviation Innovation Fund approximately equal 56 bln USD.
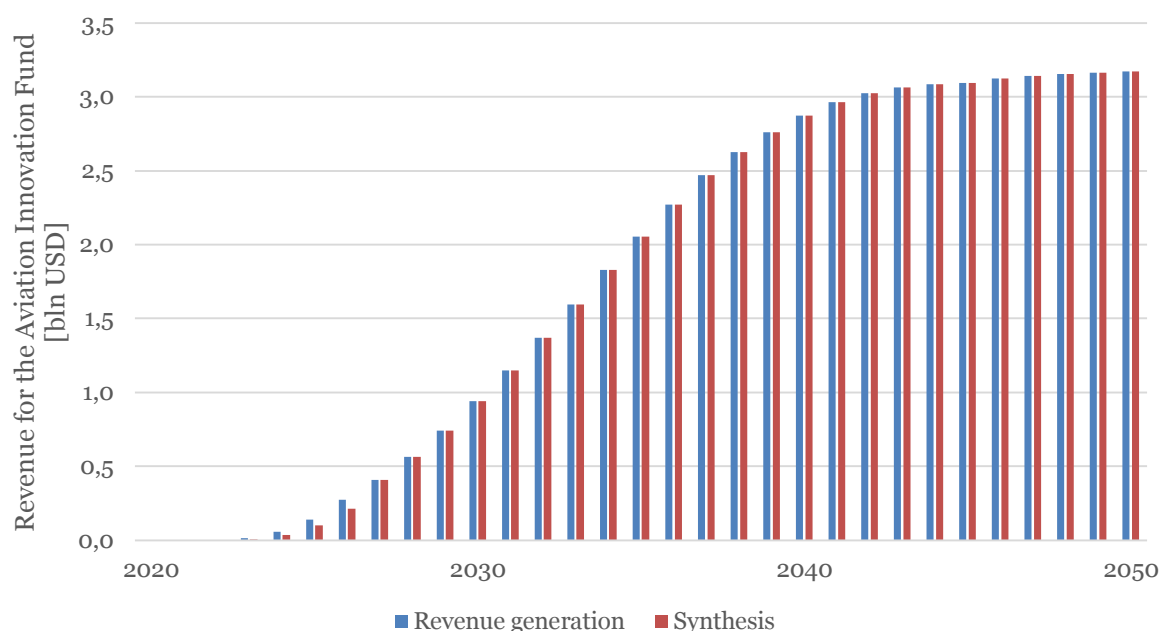
Figure 31 – Revenue stream from the global MBM for the Aviation Innovation Fund

An interesting observation is that the mean annual revenue stream follows an S-curve[22]. Three phases can be distinguished due to different growth factors in various periods combined with mitigation developments.

1. From 2020 until 2025 there is an exponential increase caused by a lack of offsets usage (negative cost abatement options) in the years 2020 to 2022 followed by a sudden uptake of offsets in the years to compensate for emissions growth.
2. From 2026 until 2035 there is a constant increase in the revenue stream due to a constant growth factor in transaction fee combined with a constant growth factor in international aviation emissions without the global MBM.
3. From 2036 until 2050 there is a declining growth of offsets usage due to the transition towards biofuels. In actual fact, paragraph 8.2 has shown the most probable scenarios in the Revenue Generation and Synthesis designs are the smooth transition towards biofuels and sharp decline in the use of offsets scenarios.

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[22] An S-curve describes a sigmoid function, a mathematical function that produces a sigmoid, or "S"-shaped curve.

In conclusion, the Revenue Generation and Synthesis designs incorporate the use of an Aviation Innovation Fund, directly stimulating innovation in the aviation industry. The other two designs lack this feature. The following scores have been awarded to each global market-based measure design, see Table 40.

Table 40 - Score on impact on technological innovation

	Strawman	Differentiating Responsibilities	Revenue Generation	Synthesis
Impact on technological innovation	+/-	+/-	++	++

8.8 CONCLUSIONS

In this chapter the four different global mandatory offsetting designs have been tested on environmental, economic, social, and institutional criteria. At the end of each paragraph a score was given to summarize the performance of each design on that specific criterion. The scores have been combined to form the aggregated Table 41. In paragraph 8.8.1 the table will be interpreted. In paragraph 8.8.2 the global mandatory offsetting designs are assessed for robustness.

Table 41 - An overview of scores on criteria

Category	Criteria	SWM	DIF	REV	SYN
Environmental	Cumulative CO_2-abatement potential *Medium uncertainty*	++	++	++	++
	In-sector emission reductions *High uncertainty*	+	+	++	++
Economic	Costs of the emission reductions *High uncertainty*	-	-	- -	- -
	Market distortion effects *Low uncertainty*	-	-	- -	- -
Social	Equity between nations *Low uncertainty*	-	++	- -	++
Institutional	Administrative feasibility *Low uncertainty*	+/-	+/-	-	-
	Impact on technological innovation *High uncertainty*	+/-	+/-	++	++

8.8.1 INTERPRETING THE SCORE ON CRITERIA

Based on the overview of scores in Table 41 various observations can be made. These are stepwise described below:

  i. ***In terms of the environmental and economic criteria there are relatively small differences in performance between the global mandatory offsetting designs.*** This is illustrated by the lack of opposite signs (+/++ vs. -/--) in each row for the environmental and economic criteria. All designs score either good or very good compared to the business-as-usual on the environmental criteria, and either poor or very poor on the economic criteria.
     > *An important implication of this finding is that, although small differences can give direction towards which market-based measure to implement, the*

decision on which of the four designs to implement exactly is difficult to make based on these criteria.

ii.   **In terms of social and institutional criteria there are relatively large differences in performance between the global mandatory offsetting designs.** This is illustrated by the existence of opposite signs in each row for the social and institutional criteria. For example, while the Strawman and Differentiating Responsibilities designs score poor on the impact on technological innovation, the other two designs score very good on this criterion.

> *An important implication of this finding is that the decision on which of the four designs to implement is mostly dependent on differences between scores on social and institutional rather than environmental and economic criteria.*

iii.   **The Revenue Generation and Synthesis designs seem to be multiplying scores of the other two designs.** This is especially true for the environmental and economic criteria. When switching from the Strawman or Differentiating Responsibilities design to either the Revenue Generation or Synthesis design the scores on 'in-sector emission reductions', 'costs of the emission reductions', and 'market distortion effects' are multiplied (i.e. a + becomes ++, and a – becomes - -).

> *An important implication of this finding is that the decision on choosing either the former or latter two designs is in fact reflecting the level of ambition of the sector to realize in-sector emission reductions compared to using offsets to maintain carbon-neutral growth.*

iv.   **It is difficult to determine a preferred design based on the scores on criteria.**
Table 41 clearly shows the difficulties in solving an international environmental problem, which by nature are "wicked problems" as was described in chapter 2. There is no design that solely has positive scores. In fact, every design has its advantages and disadvantages which are distributed differently for each design.

> *An important implication of this finding is that this observation shows the problem of choosing among the designs is difficult or perhaps impossible to solve based solely on the scores shown in Table 41. Additional analysis on robustness of each of the design is required, see next paragraph.*

8.8.2 *ASSESSING THE DESIGNS ON ROBUSTNESS*
This paragraph will assess the designs on robustness, and in specific the fourth principle of robustness: sturdiness, *i.e. the design is preferred under a wide range of conditions*. At the end of the previous paragraph it was shown that it is difficult to determine a preferred design based on the scores of criteria. To elaborate on this complexity an overview has been provided of which design is preferred under a range decision rules, see Table 42.

Table 42 - Preferred designs under different decision rules

Decision rule	Preferred design
Preferred design is the one with only positive scores	*none*
Preferred design is the one with most ++	SYN
Preferred design is the one with least - -	SWM/DIFF
Preferred design is the one that maximizes in-sector emission reductions	REV/SYN
Preferred design is the one that minimizes costs of the emission reductions	SWM/DIFF
Preferred design is the one that maximizes the sum of scores after conversion to Likert-scale[23]	SYN
Preferred design is the one that maximizes the weighted sum of scores after assigning weights to criteria and conversion to Likert-scale	$\propto weights$[24]

Table 42 shows that depending on the decision rule the preferred design is different. Since ICAO consists of more than 190 Member States is it difficult or even impossible to know which of these decision rules will provoke among the different States when they will decide on adoption of the measure or not. Therefore a different approach *"which does not solely focus on scores but rather the story behind the scores"* needs to be taken to determine the preferred design. Recall from chapter 6 that, while the defined Strawman in this thesis is an extension of ICAO's strawman, the Differentiating Responsibilities and Revenue Generation designs are in fact extensions of the Strawman, and that the Synthesis design is a combination of all three other designs. This can be interpreted as a form of path-dependency, which is schematically shown in Figure 32.
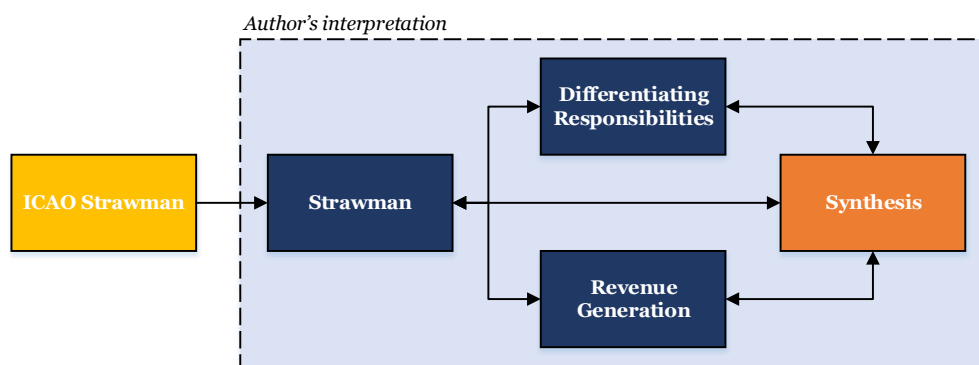
Figure 32 - Path-dependency of designs

