Will a quota obligation fly?

- Prospects for introducing a renewable fuel quota obligation on Sweden´s jet fuel market

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Environmental and Energy Systems Studies
Department of Technology and Society
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Flyger en kvotplikt? – Möjligheter för införandet av en förnybar kvotplikt på Sveriges jetbränslemarknad.

Sammandrag

Detta examensarbete har som syfte att undersöka möjligheterna för införandet av en kvotplikt på den svenska jetbränslemarknaden, något som inte tidigare gjorts i en sammanfattande studie. Målet är att utvärdera detta styrmedel från flera olika perspektiv. Fokus läggs på det legala, ekonomin I förnybara bränslen, utformingen av ett kvotsystem och effekten ett sådant system kan ha på den svenska flygsektorn.

Flygbränslets infrastruktur utreds för att bestämma svårigheterna med att använda förnybara bränslen på en stor skala och för att avgöra var bränslet bör introduceras I distributionskedjan. Ett kvotsystem föreslås, med kvoter som stiger från 2% år 2015 till 40% år 2040. Prisprognoser för förnybara bränslen, konventionella bränslen och CO_2-utsläpp samlas från flera studier. Prisinformationen används för att uppskatta den resulterande effekten på biljettpriser till tre olika destinationer från Stockholm. Effekten dessa prisförändringar kan ha på den svenska flygsektorn diskuteras och utvärderas.

Slutsatserna från detta examensarbete är:

- En kvotplikt är troligen förenligt med internationell flyglagstiftning.
- Införandet av förnybart bränsle i distributionskedjan har vissa hinder men dessa bör övervinnas enkelt.
- Konventionellt bränsle kommer förmodligen öka i pris framöver, vilket kommer höja biljettpriser. Användande av förnybart bränsle kommer troligen förstärka denna effekt fram till 2035, när förnybara bränslen förväntas bidra till att minska takten i vilken biljettpriser ökar.
- Biljettpriser under en kvotplikt förväntas öka med mellan 36% och 15% år 2040 jämfört med 2014 års priser.
- Prisökningar kommer troligtvis inte påverka utsträckningen i vilken flygtrafik används men det kan ha effekter på hur flygbolag planerar sina ruttnätverk. Detta kan komma att hämma svensk flygindustri.
- En kvotplikt är troligtvis inte det bästa styrmedlet för att minska den svenska flygsektorns utsläpp. Systemet skulle behöva införas på en större skala för att kunna vara effektivt och ge de önskade effekterna.

Nyckelord

Flyg, kvotplikt, förnybara bränslen, förnybart, biobränsle,

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Abstract

This thesis aims to investigate the prospects for introducing a renewable fuel quota on the Swedish jet fuel market, something which has not been done in a comprehensive study. The objectives are to evaluate this policy measure from several different perspectives. The focus will be the legal aspects, economies of renewable fuels, design of a quota system and the effect a quota obligation could have on the Swedish aviation sector.

The jet fuel infrastructure is examined to determine the difficulty in using renewable fuels on a large scale and where these fuels are optimally introduced into the system. A quota obligation system is designed and proposed, starting with a 2% requirement and gradually increasing to a 40% requirement in 2040. Price projections for renewable fuels, conventional fuels and CO_2 emissions are gathered from various studies. This information is used to estimate the resulting changes in ticket costs for 3 destinations starting from Stockholm. The assumed effect these price developments will have on the Swedish aviation sector are discussed, and possible consequences evaluated.

The findings of this thesis are:

- A quota obligation is likely compatible with international aviation legislation.
- Introducing renewable fuels in the fuel distribution system is associated with some technical difficulties, but these are not significant and should be easy to overcome.
- Conventional aviation fuel costs will most likely increase in price over time, and it is probable that this will have an effect on ticket prices. Renewable aviation fuel will likely exacerbate this cost increase slightly until 2035, from when it is expected to reduce the rate at which ticket prices increase.
- The increase in ticket prices by 2040 compared to 2014 under a quota obligation when using baseline projections is between 36% and 15%.
- While the increases in price are not likely to have a significant effect on the rate at which aviation is used, it may have an effect on the airlines' routes and could cause Swedish airlines to become less competitive.
- A quota obligation is likely not the best measure for reducing the Swedish aviation sector's emissions. The system would need to be introduced on a larger scale to truly be effective and yield the desired effects.

Keywords

Aviation, quota obligation, renewable fuel, renewables, biofuel,

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Preface

This thesis was written as part of the requirements for a Master of Science degree in Environmental Engineering at The Faculty of Engineering at Lund University. The original idea to make this the topic of a thesis was hatched by the Swedish Transport Agency. I would like to make a few acknowledgements before this report is sent off to the printers.

Firstly, I would like to extend a huge thanks to my thesis supervisor at LTH, Lars J. Nilsson, for helping me out along the way and always having great feedback despite the obscurity of the subject. I would also like to thank Max Åhman for giving his feedback during the course of the project. I would like to thank Therése Sjöberg at the Swedish Transport Agency for proposing the idea for a topic and for all the help along the way in terms of networking and feedback, without which this project would have been significantly more difficult.

I would also like to thank my writing companions Anders and Hannes. Despite having their own projects to worry about, they have always had time to discuss and provide input when I've had more question marks than I could wrap my head around.

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Chapter 1. Introduction

The transport sector of today is heavily reliant on the use of fuel from fossil feedstocks. These fuels have been proven to be environmentally detrimental due to their significant contribution to climate change. Alternative fuels produced from renewable feedstocks that are not finite resources are being researched worldwide, but all modes of transportation have not been receiving the same amount of attention. Renewable fuels to be used for road transportation are well established today and have been subsidized through legislative action such as tax breaks. Renewable fuels for aviation have not been stimulated through policy instruments and as a result, have not developed as rapidly as road fuels. Aviation will most likely be dependent on liquid hydrocarbons in the foreseeable future due to the long technical lifetime of aircraft and the stringent technical standards regulating aviation and its fuels. As a potential measure to curb the Swedish aviation sector's emissions the Swedish Transport Agency want to investigate the possibility of introducing a quota obligation for jet fuel. In practice this means that on an annual basis, a certain percentage of the total volume of kerosene jet fuel sold in Sweden would be required to consist of fuel from renewable stock. This thesis will be a scoping study of the effects a quota system could have on the Swedish aviation market. The introduction of such a system has the goal of creating a demand for sustainable aviation fuels despite the initial price penalty. It would serve to motivate investments in the renewable fuel industry as there would be a guaranteed demand for the products. It could also accelerate the technical maturation process of renewable fuels, as money and time would have to be invested to evaluate how they are best produced and utilized. Like any other policy mechanism, the blending requirement can be designed in a number of ways to achieve the desired targets.

1.1 Aim, Method and Scope

This master's thesis aims to map out the opportunities and difficulties associated with introducing a quota obligation for the Swedish Jet A-1 market. The research is focused on answering the following questions:

- Is it possible to introduce a quota obligation in Sweden with regards to international aviation legislation?
- How much do alternative aviation fuels cost to produce today and what are the projected costs once production technologies reach maturity?
- What effect would the introduction of a quota obligation have on airline ticket prices? If there is a change, how might this affect the Swedish aviation market?
- How should a quota system be designed and who would be required to abide by it?
- Where should the alternative fuel be introduced into the distribution network under a potential quota obligation?

