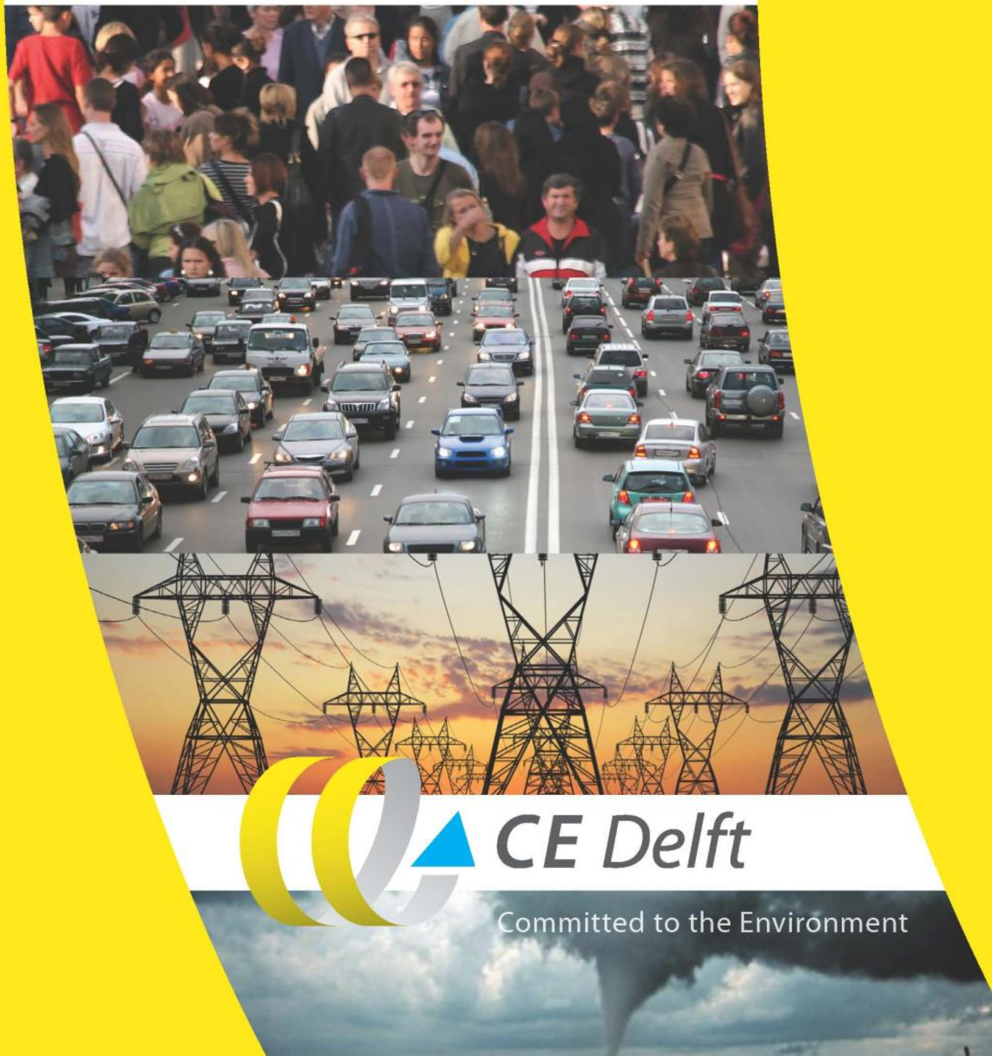
Biofuels in a Global MBM for Aviation



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Biofuels in a Global MBM for Aviation

This report is prepared by:
Jasper Faber, Saliha Ahdour
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Further information on this study can be obtained from the contact person, Jasper Faber.

Contents

Summary

The greenhouse gas emissions of aviation are projected to rise in the future, whereas climate policy objectives require that global emissions start decreasing in the coming years. In order to address emissions, ICAO has set an aspirational target of carbon neutral growth after 2020 and is developing a global market-based mechanism that will allow meeting the target.

Offsets will play a mayor role in the MBM. It is clear, however, that growth cannot be offset forever and that alternative fuels have a major role to play in limiting or reducing emissions from aviation. Currently, however, biofuels are too expensive to be used in large quantities. One of the reasons is that the production volumes remain too small to enable significant innovation and economies of scale.

The aim of this study is to analyze whether and how the global MBM can incentivize the development of sustainable biofuels for aviation. For this purpose, several design options for the MBM have been analyzed in their effect on the demand for biofuels and other impacts. These design options are:

1. Changing the emissions factor of biofuels to:
   a zero;
   b negative but increasing over time.
2. By increasing the quality criteria of offsets and thus their price.
3. By setting a maximum to the share of offsets that can be surrendered, either:
   a a constant maximum; or
   b an increasing maximum.

These MBM design have been analyzed and the effect on the demand of biofuel, aviation emissions and costs for airline operations. Due to a large price difference between fossil and bio aviation fuels, a zero emissions factor is not able to make the use of biofuels much more attractive for airlines. Also, because the price of offsets is related to the costs of CO_2 abatement and therefore probably in the range between US$ 20 and US$ 100 per tonne, increasing the quality criteria will not be sufficient to overcome the price difference between fossil and biofuels.

All the other scenarios can be designed in such a way that they would result in cost-parity between fossil and biofuels and thus incentivize demand, which would lower the prices of biofuels through learning-by-doing innovation.

In the scenario with negative emission factors, the strongly negative factors would be required to bridge the price difference between fossil and biofuels. This would result in a deterioration of the environmental effectiveness of the MBM, at least in the short term. While this could be compensated, in principle, by lowering the emissions targets, this may not be feasible in practice, as they would need to be adjusted regularly to the amount of biofuels used and thus increase the complexity of the MBM by decreasing its predictability. Another disadvantage of this scenario is that cost prices of biofuels may not always be observable, and learning rates are uncertain, so that it is unknown in advance how long the emissions factors need to stay negative.

The scenarios with maximum amounts of offsets would have the same environmental effectiveness as the baseline scenario, but the costs for the airlines would be higher because they would be required to buy a certain share of biofuels.

These results suggests that technological developments brought about by economies of scale and learning effects are insufficient to bring about the decreases in biofuel prices that are required to achieve the 2050 targets. Instead, radical technological changes are required to reduce the prices of biofuels. Possibly, the global MBM could be designed in such a way that it generates funds to further the technological developments. One way would be to set up something similar to the CDM adaptation fund, which receives 2% of the credits generated by CDM projects and can use them to fund adaptation. A similar fund, could be set up to support technological development of biofuels.

1 Introduction

1.1 Context of this study

The greenhouse gas emissions of aviation are projected to rise by about 4% per year, whereas climate policy objectives require that global emissions start decreasing in the coming years. Many have recognised that the growth of aviation emissions needs to be addressed so that the sector can contribute to combating climate change. In its 38th assembly in 2013, ICAO agreed to finalize the work on the technical aspects, environmental and economic impacts and modalities of the possible options for a global MBM scheme, as well as mechanisms for the implementation of the scheme from 2020. The results of these task will be submitted to the next assembly in 2016 for a decision.

The aviation industry has developed a long term roadmap for aviation, which relies to a large extent on biofuels for reducing emissions. Other measures, be they technical or operational, have a limited emissions reductions potential.

The Dutch fuel roadmap has recognised that for its sustainable growth, the aviation sector is heavily dependent on the development of aviation biofuels.

Demand for biofuel is a major bottleneck in the development of biofuels and is limited because of the price differential with conventional fuels. Airlines operate in a highly competitive, low-margin market in which alternative aviation fuels compete with conventional jet fuel. As long as these alternative fuels are not cost-competitive, it is expected that airlines will not use these alternative fuels on a large scale (IATA, 2013).

Even though oil prices were increasing, and some projections foresee increasing prices, this may not be sufficient to make aviation biofuels economically viable by 2020. It is difficult to reduce the unit production costs because many technologies are in an early stage of development. Therefore, reduction of costs is likely to depend on improved technology and innovation, such as the improvement of productivity of feedstock, the extraction of oil or sugars from crops and the conversion into fuel (ATAG, 2011). The price differential may decrease (or even disappear) due to innovation and economies of scale.

In order to ensure the environmental effectiveness of using biofuels, it is important that there is a harmonised standard for the aviation to make sure that the sustainability criteria are enforceable and equally applied in the aviation industry (ATAG, 2011). Regarding the sustainability criteria for aviation fuels, ATAG has suggested that these could include the following elements:

- will not displace, or compete with, food crops or cause deforestation;
- minimise impact on biodiversity;
- produce substantially lower life cycle greenhouse gas emissions than conventional fossil fuels;
- will be certified sustainable with respect to land, water and energy use;
- deliver positive socio-economic impact.

However, sustainability criteria on biofuels in road transport already exists under the EU Renewable Energy Directive (RED) and the US RSF2. Any biojet fuel that will be reported within these systems will also have to comply to these criteria. Ecofys has advised the IATA that mutual recognition between RED and RSF2 is a desirable option for the aviation sector. A global MBM is an opportunity and motivation to start the process of mutual recognition between the RED and RFS2 criteria for aviation (Ecofys, 2014).