The path-dependency can be explained and used as follows. The ICAO Strawman that was presented during the Global Aviation Dialogues in April 2015 is represented by the yellow box. However this design is unfinished, and therefore missing design elements have been added in chapter 6 to arrive at the first new design in this thesis: Strawman. The question that should be asked is: *"can ICAO extend the Strawman that improves the score on at least one criterion without any other score worse?"* In other words, *"is a Pareto improvement possible?"* From Figure 32 it can be observed that ICAO could switch from the Strawman towards the three other designs: Differentiating Responsibilities, Revenue Generation, and Synthesis. Although changing to the latter two designs would improve the score on 'in-sector reductions' and 'impact on technological innovation', the score on 'costs of the emission

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[23] A five-points scale commonly used in surveys, incorporating symmetry and balance among the scores.

[24] Preferred design can only be identified after determining the respective weights for the criteria.

reductions' and 'market distortion effects' is worsened. Therefore no Pareto improvement is possible when changing to either of these two designs. Nevertheless, switching to the Differentiating Responsibilities design improves the score on 'equity between nations' with low uncertainty, without decreasing the score on any other criteria. Therefore, judging from Table 41 and Figure 32 it can be concluded that a Pareto improvement with low uncertainty is possible when switching from the Strawman to Differentiating Responsibilities design. After that no Pareto improvement is possible since switching to the Synthesis design would decrease the score on economic criteria.

Based on this analysis is can thus be argued that the Differentiating Responsibilities design is Pareto efficient and thus a preferred design. However, to argue this Pareto efficient design is a robust design it needs to be tested whether the design is (i) truly preferred *(i.e. it is not only the preferred design based on the scores but it fits with the underlying argumentation behind those scores)*, and (ii) it is preferred *under a wide range of conditions*. Therefore the following two questions are addressed of which the first critically investigates whether the Pareto-improvement is true, and the second addresses the issue of a potential change of scope within ICAO.

i. *Does changing from the Strawman to Differentiating Responsibilities design represent a true Pareto-improvement?*
   In other words, does the change to a global mandatory offsetting design with a phased-in route-based approach not harm any involved party? According to the stakeholder analysis in Chapter 5 a number of individual countries and aircraft operators have expressed their interests of minimizing differentiation between States in order minimize market distortion effect, questioning whether the discussed change is a true Pareto improvement. The following four points combined provide insights to why it can be argued the change is a true Pareto improvement:
   > Although the individual countries and aircraft operators show their interests of minimizing differentiation, they do not argue for excluding differentiation. Hence they implicitly acknowledge the need for differentiation.
   > The proposed phased-in route-based approach differentiates on the basis of the maturity of aviation markets. Thus all major aviation States and competing economies (e.g. the U.S. and China) are included from the beginning. This increases the probability of political support from individual countries.
   > Although it is true a number of individual countries and aircraft operators have expressed their concerns, their respective overlying organizations (i.e. the ICAO and IATA) have shown commitment towards differentiating between States. Recall from paragraph 4.7 that the 2013 ICAO Resolution on the global MBM requested the ICAO Council to analyze the exemption of flights from developing countries. In addition, paragraph 5.3.3 showed IATA already opted for a flexible solution which bridges the different circumstances of fast growing airlines in emerging markets and those in mature markets.
   > The analysis in paragraph 8.2 has shown that - in the case of not passing through costs of the global MBM – on average aircraft operators are able to cope with the additional costs. In addition, paragraph 8.4 showed that –in case of 100% pass-through – the demand effects are only minimal.

ii. *Can the Differentiating Responsibilities design be considered robust when criteria become important on which other designs score higher?*
   Table 42 shows that, would any of the two criteria 'impact on technological innovation' or 'in-sector emission reductions' become key within ICAO, global mandatory offsetting designs with a revenue generation mechanism would be

preferred over the Differentiation Responsibilities design. The argument below describes why the Differentiation Responsibilities design can be considered robust.

> As was discussed in paragraph 8.8.1, choosing either of the designs including a revenue generation mechanism would reflect a higher level of ambition within ICAO to realize in-sector emission reductions and technological innovation. If for any reason these criteria become key within ICAO in the course towards the next Assembly in 2016, then including a revenue generation mechanism by switching in a later stage from the Differentiation Responsibilities design to the Synthesis design would still be possible. It is argued that this flexibility is in fact making the design more robust. To illustrate, if the design options would not be extensions of each other (e.g. comparing a tax with emissions trading) than there would be much less or even no flexibility, and choosing the Pareto-efficient design (if found) could lead to problems if other criteria become more important in the future.

In conclusion, the Differentiating Responsibilities design satisfies the fourth principle of robustness (i.e. sturdiness) because is the preferred design under a wide range of conditions. First, it is Pareto-efficient meaning no improvement on any score on a criterion is possible without decreasing at least one score on any other criterion. Second, its flexibility ensures that even when criteria become key on which other designs score better switching in a later stage is still possible. Summarizing, the assessment on robustness for each global mandatory offsetting design is shown in Table 43.

Table 43 - An overview of the assessment on robustness

Design / Principle	Legal feasibility	Political viability	Purposefulness	Sturdiness
Strawman	✓	✓	✓	X
Differentiating Responsibilities	✓	✓	✓	✓
Revenue Generation	✓	✓	✓	X
Synthesis	✓	✓	✓	X

V

Interpretation

If you do not change direction, you may
end up where you are heading.

Lao Tzu

9 Conclusions and recommendations

While the aviation industry has many economic and social benefits, its forecasted growth raises the question of how CO_2-emissions can be limited for sustainability purposes. The International Civil Aviation Organization is working towards a global market-based measure that limits the carbon pollution from international aviation. This thesis has focused upon how to achieve a robust global market-based measure. Below an answer is given to the research questions in this thesis.

9.1 DESIGNING A ROBUST GLOBAL MARKET-BASED MEASURE

In the Research Definition (see chapter 2) the main research question was phrased as follows:

> ### How can a robust global-market based measure
> ### for the aviation industry be designed?

The inclusion of the adjective 'robust' is considered vital in this thesis. It was reasoned that a robust design maximizes the probability of adoption of the global market-based measure by 2016, and implementation by 2020. This thesis has defined the following four principles of robustness.

i.	*Legal feasibility*	The design obeys the law
ii.	*Political viability*	The design is accepted in the political arena
iii.	*Purposefulness*	The design satisfies the main goal of decreasing the climate impact of aviation
iv.	*Sturdiness*	The design is preferred under a wide range of conditions

The goal of this thesis was to provide insights into designing a robust global market-based measure for the aviation industry (i) by showing the design process to arrive at the robust global market-based measure, and (ii) by applying this design process to determine the robust global market-based measure.

THE DESIGN PROCESS

The *design process* towards a robust global market-based measure consists of four phases. During the *exploration phase* the design space is identified, and by means of a literature review criteria can be found on which aviation environmental policies are to be assessed. A legal and stakeholder analysis should then be used to demarcate the design space and redefine the criteria such that they are specific for assessing the global MBM. Subsequently, the *design phase* builds upon the demarcated design space and allows for the construction of different designs by varying in design elements that have not been decided upon by the policy-maker. During the *analysis phase* the constructed designs are then to be tested upon

the redefined criteria. By means of a *marginal abatement cost curve in combination with a simulation model* the commensurable criteria can be assessed while accounting for uncertainty. Lastly, the *interpretation phase* concludes whether a robust design is achieved, and provides recommendations and a critical reflection upon the results.