In order to answer these questions, information is gathered from various sources. A literature study is performed of relevant academic peer-reviewed papers, journals and reports, reports by stakeholders in the industry, aviation legislation and news reporting. Stakeholders knowledgeable concerning the aviation fuel industry are consulted to further broaden the knowledge base. Technical information about conventional and alternative jet fuel is addressed briefly for the sake of background and terminology. A smaller case study of the Netherlands, where a vaguely similar system has been introduced, is performed. The quota obligation system is also examined from a legal perspective to evaluate its compatibility with international law and bilateral agreements. Current and projected price information is aggregated and used to evaluate what the potential change in price could be. The collected price information is then used to calculate the effect a blending requirement could have on airplane ticket prices.

The main focus of this thesis is evaluating the possibilities of introducing a quota requirement for all Jet A-1 sold in Sweden, regardless of the destination of the purchasing airplane. Introducing a system purely for the Swedish domestic aviation market is also addressed and discussed, as are the possibilities of introducing a similar system on the EU level.

Chapter 2. Background

2.1 Aviation today

Much has changed in the aviation industry since 1903, when the Wright brothers first took flight on the sand dunes of North Carolina. Air transport today is being utilized by a considerable amount of people. The UN's specialized agency on aviation, the International Civil Aviation Organization, or ICAO, estimates that 2.9 billion passengers used aviation during 2012 (ICAO, 2012) and this number does not seem likely to decrease. Forecasts published by the ICAO's environmental branch Committee on Aviation Environmental Protection, or CAEP, suggest that the combined freight and passenger traffic will increase by anywhere from 356% to 610% between 2010 and 2050 in terms of RTKs[1] (ICAO, 2013c). This projected increase in traffic will most likely bring with it positive effects in terms of increased cultural and economic exchange and a more accessible world, but will also cause increased strain on the environment. Today's aviation sector is powered solely by liquid hydrocarbons, of which the vast majority comes from fossil sources. The adverse effects associated with combustion of petroleum products are well documented and will not be discussed in depth in this report. One factor slightly differentiating aviation from conventional consumption of petroleum products is the altitude at which the resulting pollutants are emitted. In some cases this can decrease environmental impacts from pollutants and in other cases exacerbate them (IPCC, 1999). In general the problems are of the same kind, with the main problem being climate change. Emissions of CO_2 caused by aviation accounts for roughly 2% of global anthropogenic emissions of CO_2 today, but this share is likely to increase significantly over the next few decades, given the projected increase in air traffic (ICAO, 2013c). The emissions caused by aviation in Sweden made up about 5% of total GHG emissions, of which 82% consisted of international aviation and 18% domestic (Trafikverket, 2014).

2.2 Environmental targets and regulation for aviation

Further, there is currently no global system in place restricting the carbon emissions from aviation. With its basis in a multilateral agreement made in the ICAO, the 1944 Chicago Convention, aviation fuel used for international travel today is generally exempt from taxation (ICAO, 2006). The effect of this exemption is that the international aviation industry of today can consider its contribution to environmental degradation an external cost. Several paths have been proposed as a way of internalizing these costs, as well as reaching the environmental targets for aviation set out by the European Union and the ICAO. The environmental targets and aspirations set out by the ICAO are the following:

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[1] Revenue Tonne-Kilometer, a metric used in the aviation industry to describe traffic production

- A global annual fuel efficiency improvement of 2% annually until 2020. This target has been formally acknowledged by ICAO and aspirations are to continue this development from 2021 until 2050. This is calculated on the basis of volume fuel used per RTK (ICAO, 2013a).
- Aspirational goal of carbon neutral growth from 2020. The total annual amount of emissions related to aviation should not rise above the emissions in year 2020 (ICAO, 2013c).

The aviation industry also has environmental goals outside of the ones set by ICAO. It is an aspirational goal which is not legally binding, it is set by IATA[2] and ATAG[3] reads as follows:

- Reduce the total carbon emissions for year 2050 to 50% of the total 2005 carbon emissions (ICAO, 2013c).

The EU's targets specifically pertaining to aviation are the following:

- Low-carbon sustainable fuels in aviation to reach 40% by 2050 (European Commission, 2013).
- 2 million tons of sustainable biofuels to be used in aviation by 2020, roughly 1% of the estimated total world consumption (European Commission, 2013) (Ecofys, 2013)
- 75% reduction in CO_2 emissions per passenger kilometer by 2050, relative to typical new aircrafts in 2000 (European Commission, 2011a)
- In the EU-ETS[4], aviation's emission cap during 2012 for covered flights was 97% of the baseline. The baseline was the mean average annual emissions for 2004, 2005 and 2006. During 2013-2020, the annual emission cap will be set at 95% of the baseline emissions, as stated in Directive 2008/101/EC of the European Parliament and Commission Decision 2011/149/EU.

The most discussed option for internalizing the environmental costs for aviation is an MBM[5], such as a cap-and-trade or offsetting system. The aim is to introduce a cost related to emitting GHGs[6], while at the same time incentivizing companies to reduce emissions. The EU implemented a system in 2012 in which aviation was to be included. This was met by fierce resistance from countries outside of the EU (Transportstyrelsen, 2013). In this system, an aviation operator would have been required to turn in emission allowances for the entirety of a flight to and from Europe, regardless of how much of the flight took place within the airspace of countries participating in the EU-ETS. The opposing countries' assertion was that the EU violated the Chicago Convention and did not have the authority to demand compensation for activities not taking place in the EU's airspace. To avoid a trade war that would have been detrimental to all involved parties, the EU in 2012 decided to temporarily suspend the inclusion for flights departing for, or arriving from destinations outside of the area covered by the EU-ETS. This decision is more commonly known as the "stop-the-clock" decision. Flights performed within or between the countries participating in the EU-ETS were still scheduled to be covered however, and allowances would have to be turned in at the end of each accounting period. The original decision to suspend aviation's inclusion in the EU-ETS was not solely based on foreign countries opposition towards it. Talks had been ongoing in the ICAO for a long time regarding the creation of a global system for dealing with the aviation sectors' emissions. The slow progress of

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[2] International Air Transport Association

[3] Air Transport Action Group

[4] European Union Emission Trading Scheme

[5] Market-based measure

[6] Greenhouse gas

these discussions was the catalyst motivating the EU to create a system of its own. Discussions in the ICAO then made a breakthrough at its 38th Assembly in October 2013, when the ICAO decided on developing a global MBM.

The specifics of the system have not yet been finalized but are to be decided upon in 2016. The plan is then for it to be ready for implementation in 2020 (ICAO, 2013d). The EU's decision to suspend participation in the EU-ETS for non-participating countries was meant to last for one year (starting April 24th 2013). If no progress had been made towards a global MBM when the year was over, the plan was to revert the derogation and once again include the full scope of arriving and departing flights. As the deadline of the derogation drew closer, it appeared fairly certain that the original proposal of requiring aviation operators to obtain allowances for the entirety of flights would not be reinstated in 2014. In one proposal by the European Commission, operators would have been required to purchase allowances for the portions of flights taking place in the airspace of countries and territories participating in the EU-ETS. This proposal was also met with some resistance within the EU. Major actors such as the UK, France and Germany opposed this plan, arguing that efforts should be focused on the negotiations taking place in the ICAO instead of desperately trying to force a system in place. These parties wanted the present stop-the-clock system to continue on until a global MBM has been decided upon (Flynn, 2013). This proposal is what the European Parliament finally decided on. On April 3rd of 2014 the European Parliament decided to exempt all flights arriving from or departing for destinations outside of the scope of the EU-ETS. Only flights between member countries of the EU-ETS will be covered (GreenAir Online, 2014).