1.2 Aim of the study

The goal of this project is to analyse whether and, if so, how the global MBM can incentivise the development of sustainable biofuels for aviation.

To that end, the project will answer the following questions:
a How can the global MBM be designed to incentivise demand for biofuels?
b What are the impacts of the potential design options?

1.3 Outline of this report

The next chapter describes the design options for a MBM in the aviation sector. Chapter 3 gives the a review of quantitative aspects of the MBM designs.
The results from the quantitative assessment and the sensitivity analysis is given in Chapter 4. Finally, Chapter 5 describes the main conclusions from this study and in the annex, a description of the methodology for the quantitative assessment model is given.

2 Incentives for biofuels in an MBM

2.1 Introduction

The aim of this Chapter is to develop a long list of proposals of how the MBM can incentivise biofuels and to evaluate their advantages and disadvantages qualitatively.

2.2 Overview of proposed global MBMs for aviation

ICAO assembly resolution A38-18 requests the Council to make a recommendation on a global MBM scheme to the Assembly in 2016.
In principle, the council is considering three types of MBMs: an offsetting scheme; an offsetting scheme with revenue generation; and an emissions trading scheme. Almost all effort is currently devoted to the development of an offsetting scheme.

Several proposals have been made for the design of the offsetting scheme. The Air Transport Action Group has painted a rather general picture in 2013, specifying that airlines should be responsible for using offsets, and that the amount of offsets should reflect airlines emissions and emissions growth over the 2020 baseline (ATAG, 2013).

The ICAO Council and Secretariat have developed a so-called straw man proposal, in which aircraft operators would be responsible for buying offsets. The amount of offsets to be bought is a share of the fuel consumption of the operators, which could possibly be calculated on the basis of individual or sectoral growth rates, historical emissions, and possibly differentiated by route. Biofuels would have an emission factor that is yet to be determined, but it is likely to be lower than the emissions factor of fossil fuels (EC, 2014).

Germany's Environmental Protection Agency has published a study on the Aircraft Carbon Offsetting System (ACOS), which shares many of the elements of ICAO's straw man but adds an element of route based differentiation: on certain routes, e.g. on routes between least developed countries, aircraft should buy offsets for a smaller share of their emissions than on routes between industrialised countries (Öko Institut and CE Delft, 2014).

Alejandro Piera has offered an offsetting system with route based differentiation, in which there would be a gradual expansion of the system. Starting from routes between the most developed countries (Piera offers several way of defining development), the system would extend over time to gradually encompass all international aviation routes (Piera, 2014).

2.3 Design parameters that are relevant for biofuel demand

While the proposals have a varying level of detail, and not all of them address the use of biofuels explicitly, they share two design parameters that determine the extent to which the MBM can help bridge the price gap between biofuels and fossil fuels and thus act as an incentive to biofuel demand. These are:

a The emission factor for biofuels. Depending on the feedstock and the technology, biofuels can lower well to wing emissions relative to fossil fuels by a certain percentage. Studies indicate 30-80% overall emission reduction is possible (Stratton et al. 2010). MBMs can account for the lower emissions of biofuels by applying an emission factor to biofuels. In the EU ETS, the emission factor is zero. If WtW emissions are used as a basis for biofuels, emission factors would be 20-70%. The lower the emission factor, the fewer offsets need to be purchased, and hence the stronger the incentive for biofuels.

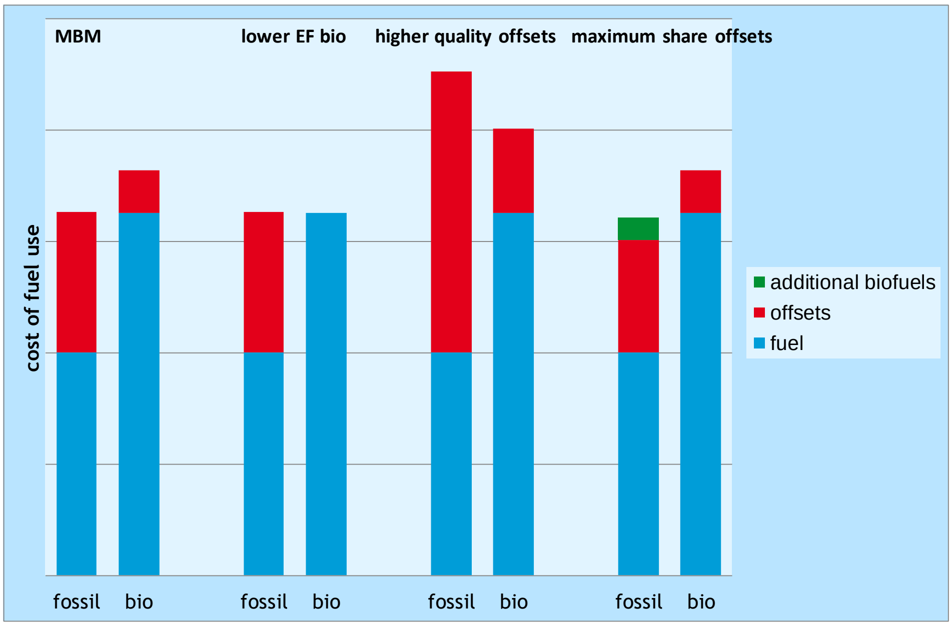
b The quality requirements for offsets. The quality of offsets varies with respect to, amongst others, additionally (how certain is it that the project would not have occurred without being part of an offset scheme), permanence (how certain is it that the emissions are permanently reduced), and credibility (how plausible is the relation between the amount of emissions reduced and the amount of offsets generated). In general, higher quality offsets sell at higher prices (Konte and Kotchen, 2010). The higher the price of offsets, the smaller the price difference between fossil fuel + offsets and biofuels.

In addition, to using one of the design parameters mentioned below to further the use of alternative fuels, it is also feasible to introduce a new design parameter:

a A maximum share of offsets. By limiting the amount of offsets that can be surrendered to a certain percentage of the total emissions (i.e. including the emissions from biofuels), a de-facto requirement to use a certain share of biofuels would be imposed on airlines. This study assumes that there is no other way to comply with a maximum share of offsets than to use alternative fuels. The requirement would act as a blending obligation, implemented as part of the MBM.

Figure 1 illustrates how the different incentive options affect the costs of using fossil fuels and biofuels. The default MBM adds the costs of offsets to the cost of using fuels. Because the emission factor of biofuels is lower than the emissions factor of fossil fuels, the cost difference between both types of fuels is reduced. A lower emissions factor for biofuels would reduce the cost difference even more. To the extent that higher quality requirements for offsets would raise their prices, this would also reduce the cost difference between using fossil fuels and biofuels. The maximum share of offsets would not reduce the cost difference, but would require airlines to use a minimum amount of biofuels.

Figure 1 Incentive options for biofuels



Apart from the design parameters above, there are other ways to incentivise the demand for biofuels. As these are not elements of an MBM, they are briefly described below but not analysed in subsequent sections.

a Direct subsidies for the use or development of biokerosine are not an element of any of the proposed MBMs. In an MBM that generates revenue, some of the funds raised could be used for subsidies. However, while subsidies for technology development may be economically justifiable, subsidies on consumption often distort markets.

b Penalties for not using biofuels are the opposite of direct subsidies. They are not an element of any of the proposed MBMs, but one could envisage that an MBM which has a revenue objective generates revenue by way of a levy on fossil fuel use. The incentive would be similar to the incentive provided by the offset scheme in combination with a zero emission factor for biofuels. The main difference is be that the level of the levy would be constant, while the price of offsets is set at the market.

2.4 Design options and qualitative evaluation

For the three design parameters identified in Section 2.3, this section develops design options and qualitatively evaluates them on the following criteria:

- environmental integrity (GHG emissions);
- the impacts on the aviation market, and in particular the level playing field;
- incentive for biofuel innovation and demand for biofuels;
- costs for airlines;
- transparency;
- special Circumstances and Respective Capabilities (SCRC) of States and simplicity.

The emission factor for biofuels

The emission factor (EF) for biofuels account for the fact that biofuels have lower well to wing (WtW) emissions than fossil fuels. The difference can be calculated and this can be used as a basis for the EF. Based on the currently available information, this would not bridge the current price differential between fossil fuels and biofuels and hence have a negligible impact on biofuel demand: biofuels would continue to be used in small amounts on a voluntary basis, but an increase in the use would require bridging the cost-gap. However it is also possible to choose a different EF to provide a stronger or weaker incentive for the use of biofuels. Diverging from the actual difference in emissions has environmental impacts, but these could be limited or compensated by other design choices.

Several choices are conceivable for the EF along two dimensions: it can be lower than, or equal to the difference in WtW emissions. If it is lower, it can be zero or negative. A second dimension is that the EF can be constant in time or increase over time. Below, we consider four options:
1. In line with the difference in WtW emissions.
2. Zero.
3. Negative.
4. Starting negative or zero, increasing to WtW over time.

The options differ in their environmental integrity and incentive for innovation and biofuel demand. The evaluation of the other criteria does not vary much.