THE DEMARCATED DESIGN SPACE

After an extensive literature review the design elements for the aviation global market-based measure were identified. By means of a legal and stakeholder analysis. By means of a legal and stakeholder analysis is found that only a global mandatory offsetting scheme satisfies the principles '*legal feasibility*' and '*political viability*'. It was shown ICAO is moving towards a global mandatory offsetting scheme of which a number of design elements seem decided upon (unalterable), and a number of design elements remain open for interpretation (alterable). An overview of the demarcated design space is given in Figure 33.
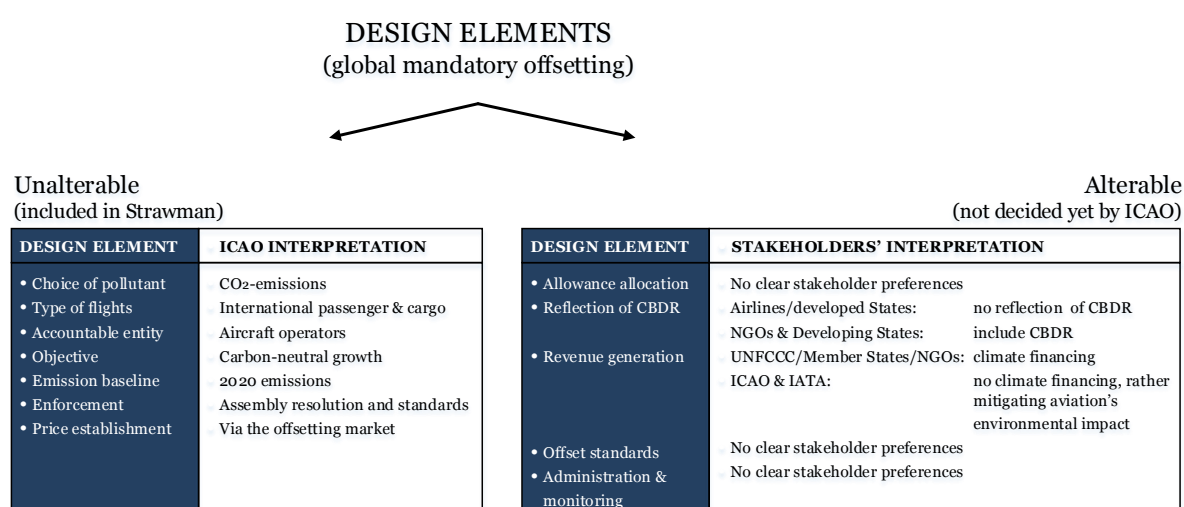
Figure 33 - Demarcated design space

CRITERIA FOR ASSESSING THE GLOBAL MARKET-BASED MEASURE

Based on a literature review an overview of criteria was provided from Solomon & Hughey (2007) that can in general be used to assess aviation environmental policies. By means of a stakeholder analysis these criteria have been redefined, such that they fit the interests and agenda of stakeholders in the global market-based measure debate. An overview is given in Table 44 below.

Table 44 - Criteria for assessing the global MBM designs

Category	Criteria	Unit
Environmental	Cumulative CO_2-abatement potential	[$GtCO_2$]
	In-sector emission reductions	[$GtCO_2$]
Economic	Costs of the emission reductions	[bln USD]
	Market distortion effects • Passenger • Cargo	[%]
Social	Equity between nations	[-]
Institutional	Administrative feasibility	[-]
	Impact on technological innovation	[bln USD]

FOUR GLOBAL MANDATORY OFFSETTING DESIGNS

By using the demarcated design space four different global mandatory offsetting designs were constructed. Their characteristics are briefly described below:

I. Strawman

This design is an extension of ICAO's Strawman and is therefore based on maintaining carbon-neutral growth from 2020 onwards. The choice of pollutant is CO_2-emissions and the respective type of flights are those from the international passenger and cargo markets. Furthermore compliance and enforcement shall happen through an Assembly Resolution and standards. Based on a qualitative analysis a number of design elements were added to ICAO's Strawman. These include that the allocation of requirements shall occur through grandfathering based on a benchmarking approach, that the use of offsets is restricted to only those offsets which are of high-quality, additional, and permanent, and that administration and monitoring shall occur by means of a body under ICAO, ICAO Member States, and aircraft operators.

II. Differentiating Responsibilities

This design is an extension of the Strawman and includes a phased-in route-based approach. The differentiation criterion is the maturity of aviation markets and it is proposed to include three consecutive phases within the global MBM. Phase 1 (2020-2023) includes all ECAC Member States, plus the top 10 States ranked by international RTKs. Phase 2 (2024-2026) includes the next 10 States, after which Phase 3 (2027-2050) include all ICAO Member States.

III. Revenue Generation

This design is an extension of the Strawman and includes a revenue generation mechanism for the purpose of mitigating aviation's environmental impact. It is proposed to that aircraft operators pay a transaction fee for each purchased offset, starting from 1 USD/tonne CO_2 in 2021 and increasing by 50 dollar cents per year. It is suggested this revenue stream flows into an Aviation Innovation Fund. This fund can be used to financially support research that helps in mitigating aviation's climate impact.

IV. Synthesis

This design combines all design elements from the previous three designs.

ASSESSMENT OF THE DESIGNS

Based on a combination of simulation results and qualitative analysis the four global mandatory offsetting designs have been assessed on the environmental, economic, social, and institutional criteria. The most important conclusions from this analysis include:

i. Since all designs realize a significant amount of CO_2-emission reductions they all satisfy the principle '*purposefulness*'.
ii. In terms of the environmental and economic criteria there are relatively small differences in performance between the global mandatory offsetting designs.
iii. In terms of social and institutional criteria there are relatively large differences in performance between the global mandatory offsetting designs.
iv. The Revenue Generation and Synthesis designs seem to be multiplying scores of the other two designs.
v. The Differentiating Responsibilities design satisfies the fourth principle '*sturdiness*' because is the preferred design under a wide range of conditions.
   > It is Pareto-efficient meaning no improvement on any score on a criterion is possible without decreasing at least one score on any other criterion.
   > Its flexibility ensures that even when criteria become key on which other designs score better switching in a later stage is still possible.

9.2 RECOMMENDATIONS FOR ICAO

Based on the multi-criteria decision analysis it is recommended ICAO uses the Differentiating Responsibilities design in this thesis as a framework for the global market-based measure in order to increase the likelihood of reaching political consensus by 2016. The corresponding design elements are presented below.

  i. The design's foundation is a global mandatory offsetting scheme.
  ii. The design focuses on carbon-neutral growth from 2020 onwards.
  iii. The design concerns the international passenger and cargo markets.
  iv. The design incorporates allocation of requirements through grandfathering based on a benchmarking approach.
  v. The design includes an offset standard that restricts the use of offsets which are of high-quality, additional, and permanent.
  vi. The design includes administration and monitoring done by a combination of a body under ICAO, ICAO Member States, and aircraft operators.
  vii. The design shall be legally enforced by an Assembly Resolution and standards.
  viii. The design includes a phased-in route-based approach, of which the differentiation criterion should be the maturity of aviation markets. See Figure 34 for an overview of which States are included when.
  ix. The design is flexible in the sense that including a revenue generation mechanism during the negotiation process at ICAO or after the global MBM's implementation is be possible.
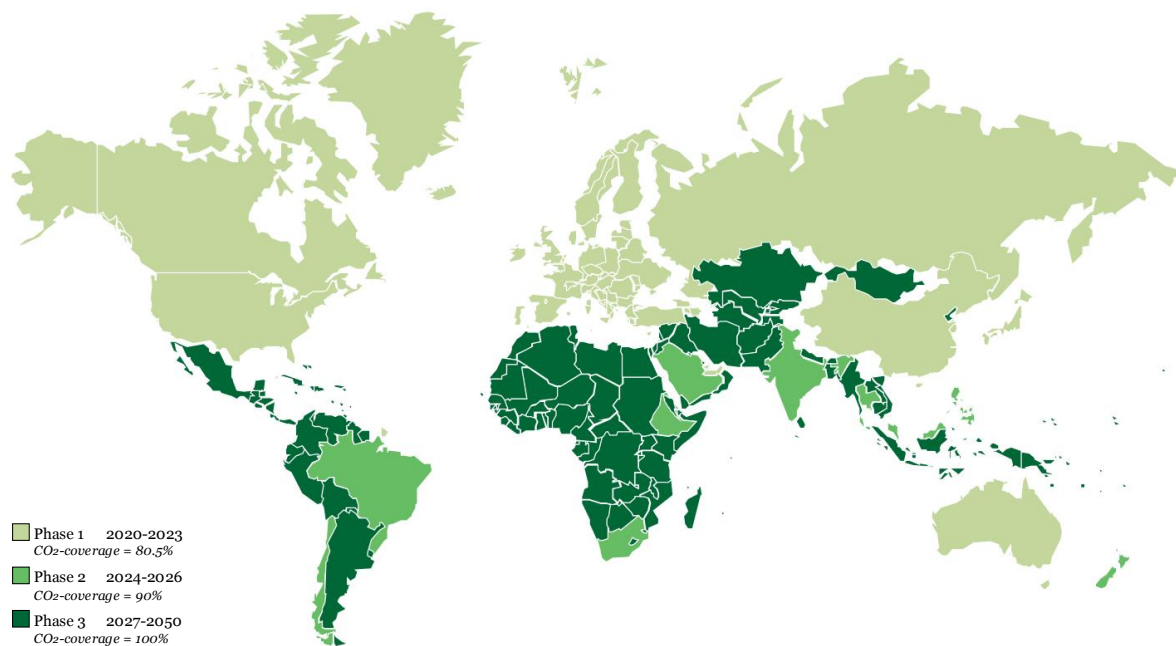
Figure 34 - Global mandatory offsetting scheme based on Differentiated Responsibilities

Based on a Monte Carlo simulation it is found that for the period 2020-2050 this design yields a mean cumulative CO_2-abatement potential of *16.5 GtCO₂*, cumulative costs of *353 bln USD*, a *55%* share of in-sector emission reductions, and minimal market distortion effects. These numbers should however be interpreted with care due to high uncertainty with regard to the business-as-usual civil aviation emissions, offset price, marginal abatement costs of biofuels and the availability of biofuels.