The development of a global MBM is not the only plan the ICAO has to reduce aviation's environmental impact. A market-based solution will be one part of the so-called "basket of measures" which presents several different approaches to the problem. The most likely alternative to introducing a cap-and-trade system is a "mandatory offsetting scheme". With this type of system, the emissions from the year 2020 would be treated as the baseline in order to achieve the target of carbon neutral growth after 2020. In the years following 2020, the annual emission cap would be equal to the baseline year. Entities on the market would be required to purchase emission offsets for units of emissions exceeding the cap. These offsets can be constructed in a variety of ways. Biofuels or purchasing emission allowances or units could be two potential means of acquiring the required offsets. The specifics of the system and how much the obliged parties would be required to offset through purchases of compensation instruments have, however, not been decided upon yet (Carbon Market Watch, 2013). Other proposed means of tackling the emission problems are developing CO_2 emissions standards for aircraft, technological innovation, operational improvements and also, the main focus of this thesis, substituting fossil-based fuels for renewable fuels. Technology goals such as emission standards can help with providing concrete goals for manufacturers of aircraft equipment. Operational improvements can consist of several different things, from altering air traffic management and routing, to how aircraft are handled and powered while on the ground at airports. None of these measures will be the sole solution. Their contributions are all required in order to reach the ambitious goals set out by the ICAO. Some methods are mature enough to be implemented within a short timespan while others will require more time to be viable. As can be seen in Figure 1, there is a gap between the projected "no action" scenario and the 50% reduction target for 2050. The graph is a general representation of the different measures' contribution to achieving the ICAO's goals and does not present absolute numbers. It does however present approximate timeframes for when the different measures are expected to make an impact.

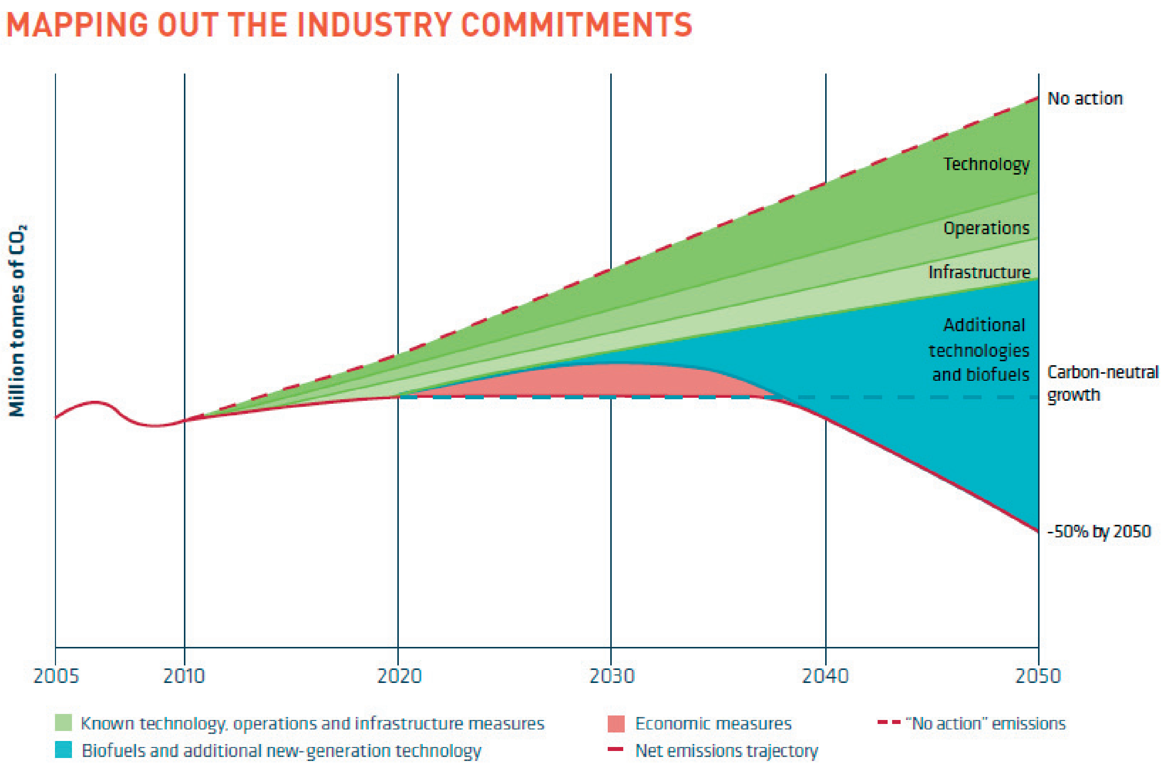

Figure 1. Schematic depiction of projected CO_2 emissions from 2005 to 2050 (ICAO, 2013b)

2.3 Renewable fuel use today

Experiments with biofuels for aviation are ongoing today, but they are not yet being produced at scale. Commercial production does exist in some locations around the world, primarily from vegetable oils and animal fats. Compared to the EU's consumption of 47 million tonnes of aviation kerosene during 2012 and the global consumption of 200 million tonnes, the renewable portion so far is miniscule (Eurostat, 2014a). Given the projected increase in traffic, the EU's *Flight path* project's target of 2 million tonnes of biofuel by 2020 might not make a significant difference for total fuel consumption (European Commission, 2013). 2 million tonnes would account for roughly 4% of the EU's total consumption today and 1% of the global consumption. Given the projected increase in traffic, it will likely be less than that in 2020. A few companies, such as Lufthansa, KLM and Alaska Airlines have performed flights with biofuels, but only on a promotional scale (European Commission, 2013). No airline has so far started using renewable fuels throughout its entire fleet. There are several organizations and initiatives aimed at promoting production and use of biofuels specifically for aviation. Some of the most notable are the North American initiative CAAFI[7] and also the two European initiatives Biofuels FlightPath and ITAKA[8]. These three initiatives are multi-stakeholder organizations engaging legislators, airlines, producers of aircraft and biofuels as well as airports. In addition to these large initiatives, there are several other similar projects going on across the world with a more regional focus. One example is the initiative NISA[9], composed of stakeholders in the Nordic countries. These organizations' aim is generally networking, for example bringing producers

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[7] Commercial Aviation Alternative Fuels Initiative

[8] Initiative Towards sustAinable Kerosene for Aviation

[9] Nordic Initiative for Sustainable Aviation

and users of fuel together. They do not actually produce fuel themselves, but they aim to facilitate the use of it.