Environmental integrity, incentive for biofuel

The environmental integrity is inversely correlated with the incentive for biofuels. At this moment, the price differential is such that only a strongly negative emission factor for biofuels would effectively increase demand for biofuels and also stimulate innovation. However, since biofuels in reality have positive emission factors, the environmental integrity could be compromised.

The negative impact on environmental integrity can be addressed in two, possibly reinforcing, ways. First, it can be contained in time: the emission factor can start at a strongly negative value and gradually increase over time to the WtW value. Since the price differential between biofuels and conventional fuels is projected to decrease over time (Faaij, 2013), this need not affect the demand for biofuels: as long as the increase of the EF tracks the decrease in the price differential between both fuels, the costs of using the fuels will remain the same.

The second way to address the negative impact is to increase the total amount of offsets required, e.g. by adjusting the emissions baseline. A lower baseline will result in a higher offset obligation. This may counteract the lower amount of offsets as a result of the negative emission factor.

Transparency

As long as the emissions factor is clearly specified, the transparency of this option for both airlines and biofuel producers would be good.

Simplicity, SCRC, and impact on aviation markets

All options are equally simple or complicated, and equally transparent. There is no distortions of the market. To the extent that biomass is produced in developing countries, incentives for biofuel production would increase exports of those countries and consequently have positive economic effects.

Costs for airlines

The cost for airlines would remain the same, because the additional costs of biofuels are compensated with a reduced requirement to buy offsets.

Other considerations

An emission factor that deviates from zero (the IPCC default value) or WtW emissions may be criticized for not having either a scientific basis or a regulatory precedent. If the sustainability of the biofuels is not guaranteed, incentives for biofuels could have negative environmental or social impacts.

Proposal for selection of options for further analysis

We propose to select two options for the emissions factor design parameter: a constant emissions factor of zero and one that starts negative and increases over time to reflect the difference in WtW emissions. The precise value of the latter will be based on a literature review of current prices of biofuels and offsets.

We propose to select two emission factors so that their impacts can be compared. The emissions factor of zero will be selected because it is in line with the current IPCC recommendation. The negative but increasing factor would be selected because it gives a strong incentive to biofuels but the negative environmental impact is limited in time.

The quality requirements for offsets

Although there is a correlation between quality requirements for offsets and their prices, the correlation is not perfect. Moreover, as the demand for offsets will grow when a global MBM for aviation is implemented, while at the same time demand from other areas may decrease, relative and absolute prices may change considerably. If the aviation MBM is the dominant source of demand, provisions of the MBM may effectively set the price.

The supply of high quality offsets may be limited in the beginning of the system, which could be a reason to lower the quality requirements or introduce tiered requirements. Below, we consider two options:

1. Strict quality requirements for all offsets.
2. Strict quality requirements for a certain percentage of offsets.

Environmental integrity, incentive for biofuel

The higher the quality of offsets, the higher the environmental integrity of the MBM as a whole. And since the quality is positively correlated with the price, the incentive for biofuel use and innovation will also be higher. However, it depends on the price of offsets whether the price difference can be overcome and whether or not the quality requirements have a material impact on the demand for biofuels.

Costs for airlines

Higher quality requirements will result in higher costs for airlines. If the strictest requirements only apply for a certain percentage of offsets, the overall costs will be lower.

Transparency, simplicity, impact on aviation markets

A system with uniform quality requirements would be simpler and more transparent than a system with tiered quality criteria. We do not foresee an impact on aviation markets, as all operators on the same market will be affected in the same way and the proposal will not entry barriers.

SCRC

Depending on how the quality requirements are set, there may be an indirect impact on SCRCs. For example, if the highest quality offsets would require that offset projects are located in developing countries, or in least developed countries, the system would cause a investment flow into these countries and provide macro-economic gains. In addition, to the extent that biomass is produced in developing countries, incentives for biofuel production would increase exports of those countries.

Proposal for selection of options for further analysis

We propose to select one option for the offset quality design parameter: strict quality requirements for all offsets. This is the most transparent and simple.

A maximum share of offsets

Under this option, airlines would calculate their total exhaust carbon emissions, including those resulting from using biofuels. In other words, this initial calculation would apply the same emissions factor to fossil fuels and biofuels. The airlines offsetting targets would be calculated on the basis of these total emissions. Of this target, they would be allowed to meet a certain percentage, e.g. 98%, with offsets. The remaining percentage would have to be met by using low carbon fuels, for which the normal emission factors would apply.

An example can be illustrative: suppose an airline emits 1,100 units of CO_2 and has an emission target of 1,000 units. Its shortfall is 100 units. Suppose that the airline is allowed to meet 90% of this shortfall by surrendering offsets, and is required to meet the rest by using biofuels. This means that it can buy 90 units of offsets and needs to reduce the other ten units by using biofuels.
If biofuels have an emissions factor that is 70% lower than the emissions factor of fossil fuels, the airline would need to use 10/(70%*1,100)=1.3% biofuels in its fuel mix.

There are at least three degrees of freedom in designing this option. First, the share of offsets that could be used, could be either constant or decreasing over time, resulting in a higher mandatory share of biofuels in the fuel mix. Second, it could be the same for all airlines or differentiated and e.g. apply only to airlines above a certain size. And third, flexibility mechanisms could be introduced in which airlines would remain responsible for using a certain amount of biofuels, but could pool this obligation with others or pay others to use biofuels on their behalf.

Below, we will analyse the following design options:

- Share of offsets:
  - constant;
  - decreasing over time (resulting in an increase of biofuels required).
- Application:
  - all airlines;
  - some airlines, e.g. those above a certain threshold.
- Flexibility:
  - with flexibility arrangements;
  - without flexibility arrangements.

Environmental integrity (GHG emissions)

In all options, the proposal amounts to replacing some offsets by biofuels mandatorily. Assuming that the quality of the offsets is good and the emissions factor is well chosen, there would be no impact on GHG emissions.

The impacts on the aviation market

When the share of offsets or the flexibility arrangements are the same for all market actors, and the prices of biofuels are the same on every location, there would be no impact on the aviation market as the cost impact would be the same for all actors and no new barriers to entry would be erected.

When a maximum share of offsets would be imposed on some airlines but not on others, and when it would result in higher costs (i.e. when the costs of offsets are lower than the additional costs of biofuels), the markets on which airlines with and without a maximum share compete would be distorted.

When the prices of biofuels vary considerably, airlines with hubs in places where biofuels are relatively cheap would have an advantage relative to airlines that have hubs in places where biofuels are relatively expensive. This could cause a distortion because the airlines with access to cheap biofuels would have a lower cost base.

Incentive for biofuel innovation and demand for biofuels

In this case, the incentive for biofuel innovation is a function of the impact on biofuel demand, since there are no additional quality criteria that could incentivise further innovation. Still, higher demand can be a strong incentive for innovation.

Assuming that the current supply of biofuels is limited and that it will take time to increase the production capacity, the share of offsets cannot be set too low at the implementation of the MBM. The incentive will therefore be larger when the share is gradually reduced over time. This would increase demand for biofuels gradually over time.

The demand for biofuels will be larger when all airlines have a maximum share of offsets, although when airlines are excluded, this can be counterbalanced by setting a lower share for the remaining airlines.

The flexibility options would not have an impact on the demand for biofuels. They do not affect the total amount of biofuels required to comply, but just allow for a redistribution of the biofuel use over actors.

Costs for airlines

Assuming that the costs of offsets are lower than the additional costs of biofuels, this option would result in higher costs for airlines.

Transparency, simplicity and SCRC

The option would reduce the simplicity of the MBM somewhat, as airlines would need to monitor and report not only their emissions and the amount of offsets, but also the amount of biofuels used. In the other MBMs, they would only need to monitor the amount of biofuels in case they would consume some. Flexibility arrangements would increase complexity further.

There would be no impacts on transparency. The impacts on SCRC would be comparable to those of the design options described above.

Proposal for selection of options for further analysis
We propose to select two options for this design parameter: one with a constant share of offsets, and one in which the share of offsets decrease over time. Both options will be applied to all airlines and modelled without flexibility arrangements. The application to all airlines ensures that aviation markets are not distorted. The flexibility arrangements may lower costs when the cost of compliance differ for various airlines, but the simple model employed in this study do not allow for a differentiation in compliance costs.

2.5 Selection of design options

We propose to select the following options for further elaboration and assessment of the impacts:
1. Emission factor of biofuels is and remains zero.
2. Emission factor of biofuels starts with a negative value that suffices to overcome the price difference between fossil fuels and biofuels (to be quantified) and gradually increases to zero (the timing is to be quantified).
3. Very strict quality criteria for offsets (criteria to be elaborated and resulting prices to be quantified).
4. A constant limit to the share of offsets (the limit will be set at the level of expected biofuel availability in 2020, to be quantified).
5. A decreasing limit to the share of offsets (the limit will start at the level to be quantified under Option 4; and decrease in line with expected biofuel availability until the share that limits aviation emissions to 50% of 2020 levels by 2050).

3 Assessment methodology of biofuels options

3.1 Introduction

This chapter provides the methodology and background information for the assessment of the impacts of the five design options in Chapter 3.7. We will assess the impacts relative to a scenario in which no incentives for biofuels are included in the MBM. Specifically, the following four aspects are assessed.