9.3 LIMITATIONS OF THIS RESEARCH

Although so far the focus has mainly been on presenting the results and possibilities of this thesis, there are also important limitations that cannot be ignored. Four important limitations are highlighted below.

ELIGIBILITY OF OFFSETS

Rather counterintuitively, although in the end this thesis recommends a global mandatory offsetting, it does not reach a conclusion on which offsets to use exactly under the global market-based measure. It merely provides requirements which the offsets should satisfy, i.e. high-quality, additional to the business-as-usual, and permanent. As was described in chapter 4 this is caused by the uncertainty about the availability of offsets after 2020.

DOMESTIC AVIATION

Although the definition of *global* market-based measure might hint towards a measure that covers global aviation emissions, this line of reasoning does not hold. Since ICAO is mandated to solely address international aviation emissions it does not have the power to include domestic aviation emission into its scheme. Therefore implementing the global market-based measure still leaves approximately 35% of aviation's CO_2-emissions unregulated.

INTERACTION-EFFECTS

In the simulation model no interaction-effects have been accounted for, while in reality they might exist. An example of an interaction-effect is that an increased demand for offsets leads to an increase in the offset price, ultimately leading to a decrease in the demand for offsets. This negative feedback loop[25] - that would potentially stabilize the demand for offsets - is not modeled. Another interaction-effect that is not modeled is the influence of the proposed Aviation Innovation Fund on the marginal abatement costs of the sector, while in fact this is exactly the goal of the proposed fund. The implications of leaving out the interaction-effects are discussed in the reflection (see Chapter 10).

NON CO_2-EFFECTS

As was described in chapter 1 the environmental impact of the aviation sector goes beyond its CO_2-emissions. Although there is still significant scientific uncertainty surrounding the non CO_2-effects of aviation, it is known a combination of NO_x-emissions, particulates, and water vapor cause an increased climate impact. However since ICAO has left out these emissions of the Strawman, this thesis has assumed these effects to be outside the design space of the global market-based measure. The implications of leaving out the non CO_2-effects are discussed in the reflection (see Chapter 10).

9.4 FUTURE RESEARCH

Building on the ideas presented in this thesis, future research could expand knowledge even further about the global market-based measure. Below three suggestions are given.

USING OFFSETS WITH SOCIAL AND ECONOMIC BENEFITS

In this thesis the difference was mentioned between minimum standard offsets and gourmet offsets. Whereas the former merely focuses on compensating emissions, the latter has additional benefits that could foster social and economic development in developing countries. Future research could focus on what gourmet offsets should be eligible under the

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[25] Negative feedback loops describe "goal-seeking processes that generate actions aimed at moving a system toward, or keeping a system at, a desired state" (van Daalen, Pruyt, Thissen, & Phaff, 2009).

global market-based measure. Furthermore research could investigate how the use of gourmet offsets might change the public perception of the aviation industry.

THE AVIATION INNOVATION FUND

Two global mandatory offsetting designs in this thesis included a revenue generation mechanism to finance the 'Aviation Innovation Fund'. This fund does yet not exist, and has been an idea presented to both show the possibilities with regard to a revenue generation mechanism and satisfy the demand of the aviation industry to mitigate its environmental impact. Future research could investigate how this fund should exactly work, who should manage this fund, how money is distributed to which parties. Furthermore it could be researched how the Aviation Innovation Fund can bring down the marginal abatement costs in the sector.

A GLOBAL MBM FOR THE SHIPPING INDUSTRY

The shipping industry accounts for even more greenhouse-gas emissions than the aviation industry, approximately equaling 3% of the global share with an expected growth in emissions from international shipping of about 2% per year (IMO, 2015). Future research could focus on what lessons can be drawn from the aviation global MBM that can be used for the maritime sector.

The greater danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieving our mark.

Michelangelo

10 Reflection

This thesis has shown how to design a robust global market-based measure for the aviation industry. Implementation of such a measure would mean an important step in combating climate change, not only for the aviation sector but - by generating knowledge - also for other global sectors in the future. This chapter provides a critical reflection upon the foundation, environmental performance, and modeling of the aviation global market-based measure, and draws upon findings in this thesis that could increase its significance even further.

10.1 THE FOUNDATION OF MARKET-BASED MEASURES

Why address aviation with a global market-based measure when climate change is regarded as the biggest market failure of this century? Perhaps more a philosophical question, this question should come to mind first before designing and implementing any market-based measure. Recall that in paragraph 3.1 the Stern review was quoted in which it was mentioned that "*climate change is the greatest market failure the world has ever seen*". Why then should any policy-maker implement a market-based measure when it is bound to lead to an inefficient allocation of goods and services (i.e. for the aviation sector an overconsumption of flights and hence a welfare loss)?

A very short answer is that – based on the analysis in this thesis - for the aviation sector only a market-based measure is politically possible, and that a potentially lacking policy probably is better than no policy. For a more detailed answer I would like to make the analogy with the electric car. During my study at the TU Delft I have been confronted repeatedly why an electric car is considered a breakthrough in environmental performance, while there are still significant carbon emissions due to an energy mix with a very low share of renewables (at least in the Netherlands), and vehicle manufacturing. In fact, research shows that the carbon emissions of grid powered electric cars in countries with coal based generation are no different to average petrol vehicles. Therefore the question - "*what is all this fuss about concerning the electric car?*" – is a valid question and is useful in discussing technologies and policies with the aim of combating environmental impact.

In my opinion, the key in answering this question lies in the *potential* of the electric car. In theory, if the batteries would be charged solely by renewable energy, emissions that would remain are from vehicle manufacturing. Although research shows that electric cars do produce more emissions in the manufacturing phase, lifecycle studies show that driving the electric car can save significant carbon emissions. Besides, the electric car has a positive effect on air quality and noise pollution. Thus the electric car is a *means* in combating the environmental impact of road transport.

The example on the electric car has shown that the real problem is not the electric car itself, but electricity generation based on fossil fuels. Therefore, the problem lies not in the means itself but more relates more to how we are using that means. To fully unlock the potential of the electric car a transition is necessary in our energy system.

A similar line of reasoning holds for market-based measures. I assume them to be a *means* in cost-efficiently reducing emissions. In theory they could lead to significant emission reductions, but research from inter alia the International Energy Agency (cited earlier in this thesis) shows that the targets of market-based measures reducing carbon emissions tend to be set too close to the business-as-usual *(whether this is true for the aviation global MBM follows later in this reflection)*. This has led to an oversupply of allowances (e.g. the EU ETS) and can raise questions with regard to the significance of market-based measures. I believe one of the most important underlying problems here to be lobbyism by the private sector, collectively pushing the cap to be set too high to realize significant emission reductions. Therefore in my opinion - for a market-based measure to really make a difference (i.e. to fully unlock its potential) - a transition is necessary in the influence of the private sector in governmental decision-making.

Although to fully unlock their potential transitions are necessary that go beyond their scope, I am an advocate of implementing both the electric car and market-based measures already at this stage. Both are a means of realizing emission reductions that are necessary in order to meet international climate targets and should be widely available whenever the before mentioned transitions are in a further phase. More importantly, I believe that the implementation of these means at this point can in fact trigger the transitions by shaping the political debate and involving the private sector more towards sustainability.

10.2 THE DIFFERENCE BETWEEN ROBUST AND IDEAL

One of the most important design choices during this thesis was whether to focus on designing a 'robust' or 'ideal' global market-based measure for the aviation sector. Although at first the difference between the words might seem trivial, the implications are not. The difference lies in the fact that in this thesis robustness was defined as a combination of legal feasibility, political viability, purposefulness, and sturdiness. It was argued that a robust design – taking into account legal and political barriers – would potentially lead to the highest chance of adoption in 2016. In fact, for the aviation sector a mandatory offsetting scheme might be ideal.

However, if I would have decided on designing the ideal global market-based measure the outcome might have been different since I probably would have defined the 'ideal' design as one that maximizes gains for a society as a whole. As a result, it might have been the case that a global levy or emissions trading would have been more ideal than a mandatory offsetting scheme. In addition other mandatory offsetting designs than defined in thesis would potentially have been possible. After finding the ideal global market-based measure it would have been up to politics to make sure to implement it.

The benefits of choosing robust over ideal are:
> *Applicability:* By taking into account the actual design space of the global market-based measure this thesis is highly applicable to current negotiations. Hence its value for ICAO and involved stakeholders is maximized.
> *Replicability:* This thesis could be used as a guide on how to design a global market-based measure for other sectors as well. In fact, when the steps followed in this thesis (from exploration to interpretation) would be followed in an earlier stage of political developments (e.g. shipping) the resulting design space might be larger than found in this thesis.

The drawbacks of choosing robust over ideal are:
> *Design boundaries*: Taking into account legal and political barriers have significantly demarcated the design space. As such, a number of design elements that were identified in chapter 4 and potentially might be more ideal for a society as a whole are not included in the designs constructed in chapter 6 (*these design elements will be referred to in the next paragraphs*)
> *Complexity*: Robustness is a much more complex concept to grasp than is ideal, challenging the researcher in defining the research and reader in understanding the essence of the thesis.