2.4 Quota obligation

As previously mentioned, the Swedish Transport Agency and the Swedish Energy Agency are investigating the prospects of introducing a quota obligation for aviation. It would be one way of addressing the growing emissions from the environmentally unregulated aviation sector. It could however prove to be a significant obstacle for an already cash-strapped industry struggling with profitability (IATA, 2013a). This argument alone may not be sufficient reasoning to continue the lack of environmental regulation within aviation however. There are currently no active subsidies for use of aviation biofuels in Sweden, but the lack of taxation on conventional jet fuel is a subsidy in itself. Part of the regulation deficiency stems from the perceived difficulties associated with introducing legislation in an industry governed by international bilateral agreements and with an inherently international business model. This complicates the process and makes it more difficult than for industries only active domestically, but it does not make it impossible. The EU and its constituent countries have in Directive 2004/35/EC declared that the PPP, or Polluter Pays Principle, is to be applied within the EU. This is currently not fully the case for international aviation.

Fuel prices would likely increase slightly due to alternative fuels costing more to produce than conventional petroleum based fuel (IATA, 2013b). Many airlines are today imposing extra surcharges on their passengers for fuel, and have been doing so for several years. The purpose of these surcharges is to keep them up to date according to current fuel prices, while keeping base fares the same. This allows airlines to rapidly adapt the ticket prices without having to alter the basis of their revenue management systems. For the past ten years, the surcharges have generally been climbing upwards due to increasing fuel prices (IATA, 2013a). With this in mind, should a quota obligation be introduced, it would likely be covered to a large extent by these fees paid by the passengers. A positive aspect of a quota obligation is that it would impact all actors on the market consuming Jet A-1 equally. There would be no competitive distortion for airlines flying routes originating in Sweden. Besides boosting the alternative fuels industry, it would also provide an indirect incentive to reduce fuel consumption, due to an increase in price. As some parts of the world is putting a price on CO_2 emissions, fuels with lower life cycle emissions of GHG could also be at an advantage from this perspective. Optimally, the price of carbon emissions under the EU-ETS and the proposed ICAO MBM will be high enough for fossil fuels to eventually be more expensive than renewable fuels. Due to this, the price of CO_2 will likely play a part in the viability of renewable fuels.

Chapter 3. Conventional aviation fuel today

Today's aviation industry uses liquid hydrocarbons produced from fossil fuels almost exclusively. This chapter briefly describes the type of fuels used within commercial aviation, both in Sweden and other parts of the world. The fuels do not vary significantly, but slight regional differences exist.

3.1 Jet A-1

Jet A-1 is the most commonly used fuel for civil aviation at present. It is petroleum-based and produced through conventional refining of oil. It consists of a spectrum of hydrocarbons, approximately ranging between 8 -16 carbon molecules (Chevron, 2006). Jet A-1 is predominant in most of the world, with the exception of the United States where a similar product, Jet A, is used. There are small differences between the two, with the main difference being a slightly lower freezing point of -47^{o}C for Jet A-1, compared to -40^{o}C for Jet A (Chevron, 2006).

The requirements for what can be labeled Jet A-1 are very stringent and are governed by specific standards. The two main specifications Jet A-1 must meet are:

- ASTM D1655 – Standard specification for aviation turbine fuels, from ASTM International (formerly American Society for Testing and Materials)
- Defence Standard 91-91, from the UK Ministry of Defence

These standards specify various chemical and physical characteristics a substance must possess to function properly as aviation fuel. Examples of limitations are freezing and boiling points, energy density, thermal stability and lubricity (IATA, 2012). The main reason for these strict guidelines is the safety aspect. Airplane engines need to function properly in extreme conditions, namely high altitudes and cold conditions. If engine failures occur, it can have disastrous consequences due to the exposed situation airplanes are in. Performing emergency landings without operational engines is associated with great difficulties and hazards.

Most of the Jet A-1 used today is produced from conventional sources of crude oil (Liu, Yan, & Chen, 2013). A small fraction also has its origin in unconventional sources of petroleum such as oil sands, VHO[10] and oil shale resources. These unconventional petroleum sources are likely to be used more extensively in the future as conventional resources become scarcer. They are not yet fully mature from a jet fuel perspective. Worth noting is the 10-50% higher life cycle GHG emissions associated with fuels produced from unconventional sources (Stratton, Wong, & Hileman, 2010). This increase stems exclusively from the more complicated and energy consuming extraction processes of the raw petroleum products. The final products will produce emissions identical to those from conventional crude oil if only examining the actual combustion phase.

3.2 Other types of jet fuel

Besides Jet A and Jet A-1, there are a number of fuels that are also used for aviation. They are all based on fossil fuels and many of them are similar to Jet A-1.

In some cold parts of the world Jet B is used. Jet B is called a "wide-cut" type, meaning that a greater interval of carbon molecules is used than in Jet A-1 (Shell, 2014b). This provides enhanced cold

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[10] Very Heavy Oil

weather performance, but at the price of more difficult handling due to increased volatility. Jet B is used in parts of Canada and Alaska.

In Russia and the countries of the CIS[11], the most commonly available jet fuel is TS-1 (Shell, 2014b). It has a higher volatility and lower freeze point in comparison with Jet A-1. It is widely accepted by aircraft manufacturers as compatible with Jet A-1.

JP-8 is a military fuel grade that is nearly identical to Jet A-1 (NATO, 2012). Jet A-1 can be converted to JP-8 if a few fuel additives are mixed in. It is not used exclusively for aviation, but can be used as propellant for several types of vehicles (US Army TARDEC, 2011). The US Army and Air Force uses JP-8 as its single fuel for all vehicles, in order to simplify logistics.

3.3 Other types of aviation fuels

Aircraft that use piston engines instead of turbine engines use other types of fuels. AVGAS, or aviation gasoline, is used by smaller aircraft than those used within commercial aviation. This fuel is typically used for activities such as flight training, flying clubs and crop spraying. This fuel is more similar to conventional gasoline than the turbine fuel, but it has higher performance requirements. Unlike most fuels available today, these fuels generally contain some amount of lead to increase octane numbers (Shell, 2014a). The total consumption of AVGAS is however insignificant when compared to jet fuels and will therefore not be considered further in this report.

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[11] Commonwealth of Independent States

Chapter 4. Alternative jet fuel

4.1 Alternative jet fuel today

Although not common, aviation fuel is also being produced in processes not using petroleum as feedstock. Fuel produced from alternative sources need to have the qualities of a drop-in fuel to be used in aviation, both today and within the foreseeable future. A drop-in fuel is fully compatible with the current mainstream fuel and they should be completely intermixable with no modifications needed for the engine to run properly. In the specific case of aviation, an alternative fuel needs to comply with the specifications of Jet A-1. Other fuel types might be possible in the future, but not at the present time. The long lifespan of airframes makes a transition to a different type of fuel nearly impossible (Karyd, 2013). In his report Karyd brings forward the argument that aircraft models first introduced 50 years ago are still being produced, albeit in slightly modified versions. If the same will be true for the models introduced today they will remain in production until around 2060 and then remain in traffic until 2090. While retrofitting old airframes with newer engines is possible, it is rarely done. The engine configuration an airplane is delivered with will in most cases remain during the lifespan. Today’s commercial aviation fleet is equipped to use Jet A-1 or one of the very similar fuels discussed in Chapter 3. Introducing fuels differing from Jet A-1 would require the introduction of new airframes and within the next 40-50 years, this appears unlikely.