1. **Effectiveness**

The intended effect of the changes to the MBM that are analysed is to positively impact aviation biofuel demand and innovation. The impact on the demand for biofuels is a function of the incentives and of the projected price differential between biofuels and conventional fuels. For each of the scenarios, we assess whether the costs of the use of biofuels become equal to the costs of the use of conventional fuels (which includes the costs of offsets) or not. If this is the case, we assume that biofuel demand increases rapidly, thus generating a virtuous circle leading to innovation in production and lower biofuel prices. If this is not the case, we assume that the share of biofuels in the aviation fuel mix will remain constant over time.

2. **The impact on CO_2 emissions**

A consequence of the changes to the MBM could be that aviation CO_2 emissions and global CO_2 emissions change. Aviation CO_2 emissions change when the share of biofuels in the fuel mix changes (note that the projected growth in aviation emissions is not considered here as we compare the projected emissions with the projected baseline emissions). Global CO_2 emissions may change when for example the emissions factor of biofuels used in the MBM differs from the actual emissions factor, or when the amount of offsets changes. We have developed a simple calculation model to estimate the impact on CO_2 emissions, both in-sector and globally.

3. **Costs for airlines**

The costs of an MBM with a biofuel incentive for airlines may be different than the costs for airlines of the MBM without a biofuel incentive. Our simple calculation model calculates the costs for offsets and the costs for biofuels of each scenario for three different airline types: an airline with a predominantly long haul network, an airline with a predominantly short- and medium haul network and an airline with a mixed network. For each of these airline types, we consider a fast growing and moderately growing airline.

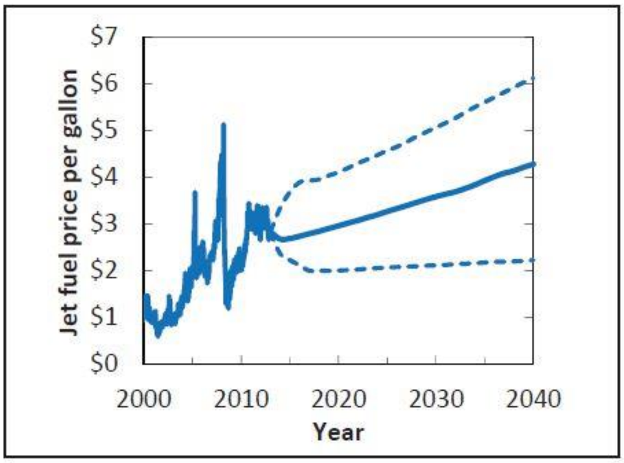
4. **GDP of selected countries**

Biofuels use feedstock from certain countries and are manufactured in certain, often the same, countries. As a result, an increased demand for biofuels will generate value in specific countries. Using information on the current value chains for biofuels, we can analyse which countries will benefit from increased demand, and compare this to the countries which benefit from increased demand for offsets.

3.2 Fuel and biofuel prices and price projections

The price of traditional jet fuel is based on crude oil which fluctuates over time (IEA, 2012). The average spot price for conventional jet fuel in 2013 was $ 0.75/L. Even though there is some uncertainty on the future fuel prices, it is expected to increase in the coming decades due to increased global demand for crude oil (see Figure 2) (IATA, 2013).

Figure 2 **EIA price projections for jet fuel in the US in 2012 US$**



Source: (IATA, 2013).

The price difference between biojet fuel and fossil jet fuel depends on the type of biofuel technology and feedstock. IATA (2013) provides the average prices of several biofuel types procured by the US military in the period 2007-2012. These average prices differ from $ 2.34/L to $ 15.59/L, see Table 1. Feedstock costs can be important factor in the production cost, such as for HEFA jet fuel (IEA, 2012).

Table 1 **Overview of average prices of different alternative jet fuels**

Type of jet fuel	Price in $/L	Feedstock
FT[1]	0.99	Natural gas coal
HOC-D[2]	2.34	Lignocellulosic biomass
DSH[3]	6.80	Sugar fermentation
HRJ/HEFA [4]	10.04	Camelina, algal oil, used cooking oil, tallow
ATJ[5]	15.59	Alcohols

Source: (IATA, 2013).

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[1] Fischer-Tropsch Jet Fuel.

[2] Hydro treated Depolymerized Cellulosic Diesel.

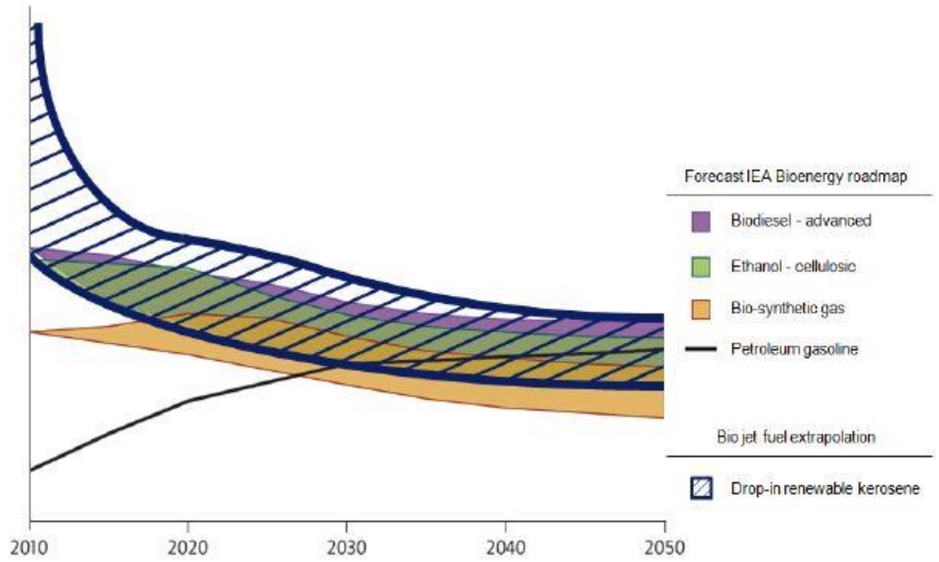
[3] Direct Sugar to Hydrocarbon.

[4] Hydro processed Renewable Jet/Hydro processed Esters and Fatty Acids.

[5] Alcohol to Jet.

Given the substantial cost reduction in the past of currently commercial biomass and biofuel technologies, the future cost reductions for current expensive technologies and biomass supplies (see Figure 3) are promising (Faaij and Van Dijk, 2012). IATA expects the price of biofuels to become competitive because the traditional jet fuel price increases and production costs of biofuels diminish (IEA, 2012). Note that biojet fuels have to be approved by the ASTM standards, which is only the case for HEFA, FT based on biomass (also called BtL or biomass to liquids) or DSHC (Ecofys, 2014).

Figure 3 **Schematic projection of biojet cost curve taken from the IEA Advance biofuel roadmap**



Source: (Faaij and Van Dijk, 2012).

These price projections might not hold for all biojet fuels. Currently, the HEFA technology is the only option for large scale production of sustainable jet fuel, although prices are still substantially higher than fossil kerosene (Faaij and Van Dijk, 2012). HEFA production using soybean oil as feedstock will probably not be cost competitive with conventional jet fuel in the next decade. The price of soybean oil in 2020 is predicted to be between $ 0.66 and $ 1.07 above the price of conventional jet fuel. Though the price of this biojet fuel is expected to increase, the price of conventional jet fuel is increasing more which makes the difference in price smaller (Winchester et al., 2013). The costs of biofuels such as FT can become significantly lower in case of a commercial scale production, but uncertainty still exists in terms of plant reliability and feedstock supply, (IEA, 2010).

IATA expects that in 2020, the share of sustainable jet fuel will be 3% (IATA, 2014). In the absence of economic incentives, we consider this to be an unrealistically high share. Instead, we assume that by 2020, 0.1% of aviation fuels will be biobased.

The learning rate[6] of currently produced bioethanol is about 20%, meaning that if production doubles, the price decreases with 20% (IPCC, 2012). The learning rate differs per type of biofuels. For example, lignocellulosic ethanol has a learning rate of 1% (Chen et al., 2012) and lignocellulose FT BTL diesel has a learning rate of 2% (De Wit et al., 2010). Lower learning rates in the pre- to early commercialization stage can be explained by several factors such as inexperience in scaling up pilot plants to commercial plants and lack of experience with new feedstock, materials and inputs. In addition, projections of learning rates are subject to uncertainties (Chen et al., 2012).

3.3 Biofuel availability

The availability of biofuels for aviation is determined by the global biomass supply and the conversion capacity to turn biomass into aviation fuels. If there is sufficient demand, for example because of the incentives in the MBM, these two factors will determine the amount of biofuels consumed in the aviation sector.

The global biomass supply was 50 EJ[7] in 2008[8]. The IPCC (2011) assumes that the technical potential in 2050 amounts to 500 EJ, of which 100–300 EJ are considered to become available, depending on, amongst others, biomass and agricultural policies. Hence, the average annual growth rate of biomass supply ranges from 1.7-4.4%.