10.3 THE USE OF MODELING

Many of the results presented in Chapter 8 are derived from Monte-Carlo simulation of a model incorporating many assumptions. These assumptions were made for various reasons including the unavailability of modeling data, limited time for extensive research w.r.t. certain data, and the ability to include uncertainty. However, as is commonly referred to by modelers: "*models are only as good as the assumptions on which they are based*". To illustrate the implications of this phrase, consider the following three events that could have a significant impact upon the results presented in this thesis.

i. Due to a lack of available data it was assumed in the model that the oil prices in 2020 and 2030 as taken by IATA, 126 USD/barrel and 135 USD/barrel, are correct, and that thus the marginal abatement costs as presented by IATA are correct. However, as of 2015 the oil price has been structurally low, falling below 50 USD/barrel.
> *An important implication of this finding is that if the oil price would structurally be this low then the marginal abatement costs might actually be higher than assumed in IATA's MAC curve and thus in my model. This would lead to very different results than presented in this thesis (e.g. greater use of offsets and less in-sector reductions).*

ii. Even though uncertainty with regard to the price of offsets was included there is the assumption that prices will restore to a more meaningful level by 2020. As of 2015 the offset price is equal to 0.60 USD/tonne CO_2.
> *An important implication of this finding is that if policy-makers are unable to restore prices in the offset market the assumption leading in this model might not hold, leading to different results (e.g. greater use of offsets and lower cumulative abatement costs).*

iii. The simulation model did not include interaction-effects (see paragraph 9.4). Therefore there is no stabilizing feedback loop regarding the demand for offsets and no decrease of marginal abatement costs in the case of a global mandatory offsetting scheme with a revenue generation scheme.
> *An important implication of this finding is that the lack of the former interaction effect could lead to underestimated in-sector emission reductions and abatement costs for all designs. The lack of the latter interaction effect could similarly lead to an underestimate of in-sector emission reduction, but at the same time lower costs of the emission reductions and less market distortion effects.*

iv. It was assumed that all the abatement options with a negative marginal abatement cost are available by 2020 and 2030. However as was already argued in chapter 3 the existence of these 'negative costs' are irrational, thus implying non-financial barriers towards implementation.

> *An important implication of this finding is that if these non-financial barriers would still exist by 2020 and 2030 then the modelling results would be different (e.g. greater use of offsets and biofuels).*

Although a significant amount of uncertainty was included into the simulation model it might be the case that the quantitative results in this thesis are incorrect due to e.g. the exclusion of a structural low oil and offset price, interaction-effects, and non-financial barriers towards abatement options. In other words, it could be questioned whether sufficient uncertainty has been taken into account. Perhaps more importantly than the quantitative results is the question whether the conclusion in this thesis would still be the same, i.e. would a global mandatory offsetting scheme with a phased-in route-based approach still be the preferred design? Or how robust is the conclusion that this design is called robust?

Evidently, in the scenario of either of these three events happening, the proposed design would still satisfy the principles of 'legal feasibility' and 'purposefulness'. The difficulty lies with whether the design would still satisfy the principles of 'politically feasibility' and 'sturdiness'. It is argued that both principles are still satisfied. Firstly, in any scenario a global levy would still not be legally feasible. Secondly, any of the tree described events would either lead to either higher marginal abatement costs for in-sector reductions or cheaper offsets. Hence a global mandatory offsetting scheme would still be favored over an emissions trading scheme due to perceived lower costs and lower administrative complexity. Thirdly, the combination of both ICAO and IATA supporting a global MBM with a differentiation between States gives confidence this design is preferred under any conditions. In conclusion, it is argued the conclusion that the Differentiating Responsibilities is a robust design is robust itself.

10.4 THE GLOBAL MARKET-BASED MEASURE FROM A CLIMATE PERSPECTIVE

Recall that at the end of paragraph 5.3 the following two hypotheses were defined:

Hypothesis 1: The global MBM is based upon a weak 2020 CNG target.
Hypothesis 2: The global MBM does not bend aviation emissions downwards.

These hypotheses were based on a letter to ICAO, sent by 27 NGOs and an international group of 40 top economists, who shared their concerns about the lack of environmental effectiveness of a mandatory offsetting scheme. This paragraph tests these two hypotheses by clarifying the meaning of the two hypothesis, i.e. eradicating the subjectivity in both statements. Furthermore additional modeling results in combination with a qualitative analysis are shown providing the foundation for answering each hypothesis. Answering these two hypothesis helps in finding an answer to the third hypothesis.

Hypothesis 3: The global MBM is not enough from a climate perspective.

HYPOTHESIS 1: THE GLOBAL MBM IS BASED UPON A WEAK 2020 CNG TARGET

Clarification

This statement relates to the objective of the global market-based measure, which in the ICAO Strawman is defined as carbon-neutral growth from 2020 onwards. The hypothesis contains the subjective word '*weak*' which is unclear for two reasons. First, in what sense is the policy weak, i.e. is it weak in terms of environmental performance, minimizing costs for the aviation sector or another criterion? Second, what is the benchmark for performance, i.e. when would the policy not be considered weak anymore?

Reading the full letter[26] shows the authors imply the climate perspective, partly solving the ambiguity. However, they do not state the benchmark on which their opinion is based. Therefore this thesis will take the international climate target of limiting warming to 2°C by 2050 as the reference point, which de facto has become the target for global climate policy.

Answer – Correct, the global MBM is based upon a weak 2020 CNG target
First, to test this hypothesis the 2°C target for aviation needs to be identified. As a source, the sectoral intensity pathway for aviation is taken from Ecofys (2015). In their methodology on science-based targets they computed the pathway from the 2°C Scenario (2DS) made the International Energy Agency, which describes an energy system consistent with an emissions trajectory that recent climate science research indicates would give an 80% chance of limiting average global temperature increase to 2°C (IEA, 2015). The resulting sectoral emissions pathways and carbon budget – the amount of carbon dioxide emissions that can be emitted while still having a likely chance of limiting global temperature rise to 2 degrees Celsius above pre-industrial levels – is shown in Figure 35.
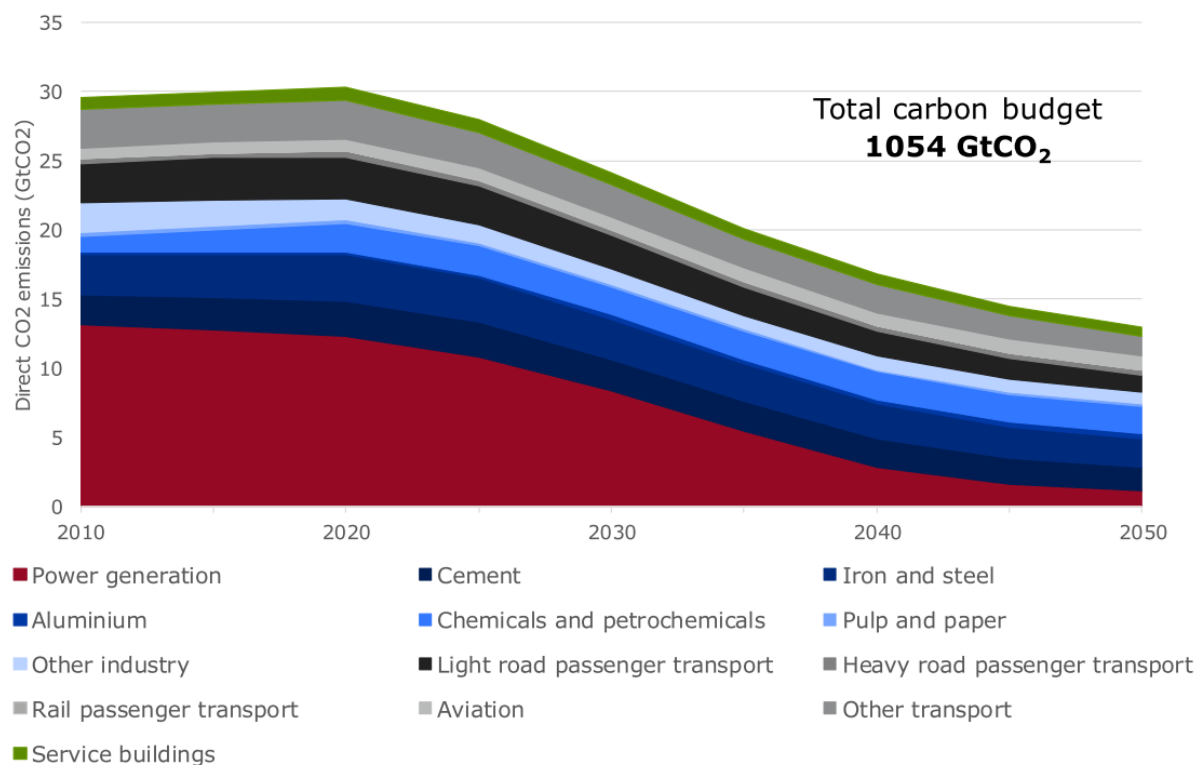
Figure 35 - Sectoral emissions pathways as adapted from Ecofys (2015)

From Figure 35 a number of important observations and remarks should be made:

1. In theory, while for most sectors the sectoral emissions pathway demands carbon dioxide emission reductions, the aviation sector would be allowed a small growth in emissions from 2020 until 2050. The reason behind this is that the sectoral emissions pathways are based upon a best of science and *least-cost modelled* 2°C Scenario by the IEA, and given the fact that the aviation sector has relatively *high abatement*

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[26] Available at: http://www.worldwildlife.org/press-releases/nobel-prize-winners-to-icao-carbon-emissions-have-a-cost

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costs, emission reductions are preferred in other sectors where abatement costs are lower.