To ensure that an alternative fuel is fully compatible with conventional fuel there is a thorough testing process in place. To guarantee compatibility with Jet A-1, the two main certifications are the following:

- ASTM D7566 – Standard specification for aviation turbine fuel containing synthesized hydrocarbons.
- ASTM D4054 – Standard practice for qualification and approval of new aviation turbine fuels and fuel additives.

The ASTM D7566 certification specifies the performance standards alternative fuels must meet to be eligible for use in commercial aviation (ASTM, 2011). ASTM D4054 on the other hand specifies the actual tests the fuel needs to be put through and is meant to guide the sponsor of a new fuel through the approval process (IATA, 2013b).

At present, two production technologies have been approved as being in accordance with ASTM D7566. These two routes are the Fischer-Tropsch synthesis and the Hydroprocessed Esters and Fatty Acids-method, both of which will be described in more detail in subchapters 4.1.1 and 4.1.2, respectively. ASTM D7566 further states that no more than 50% of a fuel may be synthetically derived. The remaining 50% (or more) needs to consist of conventional Jet A-1 or Jet A. Part of the reason for this maximum limit of mixing is the lack of aromatic compounds in many synthetically derived fuels. This deficiency can cause leaks in some fuel systems and is one of the reasons that synthetic fuels need to be blended with petroleum based fuel to be certified according to ASTM D7566 (Liu, Yan, & Chen, 2013). Once an alternative fuel has fulfilled all requirements of ASTM D7566 and has been mixed with Jet A-1 to proportions not exceeding 50% synthetic fuel, it is to be considered a ASTM D1655 fuel. This simplifies use of the fuel and it guarantees that the integration in the distribution network will be seamless.

4.1.1 Fischer-Tropsch synthetic fuel (FT)

The Fischer-Tropsch process is at present the most established technology worldwide for producing synthetic aviation fuel, or FT SPK[12] (IATA, 2013b). It was approved according to ASTM D7566 in 2009, but it had been used in South Africa for some time before that. In the process, a substrate containing carbon is gasified to produce synthesis gas, meaning carbon monoxide and hydrogen gas. From this synthesis gas, liquid hydrocarbons can then be synthesized. The process was originally developed with coal in mind, but biomass and organic waste are being looked at as potential substrates to reduce environmental impacts (Maitlis & de Klerk, 2013). It could also be used in conjunction with production of so called electrofuels, which use cheap electricity to hydrolyze water to create hydrogen gas. As of now there is no operational plant using biomass in the FT process, but research projects are ongoing. The facilities producing FT SPK today are either using coal or natural gas as feedstock and production rates are increasing (European Commission, 2013). One factor differentiating FT SPK from conventional Jet A-1 is the lack of aromatic compounds in the fuel. FT production with integrated synthesis of aromatics has not yet been certified, but research is ongoing. If this method of production is approved it could permit use of neat synthetic fuels and eliminate the need for a 50% blend requirement (IATA, 2013b). This remains to be demonstrated in practice.

Depending on the type of feedstock material being utilized and the accounting method used, the life cycle greenhouse emissions can differ greatly. If coal is used, the total emissions will often be larger than for conventional petroleum-based fuels due to the gasification process requiring energy and the higher carbon-to-energy content in coal compared to oil. The increase in GHG emissions when using coal is estimated to be between 10 and 120%, depending on if CCS[13] is being utilized or not. Natural gas is generally more benign than coal, but still boasts a life cycle emission increase of roughly 15% over conventional fuel. If on the other hand biomass is used, the result is often a reduction of life cycle emissions, in some cases by as much as 100% given specific types of land uses and feedstocks (Stratton, Wong, & Hileman, 2010).

4.1.2 Hydroprocessed Esters and Fatty Acids (HEFA)

Hydroprocessed esters and fatty acids, also known as HEFA or HRJ[14], is the second method of producing alternative jet fuel that has been approved for use in aviation according to ASTM D7566. It is today the only renewable fuel used in commercial aviation. The FT process is more developed in terms of production capacity but only when using fossil feedstock such as coal or natural gas. The HEFA method of producing aviation fuel can utilize a wide variety of substrates in the process. The common denominator is that all of the substrates are based on triglycerides and fatty acids, for example vegetable oils, animal fats or certain types of oil-producing algae. Vegetable oils and animal fats are already being processed into aviation fuel on a commercial scale while algal oils are expected to reach commercial viability within 5-8 years (European Commission, 2013).

As is the case with FT, the environmental impact from HEFA fuels differs depending on feedstock and land use changes resulting from the cultivation. The most benign process, according to Stratton, Wong and Hileman, uses oil from Salicornia, a shrub capable of growing in saline environments. Its impact in terms of GHG emissions is estimated at around a 90% decrease compared to conventional petroleum production. On the other end of the spectrum is palm oil, which if grown on certain types

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[12] Fischer-Tropsch Synthetic Paraffinic Kerosene
[13] Carbon Capture and Storage
[14] Hydroprocessed Renewable Jet

of lands can yield a drastic 700% increase in life cycle GHG emissions compared to the baseline fuel (Stratton, Wong, & Hileman, 2010). These estimates are a strong indicator that not all biofuels are on equal footing and great care needs to be taken in the procurement phase of feedstocks. The sole fact that a particular feedstock is renewable may not be sufficient proof that the resulting fuel will also be sustainable.

4.2 Future potential production methods

Besides the already certified methods of producing aviation fuel there are several production paths currently going through the ASTM D7566 approval process. This chapter will briefly mention the most prominent of these technologies.

4.2.1 Alcohol-To-Jet (ATJ)

Alcohol-to-jet is generally assumed to be the next process that will be approved by ASTM D7566. Several companies are currently working with this production path, and it is expected to achieve its certification in 2014. Several different substrates can be used, sugar is however the most prevalent at present. Using carbon monoxide from steel mills and industry off gases is also being researched and could provide another interesting feedstock. The raw material is fermented into ethanol or butanol which is then dehydrated into olefins. The olefins are then synthesized into molecules similar to conventional fuels that can be used as jet fuel (IATA, 2013b).

4.2.2 Direct Sugar to Hydrocarbons (DSHC)

The DSHC process is similar to the ATJ process in that it relies upon conversion of sugars to produce hydrocarbons. In the DSHC process, the sugar is synthesized directly into hydrocarbons by genetically modified microorganisms. The process is engineered so that the resulting hydrocarbons shall require little upgrading to be usable as fuels. It does however produce a very narrow spectrum of molecules unlike the mixture that Jet A-1 is composed of. Due to this it will most likely require blending with conventional jet fuel to be passable for use under ASTM D7566 (Biddy, Davia, Jones, Tan, & Tao, 2013).

4.2.3 Pyrolysis-to-jet (PTJ)

In the pyrolysis process, biomass is the main source of raw material. The biomass is heated in the absence of oxygen which yields pyrolysis oil. This so called “bio-crude” contains a wide variety of molecules which needs to be processed and refined, similar to conventional crude oil. Since the bi-crude consists of hydrocarbons, it can also be used as a feedstock material for the FT-process mentioned earlier. Once refined, it can be suitable for use in aviation. Pyrolysis oils are however primarily composed of aromatics, of which there is a both a minimum and a maximum limit in ASTM D1655. PTJ fuels are therefore not suitable for being mixed with conventional Jet A-1 as the aromatics limit could be exceeded, but rather with FT SPK with little to no aromatic content (Elgowainy, et al., 2012).