About half of the total amount is projected to be grown on agricultural land and may not satisfy the ATAG criteria that aviation biofuels will not displace, or compete with, food crops or cause deforestation. Hence, we estimate the maximum biomass available for conversion into aviation fuels to be 150 EJ in 2050. Based on the MODTF emissions projections for GIACCC, one can estimate the total demand for aviation fuels to range from 30–60 EJ in 2050, which is close to the biomass availability of one takes the conversion losses into account.

Under the right conditions, the conversion technology can be expanded rapidly. Statistics of the USDA show that between 2009 and 2013, US biodiesel production increased by 27% per year on average, while bioethanol production increased by 7% per year in the period 2009–2014[9]. Hence, production capacity need not be a constraint to biofuel production.

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[6] The learning rate is the rate at which the per unit cost of a technology is expected to decline with every doubling of cumulative production (Chen et al., 2012).

[7] 1 EJ = 10^{18} joules.

[8] IPCC/Chum, H., A. Faaij, J. Moreira, G. Berndes, P. Dhamija, H. Dong, B. Gabrielle, A. Goss Eng, W. Lucht, M. Mapako, O. Masera Cerutti, T. McIntyre, T. Minowa, K. Pingoud, 2011: Bioenergy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[9] www.ers.usda.gov/data-products/us-bioenergy-statistics.aspx , accessed 12 March 2015.

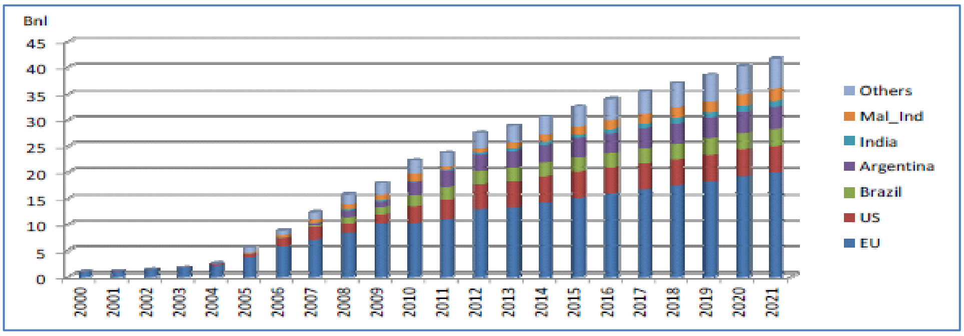
3.4 SCRC: Biomass source countries, biofuel production countries

The demand of aviation fuel will increase from 215 million tonnes in 2010 to between 460-630 million tonnes in 2050. The technical potential of biomass resources is around 500 EJ (in 2050) with potential deployment levels between 100 and 300 EJ (Faaij and Van Dijk, 2012). The technical potential consists of waste from forestry, agriculture and organic waste, but also forestry and energy crops produced in wetlands and excess agricultural land. Next to that, a part comes from energy crop production with more efficient production technologies. The global total primary energy supply from biomass in 2008 is about 50 EJ (CDB, 2014).

First generation biofuels use feedstock consisting of sugar, starch, oil crops or animal fats. Second generation biofuels use feedstock consisting of cellulose, hemicellulos or lignin (OECD & FAO, 2011). Although biofuels are traded between countries, there is little international trade in bioethanol feedstocks (such as sugar cane).
This is partially due to the non-tradable and perishable characteristics of some feedstocks. Next to that, some countries have a dual role as they are both producers of feedstock and consumers of biofuels, for example cereals-based bioethanol, sunflower-based biodiesel in the United States and in the European Union. An example of international feedstock trade is the European import of vegetable oil from countries such as Argentina, Indonesia and Malaysia. Second generation biofuels could allow an increase in trade of feedstock such as cellulosic and waste material (UNCTAD, 2014).

The major biofuel producers in the world are the US, the EU, Brazil, India, China and Thailand (EC, 2011). In 2012, the US production of bioethanol was 59% of the world production. The EU is the main producer of biodiesel (46% of global production) followed by the US, Argentina, Malaysia and Indonesia see Figure 4. The trade in bioethanol and biodiesel is a small part of the total biofuel production (4% and 7% in 2021) (UNCTAD, 2014). The global biofuel production projections for 2021 show mainly an increasing ethanol production in the US and increasing biodiesel production in the EU (EC, 2011). Brazil is a large producer of bioethanol and is expected to be the second largest ethanol producer in 2020 with a share of 33% of global production. Argentina is expected to be the largest biodiesel producer in the developing world, see Figure 4, with a share of 25% in the biodiesel production in developing countries and 8% in global production by 2020 (OECD & FAO, 2011).

Figure 4 **Global biodiesel production and projections in 2021**



Source: (EC, 2011).

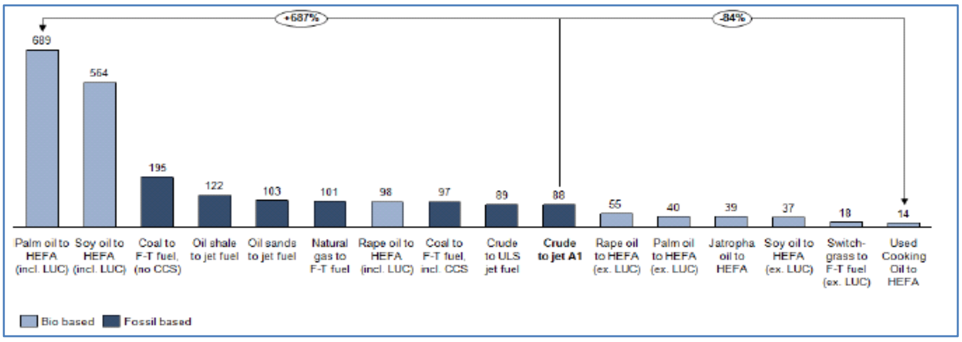
The EU and the US are expected to become large importers of biofuels in the period 2013-2022. Developing countries are net exporters for both biodiesel and bioethanol, of which Argentina, Indonesia and Malaysia are projected to be the largest net exporter of bioethanol (UNCTAD, 2014). Argentina has an expected growth of GDP in 2017 of 3.1%, and Brazil has an expected GDP growth of 2.7% in 2017 (Worldbank, 2015). It is questionable whether an increase in demand of biojet fuel will be beneficial for these countries, as this depends on the location of production and type of feedstock for the type of biojet fuel that will be produced in the coming years. Producing biojet fuel with the HEFA, DSHC and FT technology is approved, while other technologies are considered for approval (ATJ, DHC jet). Many test flights with HEFA jet fuel have been performed (for example by the KLM, with jet fuel based on used cooking oil), but the production of this fuel is still limited (IATA, 2013).

The production of biofuels for the aviation sector is not commercialized yet due to high prices. There are many small projects of airlines that use biojet fuels (IATA, 2013). The current capacities of HEFA produced by Neste Oil are 380 kt/a in Finland, 820 kt/a in Singapore and 800 kt in the Netherlands (IEA, 2012). Provided that the production of conventional jet fuel in the US alone is more than 22 billion gallon a year (NREL, 2014), the current share of biojet fuels is probably very small and close to 0%.

3.5 GHG emissions of biofuels

Comparing the LCA GHG emissions of different types of jet fuel shows that certain types of biofuel have more GHG emissions than fossil fuels and others less. Not all biofuels are environmentally beneficial as this depends on the production process. The life cycle GHG emissions for conventional jet fuel from crude oil is 87.5 gCO_2e/MJ), while the life cycle GHG emissions for jet fuel from biomass (first to third generation, see Figure 5) can differ from -2.0 to 698.0 gCO_2e/MJ) (Partner, 2010). For the HEFA biojet from soybean, the GHG emissions is about 43 gCO_2e/MJ (Malina, 2014), which is approximately 50% of the crude oil GHG emissions.

Figure 5 Well to Wing emissions of different jet fuels (gCO_2/MJ)



Source: (Faaij and Van Dijk, 2012).

3.6 Offset quality, prices and price projections

Taking the Clean Development Mechanism as an example of market based mechanism for international mission reduction, elements of differentiation between projects already exist in the form of exclusion of projects and the CDM Gold standard projects (Bakker et al., 2011). CERs from Gold Standard projects are sold at a higher price than other projects, which gives a higher market value to projects with high sustainable development benefits.
The market in Gold Standard project is developing rapidly and the price difference is shrinking (ETCACC, 2008).

Differentiation between projects can reduce the supply of CER (certified emission reduction) projects (Bakker et al., 2011). A reduced supply of CERs could result in higher prices. This makes the development of CDM projects economically more attractive (ETCACC, 2008). However, given the demand for CERs in the future it is questionable whether the impact on the carbon market will be large (Bakker et al., 2011).

Prices in the voluntary carbon market are quite volatile and differ over countries and types of projects (Conte and Kotchen, 2010). By discriminating by project type, certain projects can have higher prices. This can be done by giving preferences or penalties to a pre-defined set of project types.
An example is the Dutch program of CER purchase CERUPT with (maximum)-prices in 2001 varying from € 3.30 for fossil fuel switch and methane recovery to € 5.50 for renewable energy (Cosbey et al., 2006). Price of CERs changes over time, for example the price of CER on the spot market has decreased from approximately € 8.24 in October 2011 to € 0.02 in February 2015 (theICE.com, 2015).