2. In practice, whether or not aviation's emissions would be allowed to grow all depends on whether the total aviation emissions in 2020 are in fact corresponding to the sectoral emissions pathway. If the total aviation emissions in 2020 would be much higher than the figure suggests, than emission reductions might be required. By testing this hypothesis this question is answered.

3. The figure only shows aggregated aviation emissions (domestic and international). Therefore to yield a sector emissions pathway for international aviation these emissions must be disaggregated. Similarly to the simulation model constructed a fraction of 65% is used to denote international aviation emissions.

Combining the sectoral emissions pathway from Ecofys (2015), an assumed fraction of 65% for international aviation, and the result for the mean carbon-neutral growth target under a global market-based measure from the simulation model, yields Figure 36.
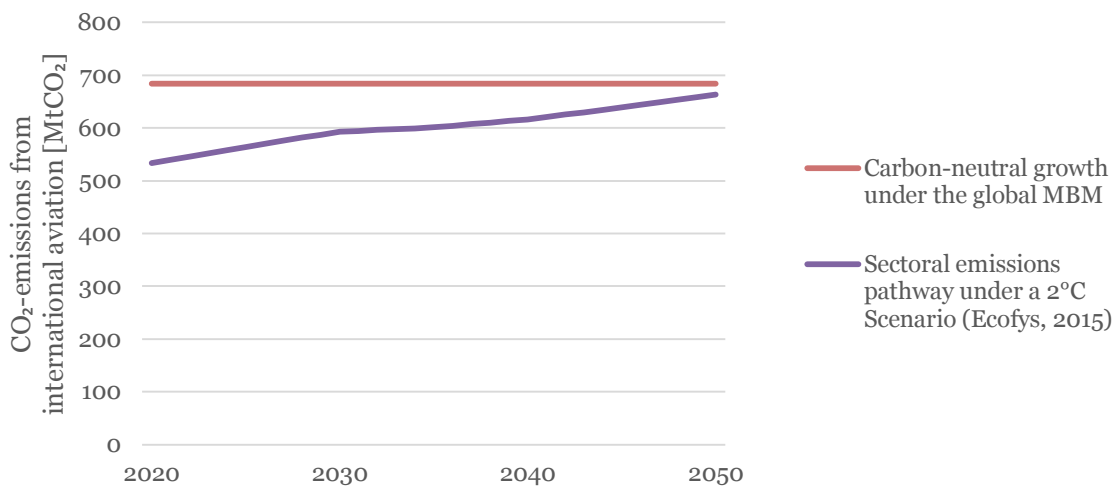

Figure 36 - Carbon neutral growth in relation to the sectoral emissions pathway

From Figure 36 it can be observed that, although the sectoral emissions pathway for international aviation under a 2°C Scenario is increasing, the carbon-neutral growth target under the global market-based measure is too high. Therefore, based on this analysis, hypothesis 1 - *the global MBM is based upon a weak 2020 CNG target* – is believed to be correct.

HYPOTHESIS 2: THE GLOBAL MBM DOES NOT BEND AVIATION EMISSIONS DOWNWARDS

Clarification
Although this hypothesis might not look ambiguous at first, it is subject to a subjective interpretation when discussing the global market-based measure. The challenge when interpreting this hypothesis is whether or not offsets can be considered aviation emission reductions. If so, then the hypothesis is easily falsifiable. However, the authors of the letter to ICAO would probably disagree, and by means of the letter implied that in the case of implementing a mandatory offsetting scheme, the sector will not reduce its emissions through technological, operational, or infrastructural measures. By making use of modeling results from chapter 8 this is discussed below.

Answer – Incorrect, the global MBM bends aviation emissions downwards

Recall the four abatement scenarios until 2050 in Figure 24. These show that in every scenario there are operational and infrastructural measures being implemented which would already falsify the hypothesis. Now the more critical reader might argue that these measures are implemented because of their negative abatement costs (in the model near-zero costs are assumed), and that their actual implementation might not occur due to non-financial barriers. Neglecting these measures leaves technological improvements, i.e. mainly the transition from conventional jet fuels to biofuels. Figure 24 shows that only in one scenario there are no technological measures taken. In fact, Table 29 shows that Scenario 3 (*No Technology*) occurs in only 21% of all model runs for the global MBM designs without a revenue generation mechanism, and almost never for the global design with such a mechanism. Therefore it is believed to be more likely that technological measures will be taken to reduce aviation emissions. To conclude, based on the modeling results in chapter 8, hypothesis 2 - *the global MBM does not bend aviation emissions downwards* – is believed to be incorrect.

HYPOTHESIS 3: THE GLOBAL MBM IS NOT ENOUGH FROM A CLIMATE PERSPECTIVE

Clarification

While the former two hypotheses concerned only international aviation, this third hypothesis zooms out and takes the total aviation sector as focus point. It is questioned whether, from a climate perspective, the global market-based measure leads to sufficient emission reductions in the total aviation sector. The hypothesis is tested by combining the findings described below:

1. Findings concerning the former two hypotheses.
2. Simulation results from chapter 8.
3. Previously omitted findings that have so far been left out of this thesis because they did not fit within the scope of this research.

Answer – Correct, the global MBM is not enough from a climate perspective

In short, findings related to the two former hypotheses showed that although the global MBM bends aviation emission downwards, it does not comply to the sectoral emissions pathway limiting a global temperature increase to 2°C by 2050. Therefore, if judging the global MBM solely on international aviation it can already be observed that the measure is not enough from a climate perspective.

To give the reader insights about to what extent the global market-based measure bends down total aviation emissions and how that relates to the sectoral emissions pathway under a 2°C Scenario, the following analysis provides a more detailed analysis on why the global MBM is not enough from a climate perspective. Combining the simulation results from modeling the business-as-usual emissions and total net aviation emissions with the global MBM, together with the aggregated sectoral emissions pathway from Ecofys (2015), yields Figure 37.
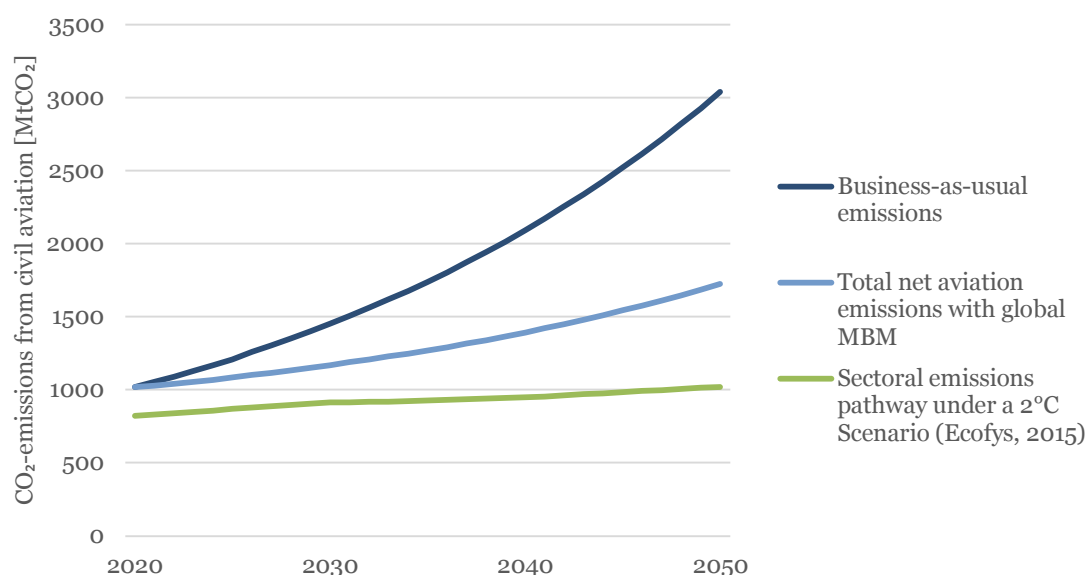
Figure 37 - The global market-based measure in relation to the 2°C pathway

From the modeling results shown in Figure 37 it can be observed that the global market-based measure has a significant carbon dioxide abatement potential bending down emissions of the aviation sector. However, despite its potential in reducing emissions, the global MBM is not sufficient in reaching the 2°C sectoral emissions pathway. There are a two important reasons for this mismatch.