Chapter 5. Case study – The Netherlands

Sweden is currently in the process of introducing a quota obligation system for road based transports. The introduction would require a certain percentage of fuel sold for use in road vehicles to be produced from renewable sources. Similar systems exist in several countries around the world. The EU's RED[15] stipulates that 10% of the energy used in the transport sector shall come from renewable sources by 2020. In Directive 2009/28/EC it is stated that the focus is on road and rail transport, aviation is not included in the reduction targets. The total energy consumption and the renewable portion is calculated according to the formula in Figure 2.

$$10\% = \frac{\textit{All}\text{ Renewable Energy in }\textit{all}\text{ forms of transport}}{\text{Petrol, diesel, }\underbrace{\text{biofuels,}}_{\text{In road and rail transport}}\;\underbrace{\text{electricity}}_{\text{In all transport}}}$$

Figure 2. Formula for counting the share of renewable energy used in transport according to Directive 2009/28/EC (Hamelinck, Cuijpers, Spoettle, & van den Bos, 2013).

Most countries have not explicitly provided for aviation biofuels to be eligible for counting. An exception to this is The Netherlands, who have stated that renewable fuels used within air transport can be included in the total pool of renewable energy used in transport (Hamelinck, Cuijpers, Spoettle, & van den Bos, 2013). The introduction of such a system is unprecedented, but no requirement is placed on the actual aviation fuel used to have a 10% renewable content by 2020. It only means that the renewable fuel used in aviation is allowed to be included in the total use of renewables.

Companies providing road fuel to the Dutch market, either by producing it or importing it, will be obliged to create an account in a register managed by the authorities. In this system, obliged parties will be required to register fuel placed on the market, as well as a specific percentage of renewables based on the quantity of aforementioned fuels. If a party exceeds its targets of renewables, it may sell the surplus of renewable fuel credits to other actors on the market as a "bio-ticket". This allows for companies with difficulties attaining or producing sufficient amounts of renewable fuel to still achieve the total target of 10% by 2020. When counting the percentages, the aggregate sum of renewable fuel must equal or exceed the annual target. Fuels produced from waste, residues, non-food cellulose material and ligno-cellulose material for which there is no alternative use or market are also available for double counting. In addition to this, gasoline and diesel are subject to an additional requirement requiring their individual minimum amount of biofuel content to be 3.5%. Hypothetically, should a new production route for renewable diesel make it economically viable to fill the entire annual quota purely with diesel, gasoline would still be required to contain 3.5% biofuel. The jet fuel sold is not be required to contain any renewable component. Should however sustainable fuel be mixed in, it will grant bio-tickets which can then be sold to an obliged party (Hamelinck, Cuijpers, Spoettle, & van den Bos, 2013).

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[15] Renewable Energy Directive

The introduction of this system is a statement in recognizing aviation's potential contribution to lowering total emissions. It can serve to motivate fuel producers to not only focus on renewable fuels for land transport, but also aviation fuels. Due to the differences in technological maturity for production of road fuel and jet fuel, as well as aviation fuel not having a minimum limit of renewable content, it will be difficult to predict the contribution of renewable aviation fuel to the goal of 10%. The Netherlands' aviation sector is Europe's 6th largest, consuming roughly 3.4 million tonnes of jet fuel in 2012 (Eurostat, 2014a). In comparison, the Netherlands' consumption of gasoline in transportation was about 3.9 million tonnes during the same period (Eurostat, 2014a). No production of renewable aviation fuel is currently taking place in the Netherlands, but the Dutch company SkyNRG in collaboration with, among others, the Finnish oil company Neste Oil are investigating the prospects of starting up production in Rotterdam. Neste owns a biorefinery capable of producing aviation fuel that is currently used exclusively to produce fuel for road vehicles. According to Neste, the refinery's production capacity is 800000 tonnes annually (Neste Oil, 2013). The production rate of aviation fuel stands in contrast to the Netherlands' production of biodiesel which reached roughly 1.2 million tonnes during 2012 (Eurostat, 2014b). There is currently a significant difference in technological maturity which brings with it a discrepancy in cost competitiveness when compared to road fuels (Ecofys, 2013). As companies operate to create profits for their owners, they will most likely want to fulfill their obligation of renewable fuel with the most economically viable option, which at present is not renewable aviation fuel. This does not mean alternative aviation fuels will never be a viable option. The costs associated with small scale production and distribution will likely be reduced if production is scaled up.

The Netherlands are well positioned to pioneer the commercial use of biofuels. They are already one of the key logistic hubs in the trade of jet fuel. The ports of Rotterdam and Amsterdam are very important in terms of jet fuel logistics in Europe. They supply three of Europe's four largest airports with fuel through the use of pipelines. Should production in Rotterdam become a reality, the produced fuel could easily be exported to these locations. The company SkyNRG is based in the Netherlands and is currently the world's leading trader in renewable aviation fuel. So far, they have sourced their jet fuel from production facilities in the US. Once delivered to the location where it is to be used, it has been put in trucks used specifically for renewable fuel and has never entered the conventional fuel infrastructure. This system works when dealing with small amounts of fuel for a select number of flights, but to introduce renewable aviation fuels on a larger scale would require a more sophisticated approach (Hamelinck, Cuijpers, Spoettle, & van den Bos, 2013). The Netherlands have the necessary infrastructure in place to be able to utilize renewable aviation fuels more extensively. They also have some political ambition to promote the use of alternative aviation fuels.

The fact that the Netherlands is the only country in the EU to explicitly allow for the counting of aviation biofuels toward the total target describes well the lack of political support. This lack of interest will likely make it more difficult for aviation to get access to affordable raw materials for renewable fuel production. It remains to be seen to what extent aviation biofuels will contribute to the Netherlands 10% share of renewable fuel in transportation.

Chapter 6. Introducing a quota obligation in Sweden

For a quota obligation on jet fuel to be possible, there are a number of questions that need to be answered. This chapter will address the most important issues associated with introducing this specific policy instrument.

6.1 Motivation for a quota obligation

There are several reasons for the possible introduction of a policy instrument for aviation. As of today, there is no economic penalty tied to aviation's contribution to climate change. Generally speaking, introducing a mechanism aiming to regulate international aviation is difficult. One of the main advantages of using a quota obligation is that it does not appear to be prohibited by international, bilateral treaties. This reasoning will be expanded upon in chapter 6.2. Another reason for using this as a mechanism is that the legislators generally know exactly how effective the measure will be. In the case of quota obligations, the threshold for how much renewable content fuel is required to contain is set beforehand. It is then up to the obliged parties to reach these goals in the most cost-effective way they prefer. If the penalties for not reaching the set quota are sufficiently high, the parties affected by the obligation will have no choice but to comply.

The most commonly proposed alternative measure is taxation of aviation fuel. If the legal obstacles with taxation are disregarded, problems with the effectiveness still remain. Determining beforehand how big the willingness to pay for certain goods and services is can be difficult to predict accurately. If a taxation rate is set at a level that is too low, the taxes may not cover the abatement costs. Setting a tax rate too high does not have any adverse environmental effects, but it might burden society in other ways, for example in terms of financial prosperity.