Current CDM prices may not be the best indicator of offset prices. They are low because of changes in the rules of the largest carbon market, the EU ETS, and the fact that, once a CDM project has been initiated, the costs of producing CERs is often quite low[10]. Specific reports of the costs of CDM credits, such as Wetzelaer et al. (2007), have since then been few in number. Another way of estimating the relation between offsets quality and prices is to analyse the abatement costs of various technologies. McKinsey & Co (2010) calculate that solar PV – one of the more expensive abatement technologies – is available for about € 20 (US$ 22) per tonne of CO_2, and Carbon Capture and Storage for € 50–80 (US$ 55 – 88)[11]. Estimates from other authors have the same order of magnitude.

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[10] Newell, Richard G., William A. Pizer, and Daniel Raimi, 2013, Carbon Markets 15 Years after Kyoto: Lessons Learned, New Challenges, Journal of Economic Perspectives, Volume 27, 123-146.

[11] http://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/Sustainability/cost%20curve%20PDFs/ImpactFinancialCrisisCarbonEconomicsGHGcostcurveV21.ashx

4 Results quantitative assessment

This chapter presents the results of the quantitative assessment of the various scenarios. The basic assumptions of the quantitative assessment are:

- As a result of the MBM, the aviation sector emissions will be capped at their 2020 level.
- Airlines will use biofuels in larger quantities than currently when the cost of doing so is less than or equal to the costs of using fossil fuels[12].
- When using biofuels is cost-effective for airlines, the available production capacity will set a limit to the total amount of biofuels that can be used. We expect the production capacity of biojet fuels can increase maximally at an annual rate that is twice as high as the annual increase in global biomass production.

In a sensitivity analysis, we assume a much faster reduction in biofuel prices as a result of exogenous technological developments, which allow the commercial use of different feedstocks and conversion technologies. In this optimistic scenario, the difference in price between biojet fuels and conventional fuels will become zero in 2030.

The next section describes the baseline scenario, with which the results of the other scenarios are compared. Sections 4.2 through 4.6 present the results of impact assessment of the five scenarios described in Chapter 2. Section 4.7 presents the results of the sensitivity scenario.

4.1 Baseline scenario

The baseline scenario is a possible MBM scenario in which there are no special incentives for the use of biofuels. The net aviation sector emissions are capped at their 2020 level and in order to reach this targets, airlines are required to buy offsets. The amount of offsets they need to buy is determined by their increase in emissions since 2020 and the sectoral increase in emissions since 2020. The baseline scenario assumes that biofuels are not used in the aviation sector in significant amounts.

The other relevant assumptions in the baseline scenario are presented in Table 2.

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[12] A situation in which the costs of using biofuels are less than the costs of using fossil fuels is hypothetical. As long as fossil fuels are available and the supply of biofuels is less than the total demand for fuel, the costs of fuel use will be set by the marginal fuel, which is fossil fuel. Even when biofuels could be produced at costs lower than the price of fossil fuels, their sale price will track the fossil fuel price closely. In that situation, biofuel producers will make a profit.

Table 2 **Assumptions in the baseline scenario**

Parameter	Estimation	Source
Future biofuel share Current biofuel share	3% Approximately 0.001% (Around 2,000 kt HEFA biofuel against demand of 215 million kt jet fuel)	Estimated by IATA (2014) for 2020 (IEA,2012 and Faai & Van Dijk, 2012)
Price difference	\$ 0.66- 1.07 L Assumed to be \$ 1	In case of soybean bio fuels (IATA, 2013)
Price of offset	US\$ 20 per tonne of CO_2	Currently fallen to app. US\$ 0.20 (the-ice.com), but this is due to a restriction on CDM use in the EU ETS, the largest carbon market by volume. In earlier phases of the EU ETS, CDM prices ranged from US\$ 16 – US\$ 30
Emission factor of fossil fuel	87.5 gCO_2e/MJ	(Partner, 2010)
Emission factor of biofuel	-2.0-698.0 gCO_2e/MJ Assumed to be 43 gCO_2e/MJ (rapeseed oil HJR)	Emissions depend on the type of feedstock, land use and production process (Partner, 2010)
Learning rate	Assumed to be 0.1	
Aviation emissions growth	4% per year?	CAEP7 baseline

The results of the baseline scenario are shown in Table 3.

Table 3 **Main results of the baseline scenario**

	2020	2025	2030
Aviation emissions (Mt)	1,050	1,300	1,600
Offsets (Mt)	0	250	550
Share of biofuels	0.1%	0.08%	0.07%
Costs of offsets (million US\$)	0	4,500	10,700
Costs of biofuels	Constant at US\$ 800 per metric tonne higher than the fuel price		

Source: aviation emissions: MODTF.

4.2 Scenario 1: Biofuel emissions factor is zero

In Scenario 1, the emissions factor of biofuels is zero. With a price difference of US$ 1 per liter of fuel between biofuel and fossil fuel (US$ 800 per tonne of fuel) and an offset price of US$ 20 per tonne of CO_2, the cost difference between using fossil fuel and biofuel would still remain high (US$ 736 per tonne of fuel). This means that biofuels will not become cost-effective unless the price of offsets increases to over US$ 250 per tonne of CO_2.
Figure 6 shows for different price differences between fossil fuels and biofuels the price of offsets that ensures that using biofuels costs just as much as using fossil fuels. Only when biofuels are much cheaper than currently – around US$ 100 per tonne above the fossil fuel price (or US$ 0.80 per liter), are foreseeable offset prices enough to achieve cost-parity.

Figure 6 Minimum required price of offsets to achieve cost-parity between biofuels and fossil fuels

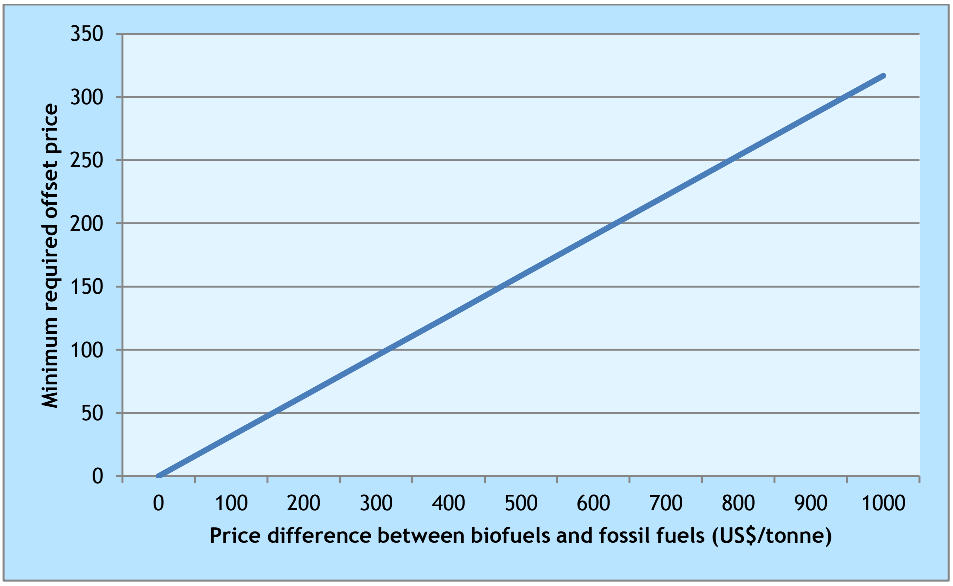

Table 4 the main results of the scenario in which the emissions factor of biofuels is set at zero, relative to the baseline scenario. Because the costs of using biofuels are still very high, there will not be an impact on biofuel use. This means that the CO_2 emissions and the costs will not change either.

Table 4 The main results of Scenario 1 ($EF_{biofuels} = 0$) compared to the baseline scenario

	2020	2025	2030
Change in biofuel use	0%	0%	0%
Biofuel price (difference with fossil fuel, US$/tonne)	800	800	800
Change in CO_2 emissions	0%	0%	0%
Cost increase relative to baseline scenario	0%	0%	0%

4.3 Scenario 2: Negative and rising emissions factor for biofuels

In Scenario 2, the emissions factor of biofuels is negative at the start and gradually increases. The emissions factor in 2020 will be set to the level where the costs of using biofuels and fossil fuels are equal. This level depends on the price difference between fossil fuels and biofuels and the price of offsets.

The minimum required emissions factor for biofuels that renders biofuels cost-effective depends on the fuel price difference and offset price. At low offset prices or high fuel price differences, the emissions factors become quite large and the relation becomes very sensitive to small changes in fuel and offset prices.

Using the base assumptions of this study, a fuel price difference of US$ 800 per tonne of fuel, and an offset price of US$ 20 per tonne of CO_2, the required emissions factor at the start of the system is -12.67. This means that for each tonne of CO_2 emitted from biofuels, initially almost 13 fewer offsets need to be acquired.

The emissions factor can decline over time as biofuels become cheaper. The rate by which they can decline depends on the learning rate and the increase in biofuel production. Our assumption is that the supply of biofuel will increase rapidly from 0.1% of aviation fuel in 2020 to 3% in 2025 and 6% in 2030. Under our assumptions of the learning rate – a reduction in costs of 10% for each doubling of production – the price difference between biofuels and fossil fuels will decrease from US$ 800 in 2020 to approximately US$ 400 in 2025 and US$ 300 in 2030. Table 5 indicates how the price of biofuels would evolve under different learning rates. If the learning rate is 15% or higher, the emissions factor could be set at zero or higher in less than 10 years.