1. As hypothesis 1 showed, the global MBM is based upon a weak 2020 carbon-neutral growth target.
2. The global MBM *only* regulates international aviation emissions, representing roughly 65% of civil aviation emissions. Without additional policy measures domestic aviation emissions remain unregulated, allowing exponential growth in rapidly developing domestic aviation markets (e.g. China, India, Brazil, and Argentina).

In fact, modeling results show that although the carbon dioxide abatement potential of the global market-based measure is approximately 16.6 $GtCO_2$, the remaining gap for the aviation sector to reach the 2°C sectoral emissions pathway equals **11.7 $GtCO_2$** in the period 2020 to 2050. Furthermore, the aviation sector would constitute roughly **7.5%** of the global carbon budget by **2040**, and **11.7%** by **2050**. These findings support the hypothesis that – from a climate perspective - the global market-based measure is not enough.

Taking into account non-CO_2 effects of aviation

At this point the problem-solving oriented reader might conclude the global MBM is not sufficient, and that the remaining gap is indeed 11.7 $GtCO_2$ and should be solved by additional regulatory measures. There is not much wrong with this way of thinking, however as is believed Buddha has said: "*there are only two mistakes one can make along the road to truth; not going all the way, and not starting*". Certainly, by testing these three hypotheses a start has been made with analyzing whether the global market-based measure is enough from a climate perspective. However the critical reader should ask himself whether we have gone "*all the way*" and have reached the end of "*the road to truth*".

In fact, although at this point of the analysis we might see the end of the road, we are not there yet. Limited by the design boundaries, in assessing the environmental performance of the global market-based measure so far only the carbon dioxide emissions have been taken into account. However recall from paragraph 1.2 that the environmental impact of aviation is

greater than only its CO_2-emissions. In fact, its climate impact is found to be in the range of 2 to 4 times as high due to the climate impact of NO_x-emissions, particulates, contrails and cirrus clouds. Due to scientific uncertainty and political feasibility these effects are not included in the debate on the global market-based measure, and therefore are easily overlooked. Nevertheless, to reach the end of "*the road to truth*" it should also be assessed how large the remaining gap is when these non-CO_2 effects are taken into account. In order to analyze this gap a quick-search has been performed in existing literature on what multiplier (i.e. the number by which CO_2-emissions can be multiplied to determine the full climate impact of aviation, measured in CO_2-equivalent) should be used. The results are shown in Table 45 below.

The different studies in this literature review present a multiplier in the range of 1.5 to 4, showing the large scientific uncertainty concerning the non-CO_2 effects of aviation. In this thesis a multiplier of 2.4 is assumed that corresponds to the study performed by Marbaix et al. (2008) and reflects the median of these studies.

Table 45 - The aviation multiplier

Relevant study	Aviation multiplier (adding non-CO_2 effects)
Penner (1999)	2.7
Sausen et al. (2005)	1.9
Jardine (2005)	1.9
Brand & Boardman (2008)	1.5-4
Marbaix, Ferrone, & Matthews (2008)	1.5-4 (most likely 2.4)
Kollmuss & Crimmins (2009)	>2

While various studies discuss the aviation multiplier, an aspect that has not deserved much attention in literature is to what extent CO_2-abatement measures decrease the non-CO_2 aviation emissions. To illustrate, by redesigning the air space in China planes could fly more efficient routes, thus not only leading to less CO_2-emissions but less water vapor and particulates as well. This thesis defines an *abatement multiplier* that takes into account the abatement of non-CO_2 emissions from improvements in infrastructure, operations, technology, and the use offsets. By using this number the abatement potential of the global MBM in terms of CO2-equivalent emissions can be estimated. Table 46 shows the assumed abatement multiplier by type of mitigation. These numbers are far from perfect, but reflect the differences between the different type of measures, e.g. one offset unit results in only one tonne of CO_2e-emissions abated while a technological improvement is assumed to have 1.5 times the abatement potential. For example, the use of biofuels leads to less sulphur dioxide and soot emissions (ATAG, 2011).

Table 46 - The abatement multiplier

Type of mitigation	Abatement multiplier (adding non-CO_2 effects)
Infrastructure	2.0
Operations	1.5
Technology	1.5
Offsets	1.0

Combining the simulation results from modeling the business-as-usual emissions *including the aviation multiplier* and total net aviation emissions with the global MBM *including the abatement multiplier*, together with the aggregated sectoral emissions pathway from Ecofys (2015), yields Figure 38Figure 37. Note the emissions are shown in $GtCO_2$-equivalent.
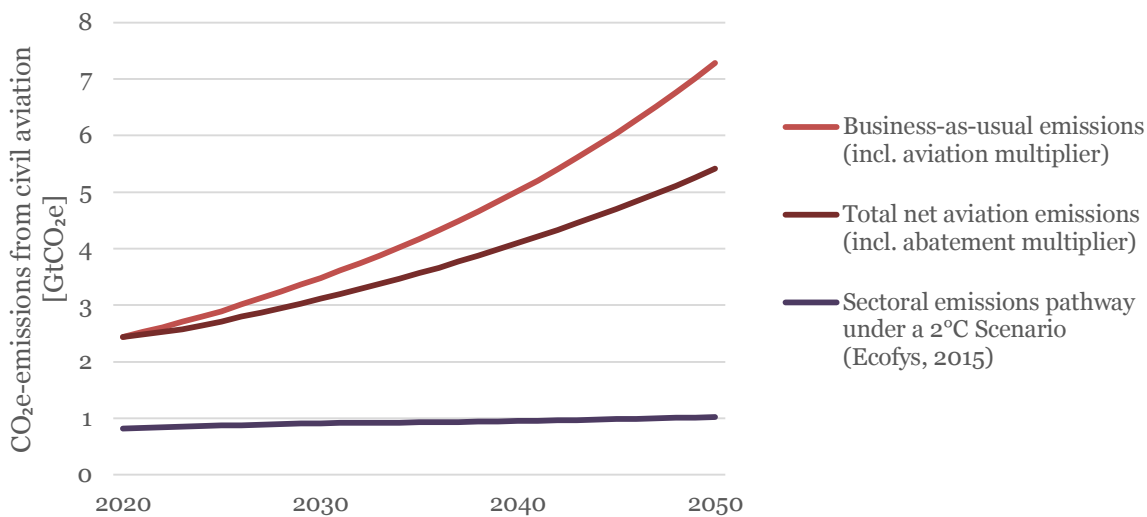

Figure 38 - The global MBM in relation to the 2°C pathway with multipliers

From the modeling results shown in Figure 38 it can be observed that by taking into account non-CO_2 effects the gap after implementing the global MBM to reach the 2°C sectoral emissions pathway is larger. In fact, the remaining gap equals **85.5 $GtCO_2e$** in the period 2020 to 2050. This is caused by the assumed abatement multiplier being smaller than the aviation multiplier, especially from the use of offsets. The share of aviation in the carbon budget would be significantly higher when adding non-CO_2 effects, see Figure 39. From a climate perspective it is therefore very important to realize that by "*shrugging the shoulders because it [non-CO2 effects] is too complex*" we are imagining things to be better than they actually are. This analysis supports the argument that the global market-based measure is not enough from a climate perspective.
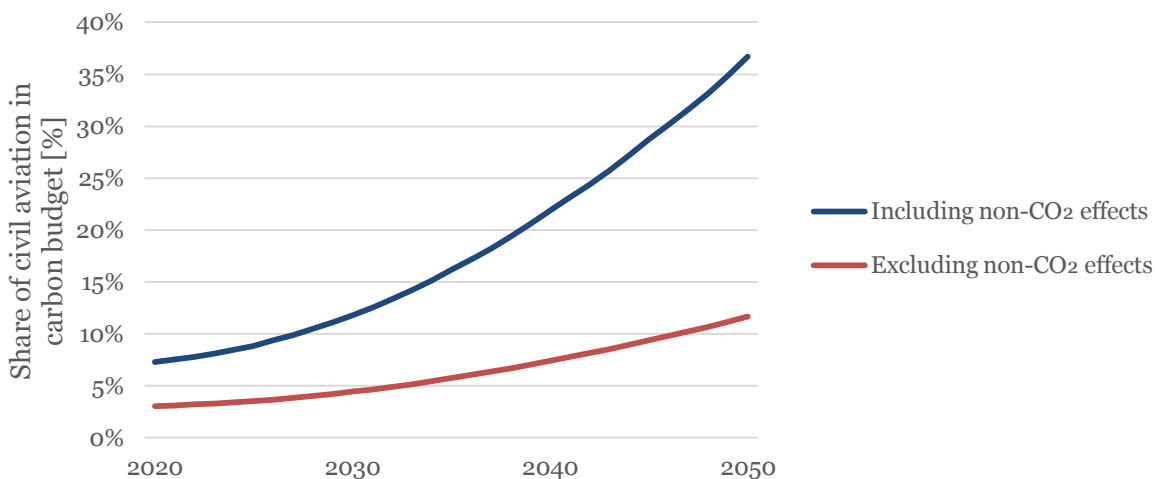

Figure 39 - Share of civil aviation in carbon budget

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Other factors adding to the complexity

The previous analysis has focused upon whether the global MBM's climate performance is in line with the target of limiting global temperature increase to 2°C by 2050. Now, if in theory ICAO would be able to match the objective of the global MBM with the 2°C-pathway, would the climate be saved? Below a number of factors are described shortly that add to the complexity of the global MBM's climate performance.