Economic aspects are often hampering renewable energy, so also in the case of alternative aviation fuels. If renewable fuel was economically competitive and widely available, no policy instrument would be needed to encourage its use. Due to the technical problems associated with switching to a type of fuel that is not interchangeable with the current fossil based varieties, alternative fuels are absolutely necessary to tackle aviation's environmental impact. The difficulties alternative fuels face lie partly in the increased cost for the end users, but also in the investments needed to scale up production. Investors do not back projects pro bono, they lend money to be able to get a return on their investment. If there does not appear to be a market for the product, prospects are most likely grim for that type of production. This is currently the case for aviation. As renewable aviation fuels today cannot be considered more than a novelty act due to its low market penetration, money is not being invested to a sector that has not proven to pay dividends.

A quota obligation serves the purpose of creating a market despite the renewable fuel not being economically competitive when compared to conventional fuel. As the obliged parties will be required to reach a certain percentage of renewable content, they will need to either purchase fuel from others or invest in their own production capacity. This can help new production methods crossing the "Valley of Death". In the field of renewable energy, this is one of the main obstacles new technologies face on their road to commercialization. Once a technology has been developed and proven to be conceptually sound in demonstrative projects, it needs to exhibit functionality on an commercial scale. The scaling up of production often requires significant investments, especially in the case of fuel production due to the technology requirements and complexity of refineries (Bloomberg New Energy Finance, 2010; International Council on Clean Transportation, 2013). This is where many renewable aviation fuel production methods are today. They have been proven to function as a substitute for, or complement to Jet A-1, and have been, or are soon to be certified according to ASTM D7566. These certifications and technical approvals say nothing about their commercial viability however. Very few plants producing renewable aviation fuels are however doing so on a commercial scale today. Many are standing on the threshold of the "Valley of Death", looking for the necessary funds for making the transition from a promising technology to a commercially viable option. Should a quota obligation be introduced, it may ease some of the concerns potential investors may have about renewable aviation fuel's prospects.

Potential problems exist for blending requirements however. When filling the quota, obliged parties will most likely want to do so in the most cost effective way possible. Unless more detailed requirements are specified, a quota obligation may only benefit the most mature technology (the most economically beneficial). Problems can arise if the most mature technology is not the most environmentally benign. In the case of aviation, this is not necessarily a big problem. There is currently no renewable jet fuel production route that has reached widespread commercial viability. The blending requirements can be constructed to address this problem by specifying "sub-quotas" to the total quota. These sub-quotas may specify volumes or percentages required to be produced from certain types of feedstock. This has been done in the US Renewable Fuel Standard Program where it is required for obliged parties to utilize renewable fuels in specific proportions. Of these renewable fuels, certain sub-quotas are required to be produced from for example cellulosic and biomass feedstocks. By doing this, more than one kind of production method can be stimulated and encouraged in order for diversifying the technical development. Another option for encouraging production of specific types of renewable fuels is allowing fuels from specific feedstocks to be double counted towards the target. In practice, this means that if one MJ of fuel produced from the specific feedstock is made available on the market, it counts as two MJ when calculating the totals at the end of the accounting year. By doing this, producers have the option of producing fuels with technologies that may not be as financially beneficial as others per actual volumetric unit but still viable when taking this added benefit into account.

Quota obligations for gasoline and diesel fuel are already being suggested in Sweden, with the proposed system originally scheduled to become active in 2014. The introduction has been postponed, but has not been taken off the table yet. Sweden's government motivated their decision to introduce a quota obligation on fuels for road use by stating their ambition to reduce dependence on energy from fossil sources, and to fulfill Sweden's political goals regarding climate and energy. The same statement could be applied to aviation fuel. Since the Swedish government appears to be interested in pushing for renewable fuel use, aviation should not be exempted.

6.2 Legal feasibility

Before trying to assess the technical feasibility of introducing a quota obligation, the legal aspect must be examined. Several ICAO conventions and resolutions govern international aviation. If these documents can be interpreted as prohibiting the introduction of a quota obligation, it could prove very difficult to introduce such a system. In accordance with these conventions and resolutions, aviation fuel sold for use within international aviation is exempt from taxation. If the introduction of a quota obligation, and the probable price increase it will bring, in any way can be looked at as a tax the proposal will most likely be impossible to use in practice. The governing documents must therefore be examined to ensure compliance with these international policy guidelines. Civil aviation is governed mainly by the ICAO’s master document, the Chicago Convention, established in 1944. The Convention generally addresses rules for flying and landing in other nation’s airspace and aerodromes, but there is also an article pertaining to taxation and fees. Article 24 of the Chicago Convention is titled *Customs duty* and reads as follows:

> *a) Aircraft on a flight to, from, or across the territory of another contracting State shall be admitted temporarily free of duty, subject to the customs regulations of the State. Fuel, lubricating oils, spare parts, regular equipment and aircraft stores on board an 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. This exemption shall not apply to any quantities or articles unloaded, except in accordance with the customs regulations of the State, which may require that they shall be kept under customs supervision.*

As can be seen, the first section of article 24 states that the supplies onboard an aircraft landing in a foreign territory shall be exempt from any fees as long as they are brought along when the plane leaves. Taxes cannot be levied on goods that are not imported by the aircraft in question. What this means for fuel is that the remaining fuel in the airplanes tanks cannot become a subject for taxation. The continuation of Article 24 reads as follows:

> *b) Spare parts and equipment imported into the territory of a contracting State for incorporation in or use on an aircraft of another contracting State engaged in international air navigation shall be admitted free of customs duty, subject to compliance with the regulations of the State concerned, which may provide that the articles shall be kept under customs supervision and control.*

The second section states that spare parts and equipment imported into a country for use within international aviation on an aircraft from another state shall be exempt from customs duties. It does not mention the import or sales of fuel; it is a common misconception that the Chicago Convention prohibits taxes from being levied on aviation fuel. There are however other ICAO resolutions providing policy guidelines on the topic of taxation. For this application, the main document is the ICAO’s Document 8632, or *ICAO’s policies on taxation in the field of international air transport*. The Chicago Convention exempts fuel already stored in an airplane’s tanks when making a landing in a foreign territory. In Document 8632 this exemption is expanded, making all fuel sold for use within international aviation exempt. The document reads as follows:

> *a) when an aircraft registered in one Contracting State, or leased or chartered by an operator of that State, is engaged in international air transport to, from or through a customs territory of another Contracting State its fuel, lubricants and other consumable technical supplies shall be exempt from customs or other duties on a reciprocal basis, or alternatively, in the cases of fuel, lubricants and other consumable technical supplies taken on board […] such duties shall be refunded[…]*

The motivation for this recommended reciprocal exemption between member countries is also given in Document 8632 and reads:

> *The Council recognized the obvious practical difficulties inherent in adopting any other course of action and pointed out that its policy on fuel as set forth in the Resolution appeared to be the only one available in the foreseeable future which would, in a simple and effective manner, assure equitable treatment for international aviation throughout the many jurisdictions into which it operated.*