Table 5 The development of biofuel prices under different learning rates

Year	Learning rate	2020	2025	2030
Airline emissions		1,100	1,300	1,600
Biofuel share		0.10%	3%	6%
Biofuel price difference (US$)	5%	800	600	550
	10%	**800**	**400**	**300**
	15%	800	200	0
	20%	800	0	0

Note: This study assumes a 10% learning rate.

It should be noted that learning rates are can only be derived with reasonable accuracy if production volumes and costs can be observed. This need not be the case here. As long as fossil fuels are available and the supply of biofuels is less than the total demand for fuel, the costs of fuel use will be set by the marginal fuel, which is fossil fuel. Even when biofuels could be produced at costs lower than the price of fossil fuels, their sale price will track the fossil fuel price closely. In that situation, biofuel producers will make a profit.

Table 6 shows the effectiveness, CO_2 impact and cost impact of the scenario with negative biofuels. When the share of biofuels rises as rapidly as projected, the CO_2 emissions increase relative to the baseline because in this scenario, biofuel use is overcompensated (and thus less offsets than required to reach the cap is acquired). The costs (for offsetting and use of biofuels) are equal to the baseline scenario.

Table 6 The main results of Scenario 2 (negative $EF_{biofuels}$) compared to the baseline scenario

	2020	2025	2030
Biofuel share	0.1%	3%	6%
Biofuel price (difference with fossil fuel, US$/tonne)	800	400	300
Change in CO_2 emissions	0%	20%	35%
Cost increase relative to baseline scenario	0%	0%	0%

4.4 Scenario 3: Strict quality criteria for offsets

Strict quality criteria for offsets would increase their price and thus decrease the cost difference between using fossil fuels and using biofuels. However, as shown in Scenario 1 (Section 4.2), the costs of offsets need to increase to several hundreds of dollars per tonne of CO_2, depending on the emissions factor of biofuels and the price difference between biofuels and fossil fuels.

Table 7 shows the assumptions required to make biofuels cost-competitive with fossil fuels. It is not known which quality criteria would result in these prices. Section 3.6 suggests that even restricting offsets to technologies such as CCS and solar power, which are generally considered to be amongst the more expensive abatement options, will not raise the offset price beyond US$ 100.

Table 7 Assumptions for Scenario 3 (strict offset criteria)

	2020	2025	2030
Biofuel emission factor	50%	50%	50%
Required offset price (US$/tonne CO_2)	500	250	200
Biofuel share	0.1%	3%	6%
Biofuel price (US$/tonne fuel)	800	400	300

Table 8 shows that even if quality standards could be set so that the prices would reach the required level, the cost impact for airlines would be very large.

Table 8 The main results of Scenario 3 (strict offset quality standards) compared to the baseline scenario

	2020	2025	2030
Biofuel share	0.1%	3%	6%
Biofuel price (difference with fossil fuel, US$/tonne)	800	400	300
Change in CO_2 emissions	0%	0%	0%
Cost increase relative to baseline scenario	2,500%	1,000%	700%

4.5 Scenario 4: A constant maximum share of offsets

Scenario 4 sets a maximum for the share of offsets that can be surrendered (or, alternatively, a minimum share of emission reductions that needs to be achieved by using biofuels). In line with the biofuel availability in 2020, which is assumed to be 0.1% of total aviation fuel demand, we limit the amount of offsets that can be surrendered to 99.9% of emissions of an airline in a given year minus the emissions target for that airline. This results in a modest increase in both the share and the amount of biofuels for the sector.

Table 9 shows that while this constant maximum share of offsets would result in a modest increase in the share of biofuels, prices of biofuels would decrease not by much. The CO_2 emissions would remain the same as in the baseline scenario and the costs of biofuels would be borne by the airlines.

Table 9 **The main results of Scenario 4 (constant maximum share of offsets) compared to the baseline scenario**

	2020	2025	2030
Biofuel share	0.1%	0.2%	0.2%
Biofuel price (difference with fossil fuel, US$/tonne)	800	700	700
Change in CO_2 emissions	0%	0%	0%
Cost increase relative to baseline scenario	0%	6%	4%

4.6 Scenario 5: A decreasing maximum share of offsets

Scenario 5 sets a decreasing maximum share of offsets that can be surrendered (or, alternatively, an increasing minimum share of emission reductions that needs to be achieved by using biofuels). The shares are set at 98.5% of emissions of an airline minus the emissions target for that airline in 2025, and at 97% of emissions minus the target in 2030. This results in a significant increase in both the share and the amount of biofuels for the sector, in line with the increases of Scenarios 2 and 3.

Table 10 shows that this scenario results in a cost increase for airlines that is large at the start of the system and diminishes over time as biofuels become less expensive.

Table 10 **The main results of Scenario 5 (decreasing maximum share of offsets) compared to the baseline scenario**

	2020	2025	2030
Biofuel share	0.1%	3%	6%
Biofuel price (difference with fossil fuel, US$/tonne)	800	400	300
Change in CO_2 emissions	0%	0%	0%
Cost increase relative to baseline scenario	0%	84%	65%

4.7 Sensitivity analysis

4.7.1 Exogenous technology development driven by financial support

In the sensitivity analysis, an optimistic development of biofuel technology is presented with decreasing biofuel prices driven by this (exogenous) technology development. Assuming that over time different biofuels can be developed and that their production will become cheaper, it is possible to allow for large decreases in biofuel price. Currently, biojet fuels are often produced using the HEFA-technology with a feedstock of vegetable oils, which is approximately twice as expensive as fossil jet fuel. In an optimistic scenario, it will be possible to produce biojet fuel out of (useless) waste streams from lingocellulosic material by 2020, allowing the price difference to be twice as small. By 2030, again assuming a rapid technological development, a bio crude can be produced from a wide range of biomass sources using hydro thermal upgrading, resulting in a biofuel price close to the price of fossil fuels.

4.7.2 Baseline scenario

In this baseline scenario the price difference between biofuel and fossil fuel decreases over time due to exogenous technology development, which allows for cheaper production of biojet fuel. This change in biofuel price is only technology driven so the biofuel shares are equal to the baseline scenario in Section 4.1.

The main results for this new baseline scenario is presented in Table 11. The changes are compared to the baseline scenario in Section 4.1. Next to that, the results show that the assumed price difference development only affects the costs of biofuels and not the amount or costs of offsets.

Table 11 **Results baseline (technology development)**

	2020	2025	2030
Biofuel share	0.1%	0.08%	0.07%
Biofuel price (difference with fossil fuel, US$/tonne)	800	400	100
Change in CO_2 emissions	0 %	0 %	0 %
Cost increase relative to baseline scenario	0 %	-3%	-2%

4.7.3 Scenario 2: Negative and rising emission factors for biofuels

In this scenario, the price differences and biofuel shares are equal to the baseline. An exception is the biofuel share in 2030, which is expected to be 3% given the negative emission factor in that year *(1.6 offsets less per emitted metric ton of emission by biofuels)*. Comparing the results of Scenario 2 to the baseline of the sensitivity analysis gives the results presented in Table 12. These show that net emissions increase while the cost for airlines of biofuels and offsetting decreases. The latter is caused by the lower price of biofuels over time and the compensating emission factor that gives lower offsetting costs.

Table 12 **Results Scenario 2 (compared to results in Scenario 4.7.2)**

	2020	2025	2030
Biofuel share	0.1%	0.08%	3%
Biofuel price (difference with fossil fuel, US$/tonne)	800	400	100
Change in CO_2 emissions	0%	0.6%	4.9%
Cost increase relative to baseline scenario	0%	0%	0%

4.7.4 Scenario 3: Strict quality criteria for offsets

In this scenario, strict quality criteria for offsets are in place, leading to higher prices of offsets. Given the assumed technology progress, it is assumed that the biofuel share in 2030 will be 3%. Table 13 shows the main results of this scenario. The net emissions do not change compared to the baseline scenario, however, the costs for airlines to offset increase significantly (three times larger costs). The amount of emissions that have to be offset are lower, and next to higher offsetting costs, the costs for biofuels have also increased.

Table 13 Results Scenario 3 (compared to results in Scenario 4.7.2)

	2020	2030
Biofuel share	0.1%	**3%**
Biofuel price (difference with fossil fuel, US$/tonne)	800	**100**
Change in CO_2 emissions	0%	**0%**
Cost increase relative to baseline scenario	0%	**216%**

4.7.5 Scenario 4: A constant maximum share of offsets

This scenario describes a situation with a maximum share of offsets of 99,9% in 2030. In this year, the biofuel share is assumed to be 3% given the exogenous technology development. The main results of this scenario with changes compared to the baseline Scenario 4.7.2 is presented in Table 14. The maximum share leads to a higher biofuel share and thus less net emissions and higher (biofuel) costs for airlines.