1. *Stakeholder disparity*
   Self-evidently, in order to ensure any climate gains from the global MBM it needs to be adopted and implemented. As the stakeholder analysis has shown Member States within ICAO have diverging views on the purpose and design of the global MBM, meaning implementation by 2020 is not a given.

2. *Compliance and enforcement*
   So far in this thesis it has been assumed that once implemented, all affected entities by the global MBM will comply to the system. However, as paragraph 5.4 has shown, enforcement is based upon Assembly Resolutions and standards which are both non-binding.

3. *The offset quality*
   The EU ETS has shown that airlines favour cheap over high quality offsets, and that without sufficient quality restrictions it is questionable whether a purchased offset credit truly represents one tonne of emissions reductions (Carbon Market Watch, 2013).

In conclusion it can be argued that hypothesis 3 - *the global MBM is not enough from a climate perspective* – is believed to be correct. Adding to the challenge of reaching a global MBM that is in line with the international climate target of limiting warming to 2°C by 2050 are non-CO_2 effects, stakeholder disparity, compliance and enforcement, and the offset quality.

10.5 POLICY RECOMMENDATIONS FOR A GREATER CLIMATE INTEGRITY

This paragraph aims at providing additional policy recommendations for ICAO in order to overcome the global MBM's shortcomings in terms of climate integrity. Firstly, the focus will be on how to bridge the CO_2-emissions gap towards the 2°C sectoral emissions pathway. Second, recommendations are provided that also take into account the non-CO_2 effects of aviation.

BRIDGING THE CO_2-EMISSIONS GAP

The previous paragraph has shown that the CO_2-emissions gap is caused by (i) a carbon-neutral growth target that is unaligned with the sector's 2°C-target, and (ii) the exclusion of domestic aviation in the global MBM. Below three policy recommendations are provided that address these issues.

> *Compatibility*
   In order to allow for regulatory measures that address domestic aviation, the global MBM design should be compatible with regional or national market-based measures that cover aviation, while ensuring that it avoids double regulation at points of departure and arrival.

> ***An annual decrease of the emission baseline from Phase 2 onwards***
> Since carbon-neutral growth is not sufficient in reaching the 2°C-target, the emission baseline of the global MBM could be adjusted after its implementation. Instead of keeping the emission baseline constant, ICAO could alter the measure in such a way that every year the baseline decreases with a certain percentage compared to the previous year. Due to the fact that political support for such an alteration might be limited at this point, it is suggested that ICAO first focuses on developing the MBM and reaching consensus in 2016, after which it can aim at finding political support for this alteration after adoption of the MBM. It is recommended that ICAO decides on investigating the alteration during its 40th Assembly in 2019, adopts it during the following Assembly in 2022, and implements it during Phase 2 starting at 2024. See Figure 40 for suggested alterations of the emission baseline.
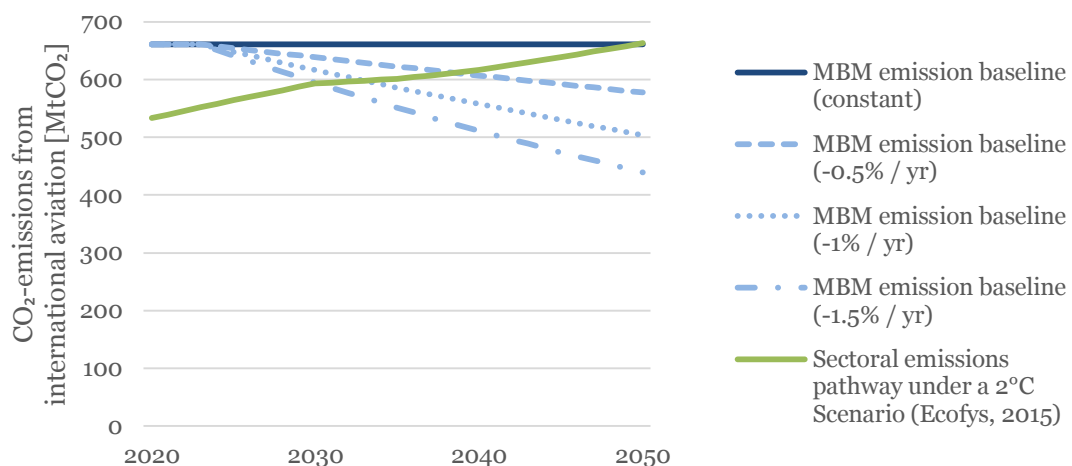

Figure 40 - Annually decreasing the emission baseline

> ***Openness towards voluntary commitments***
> The design should allow States to make voluntary commitments when it is based upon a phased-in route-based approach. In other words, a State included in one of the later stages of the scheme should be given the opportunity to voluntarily join the scheme in an earlier phase. Arguments for a (developing) State to voluntarily commit earlier to the global MBM could include that it fits well with their National Appropriate Mitigation Plan[27] (NAMA) or reputational importance.

INCLUDING NON-CO_2 EFFECTS OF AVIATION IN THE GLOBAL MBM

During the Global Aviation Dialogues in April 2015 ICAO has made it clear to only include CO_2-emission in the global MBM. As such, including the non-CO_2 effects of aviation seems far away. Nevertheless the previous paragraph has shown these non-CO_2 effects pose a significant challenge to the aviation sector reaching the sector's 2°C-target. Below two policy recommendations are provided to help ICAO in overcoming this challenge such that

Climate-neutral growth

Instead of incorporating only CO_2-emissions into the global MBM the *scope* of the scheme could be broadened to allow for inclusion of other aviation pollutants. By means of the aviation multiplier the required yearly emission reductions can be calculated. An abatement multiplier would be useful for airlines to assess how many CO_2-equivalent emissions each type of mitigation option enables. Furthermore, the *objective* of the scheme could be altered from '*carbon-neutral growth*' to '*climate-neutral growth*'. The suggested date of the

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[27] Nationally Appropriate Mitigation Action (NAMA) refers to a set of policies and actions that countries undertake as part of a commitment to reduce greenhouse gas emissions.

implementation would be at the start of phase 3 when all countries are included in the scheme. By 2027, this policy adjustment would replace the previously proposed alteration of annually decreasing the CO_2-emission baseline by 1%. See Figure 41 for the proposed emissions pathway corresponding to '*climate-neutral growth*'.

Towards zero climate impact
In working towards mitigating the total climate impact of aviation the *objective* of the global MBM could be focused towards reaching zero CO_2e-emissions by 2050. This way of target-setting is different than when defining a target based on current emissions, and was already described in paragraph 4.3. Modeling results show that from Phase 3 onwards an annual decrease of the emission baseline of ***70 MtCO₂e*** is necessary in order to reach zero emissions by 2050. See Figure 41 for the corresponding emissions pathway.
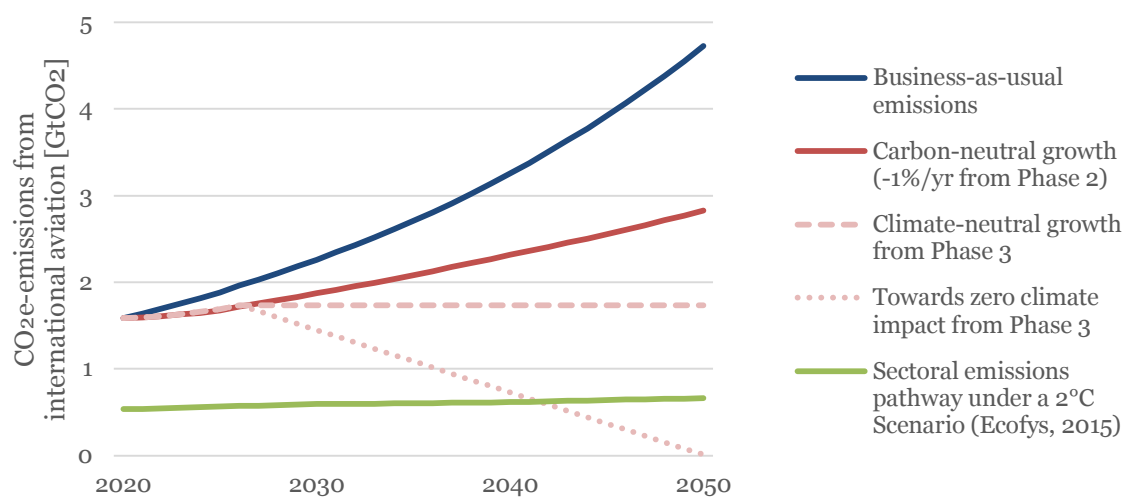

Figure 41 - Including the non-CO_2 effects of aviation in the global MBM

10.6 A FINAL STATEMENT

I would like to end this thesis on a more personal note by shortly looking back upon the last seven months as a researcher. It has been a very insightful period with highlights being meetings with members from ICAO at Ecofys and IATA during a dinner after the World Bio Markets 2015 Conference. If someone would ask me at this point what I would have done differently if I could conduct this research again it would be spending more time on writing out the research plan in an earlier phase, contacting ICAO at the start of this thesis, and reducing the scope of the research.

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