Table 14 Results Scenario 4 (compared to results in Scenario 4.7.2)

	2020	2030
Biofuel share	0.1%	**3%**
Biofuel price (difference with fossil fuel, US$/tonne)	800	**100**
Change in CO_2 emissions	0%	**-2%**
Cost increase relative to baseline scenario	0%	**13.5%**

4.7.6 Concluding remarks

Given the optimistic scenario with exogenous technology development due to R&D subsidies for biojet fuels gives some (small) differences compared with the main model. Allowing a price difference between biojet fuel and fossil fuel of $ 100/t in 2030 gives mainly lower costs for biofuels, as the price changes are mainly technology driven instead of demand driven.

Adding some scenarios does change the amount of offsets to be bought and thus the net emissions, as the biofuel share is expected to be 3% in 2030 after the large price decrease due to technology progress. The change in net emissions differs per scenario. In case of negative emission factors, the net emissions increase. In the scenario of strict quality of offsets there is no change in net emissions. A constant maximum of offsets leads to a small decrease in net emissions.

The total costs of offsetting and biofuels for airlines also depends on the scenario. The scenario of negative emission factors gives a small decrease in costs while in the scenarios of strict offset quality and constant maximum share of offsets, a significant increase in total costs is observed. This increase is especially very large for the scenario of strict quality of offsets, however, the price difference including offsetting is zero.

The sensitivity analysis shows the effect of lower biojet fuel prices over time. For the design of MBM, a decrease in net emissions is only reached in Scenario 4 with a constant maximum share of offsets. In the main model, a reduction of emissions is not reached in any scenario. The total costs for airlines only decreases in Scenario 2, which is also the case in the sensitivity analysis. In conclusion, lower biojet fuel prices only lead to lower total cost in a situation with a MBM with negative emission factors, while lower emissions are only reached through a maximum share of offsets.

The technology assumptions in the sensitivity analysis are very optimistic. In order to increase the chance of this scenario becoming reality, further research and development will be needed. A comparison of base case results and the sensitivity analysis shows that market-driven technological development is not sufficient to lower biofuel prices.

5 Conclusions

In principle, there are several ways in which the MBM can be designed to incentivise biofuel use to a greater extent. This report has explored three ways and developed five scenarios:

1. By changing the emissions factor of biofuels to:
   a zero;
   b negative but increasing over time.
2. By increasing the quality criteria of offsets and thus their price.
3. By setting a maximum to the share of offsets that can be surrendered, either:
   a a constant maximum, or;
   b an increasing maximum.

Given that the price difference between fossil and bio aviation fuels is quite large (biofuels are about double the price of fossil fuels, or US$ 800 more expensive per tonne), a zero emissions factor is not able to make the use of biofuels much more attractive for airlines. Also, because the price of offsets is related to the costs of CO_2 abatement and therefore probably in the range between US$ 20 and US$ 100 per tonne, increasing the quality criteria will not be sufficient to overcome the price difference between fossil and biofuels.

All the other scenarios can be designed in such a way that they would result in cost-parity between fossil and biofuels and thus incentivise demand, which would lower the prices of biofuels through learning-by-doing innovation.

In the scenario with negative emission factors, the strongly negative factors would be required to bridge the price difference between fossil and biofuels. This would result in a deterioration of the environmental effectiveness of the MBM, at least in the short term. While this could be compensated, in principle, by lowering the emissions targets, this may not be feasible in practice, as they would need to be adjusted regularly to the amount of biofuels used and thus increase the complexity of the MBM by decreasing its predictability. Another disadvantage of this scenario is that cost prices of biofuels may not always be observable, and learning rates are uncertain, so that it is unknown in advance how long the emissions factors need to stay negative.

The scenarios with maximum amounts of offsets would have the same environmental effectiveness as the baseline scenario, but the costs for the airlines would be higher because they would be required to buy a certain share of biofuels.

These results suggests that technological developments brought about by economies of scale and learning effects are insufficient to bring about the decreases in biofuel prices that are required to achieve the 2050 targets. The sensitivity analysis shows that radical technological changes are required. Possibly, the global MBM could be designed in such a way that it generates funds to further the technological developments. One way would be to set up something similar to the CDM adaptation fund, which receives 2% of the credits generated by CDM projects and can use them to fund adaptation. A similar fund, could be set up to support technological development of biofuels.

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Annex A Methodology for quantitative assessment

A.1 Baseline model

The model used to calculate the effects of different design options of an MBM in the aviation sector is based on calculations of future emission levels and the resulting offsets (in a situation with and without biofuels) that have to be bought to reach the emission targets. The future emission levels depend on the growth of aviation sectors. The offsets to be bought correspond to the amount of emissions to be reduced in order to achieve the emission target (level of 2020). This is calculated in the situation with and without biofuels. Calculating the costs of offsetting emissions depends on the price difference between fossil jet fuel and biojet fuel and the price of offsets. Several types of costs are calculated: price difference between fossil and biojet fuel including offsetting costs; additional costs of offsetting with biofuels compared to offsetting without biofuels; and the offsetting costs with biofuels.

A.2 Assumptions

The biofuel share, the emission factor of biofuel and the price of offsets are assumed values based on the literature review in Chapter 3. Next to that, the emissions target is set to the emission level in 2020. The price difference between fossil jet fuel and biojet fuel in 2020 in $/tonne is calculated by multiplying the price difference in $/l by the density of kerosene (kg/l) and by 1,000. The price difference between fossil jet fuel and biojet fuel in 2025 and 2030 is calculated based on the price difference and the learning rate which are assumed based on the values known in literature. This price difference is calculated by multiplying the price difference in US$ 2020/tonne fuel by the growth rate of biofuel use and the learning rate. The growth rate of biofuel use is calculated by dividing the difference in biofuel use by the biofuel use in 2020. The biofuel use is the aviation emissions in a future year multiplied by the share of biofuels. Because the learning rate is based on the doubling of biofuel production, while this may not be the case in the baseline (due to growth in the aviation sectors and a constant share of biofuels), the growth rate of biofuel use is calculated using a log formula.

A.3 Calculation method

Emissions:

Aviation emissions: The growth of emissions is calculated for the total sector and six individual sectors (long haul fast, mixed fast, short haul fast, long haul medium, mixed medium and short haul medium). There is a difference in growth rate of the sector between fast growing sectors and medium growing sectors. The emissions of a certain type of sector is calculated by multiplying the emissions in 2020 to the growth rate to the power of the time difference.

Basic calculation of offsets: The amount of offsets to be bought in case biofuels are not included are calculated by multiplying the future emission level by the average growth rate of the individual sector and general aviation sector.

Emissions to be offset: The difference between the future emission levels including the use of biofuels and the emission target is the emissions that have to be offset. This is calculated by multiplying the future emission level by one minus the emission reduction by biofuels. The emission reduction by biofuels is calculated by multiplying the share of biofuels by one minus the emission factor of biofuels.

Net emissions: The net emissions are calculated by subtracting the future emission levels by the emissions that are offset and the emission reduction by biofuels. These are not actual net emissions of the aviation sector, but overall net emissions as a part of the emissions are offset by emission reductions in other sectors.

Offsetting costs:

Price difference including offsets: By subtracting the costs of offsetting emissions from the price difference between fossil jet fuel and biojet fuel, a comparison can be made between these two extra costs for the aviation sector. The offsetting costs are calculated by multiplying an emission factor of kerosene by the price of offset and multiplied by one minus the emission factor of biofuels.

Additional costs: The additional costs are calculated by dividing the offsetting costs with by the offsetting costs without biofuels. The first is calculated by multiplying the emissions to be offset by the price of offsets and adding this to the costs of biofuels divided by the emission factor of kerosene. The biofuel costs are calculated by multiplying the aviation emissions to the biofuel share and to the price difference between fossil jet fuel and biojet fuel.
The offsetting costs without using biofuels are the emissions to be offset multiplied by the price of offsets.

Offsetting costs including biofuels: This calculation is the same as the calculation of additional cost, however the division by the offsetting costs without biofuels does not take place.

A.4 Scenarios

Scenario 1: Emission factor is zero

In this scenario an additional emission factor is added in the model to calculate the costs in case an emission factor of zero is assumed. In this case, the emissions to be offset and the price difference including offset cost depend on this new emission factor, leading to a decrease in offsetting costs.

Scenario 2: Negative emission factor but increasing to zero

In this scenario the additional emission factor is found at which the price difference including offsetting costs is near zero. This is the negative value of the emission factor needed to provide an incentive for the aviations to use biofuels.

Scenario 3: Higher price of offsets

In this scenario the price of offsets is calculated, such that the price difference including offsetting costs is zero. This is done by dividing the price difference between fossil jet fuel and biojet fuel the emission factor of kerosene and the emission factor of biofuels.

Scenario 4: Constant limit of emissions to be offset

In this scenario the share of biofuels is calculated such that the emissions to be offset are limited by a percentage of the target. This is done by first adding the emissions to be offset to the target and dividing this by the future emission level. Secondly, one minus the result of this first calculation is divided by one minus the emission factor, resulting in the share of biofuels.

Scenario 5: Decreasing limit of emissions to be offset

In this scenario, the same calculations as in Scenario 4 are used.
The difference in the model is that the limit of emissions to be offset are decreasing over time.