One of the main principles of international aviation is for all rules to be non-discriminatory. In Document 8632, ICAO points to the assumption that taxation on fuel may be done differently in different countries, tipping the scales in an unfair way in some jurisdictions. Worth noting is that the ICAO's conventions are not legally binding, they are meant to be guidelines for the bilateral agreements countries use to regulate civil aviation. In 97% of these bilateral agreements fuel is however considered exempt from taxes (ICAO, 1998), underscoring how difficult it would be to introduce a fuel tax. These agreements prevent ICAO's member countries from levying fees on fuel used for anything but domestic routes within their sovereign territory. The bilateral agreements are called Air Service Agreements and generally follow the guidelines set out by ICAO. In a standardized Swedish draft of an air service agreement, the same general principles can be found (Transportstyrelsen, 2012). ICAO's Document 9082, *ICAO's policies on charges for airports and air navigation services* further describes what fees are allowed to be imposed on aircraft operators. In general this document states that fees and charges are to be non-discriminatory in nature and aircraft operators should only have to pay for services and functions provided for, directly related to, or ultimately beneficial for, civil aviation operations (ICAO, 2009). ICAO also makes a differentiation between taxes and charges. In a resolution the following is stated:

> *ICAO policies make a distinction between a charge and a tax, in that they regard charges as levies to defray the costs of providing facilities and services for civil aviation, whereas taxes are levies to raise general national and local governmental revenues that are applied for non-aviation purposes* (ICAO, 1996)

Simplified, charges are levied for actions directly related to aviation while taxes are collected by the region's government first, to be redistributed afterwards. ICAO strongly encourages charges to be cost-specific, as in expenses directly resulting from aviation.

For the purpose of introducing a quota obligation, these policy guidelines set out by ICAO do not appear to be a hindrance. Should this system become a reality, the price of Jet A-1 in Sweden would most likely increase slightly, due to renewable fuel costing more than conventional petroleum-based fuel. When looked at in the light of these ICAO documents, it would be difficult to make the assertion that this price altering is a tax and not a charge. It is a cost directly associated with the acquisition of fuel and should therefore be viewed as such and not as a method for the Swedish government to increase revenue. As the objective of the quota obligation would be to require a certain percentage of the aviation fuel sold in Sweden to consist of a renewable component, it would affect all consumers of aviation fuel the same, regardless of origin. No airplane operator refueling at a Swedish airport would receive a direct competitive advantage or disadvantage from this policy instrument's introduction as everyone uses the same fuel, Jet A-1. As there is no precedent for this type of mechanism, it is difficult to know with certainty what the aviation community's reception would be.

6.3 Production

Should a quota obligation for aviation become a reality, it would create a demand for renewable aviation fuel in Sweden. The required amounts of fuel would either have to be imported from foreign producers or produced within the borders of Sweden. At present in Sweden, no production facilities for renewable aviation fuel exist. The virtually non-existing market combined with the significant capital expenditures required present obstacles that are currently difficult to overcome. Due to the limited quantities initially required under a quota obligation, it is unclear if large investments will be made in Swedish production in the near future.

The renewable aviation fuel produced today consists of HEFA-fuels for the most part, as mentioned previously in chapter 4.1. In a Norwegian study, it was found that the best suited technologies for production of renewable aviation fuels in Norway were the FT-process and the ATJ-process. The HEFA process, while at present more technologically mature, was deemed not suitable for production in Norway due to high prices of non-edible vegetable oils and sustainability concerns when utilizing edible vegetable oils. The study found that the FT- and ATJ-processes using forest feedstock suited Norway well due to the ample supply of forest biomass available, both imported and domestic (Ramböll, 2013). Seeing how Norway and Sweden are very similar in climate and agricultural conditions, it does not seem unreasonable to think the same assumption would be valid for the Swedish market. The only larger publically available study on production of aviation biofuels in Sweden, performed by Värmeforsk, investigated the possibilities of a FT-production facility in adjacency to Arlanda, Stockholm's and Sweden's largest airport. The aviation fuel would have been produced using wood chips as feedstock. In order to keep costs down, the production facility would have been combined with a district heating facility to utilize as much of the consumed energy as possible. The heat supplied to the district heating network would have worked as an indirect subsidy for the aviation fuel due to marginal income received. In the study, two different plant sizes were investigated and analyzed. (Ekbom, Hjerpe, Hagström, & Hermann, 2009). This type of operation could be one way of capitalizing on the excess heat produced in the FT-process.

The fuel company Solena, the airline SAS and Swedish state-owned airport developer Swedavia have signed a memorandum of understanding for developing a fuel production facility near Arlanda (Ekbom & Jaresved, 2013). Solena has previously signed an agreement worth around 550 million USD with British Airways for developing a production facility in the vicinity of London (GreenAir Online, 2014). The Arlanda project is currently in its early stages and not much information has been made public yet. What will become of it remains to be seen as more information becomes available, but it is an interesting development and currently the most active project for producing renewable aviation fuels in Sweden.

Another option for making alternative fuels in Sweden is production of so called electrofuels as a backstop technology. This type of fuel is not produced from a particular type of traditional feedstock, such as biomass. The main source of energy input is electricity which is used to electrolyze water to create H_2. CO_2 is captured from air, water or the use of biomass and is then processed to convert some amount to CO, which is combined with the H_2 to create a synthesis gas. Electrofuels are not proposed as its own production route under the ASTM D7566 certification. It could however be used to produce feedstock materials for the FT-process described in section 4.1.1. One option for obtaining the CO_2 is from biogas. Biogas consists of a mixture of CH_4 and CO_2, and when it is upgraded to be used as a fuel, the CO_2 is removed. This excess gas could be used in the process of producing electrofuels. One of the big advantages of electrofuels is that these fuels can be used as a type of energy storage. When electricity is cheap and abundant and demand is low, instead of reducing the power plants' output, the excess electricity can be used to drive this electrolysis process. Optimally, renewable sources of energy would be used to produce these types of fuels, in theory creating a carbon neutral liquid hydrocarbon. The cost of these fuels has not been accurately estimated and no production facilities exist or have been planned in Sweden (Nikoleris & Nilsson, 2013). With the Swedish electricity supply coming mainly from low-carbon sources, this could be an option in future scenarios where supply of conventional petroleum and biomass is scarcer and more expensive than it is today.

6.4 Practical implementation

If all of the prerequisites are fulfilled and legislators would make a decision to introduce a quota obligation, there are several questions that need to be addressed. For the application of this study, the two most important ones are the design of the obligation system and how to introduce renewable fuel in the distribution network.

6.4.1 Design of system

In a situation such as with aviation, introducing a policy instrument will to some extent affect competing stakeholders on the market. The goal is to cause as little competitive distortion as possible while still striving to achieve whatever goals are to be met. If a policy mechanism does not encourage actors on the market to comply with reaching the targets, it is not filling its purpose properly. In the case of aviation, potential behaviors legislators could wish to encourage are more fuel efficient flight planning, shifting from old, less efficient aircraft to newer technology, use of alternative fuels with lower life cycle emissions of GHG and so on. As is generally the case in the transportation sector, the phase contributing the most to detrimental environmental effects within aviation is the consumption of fuel. It is therefore desirable to design a policy instrument to encourage reduced use of fossil fuels, either through increased fuel efficiency, reducing the environmental impacts fuels have or reducing the demand for aviation in general.

Introducing a quota obligation would primarily serve the second of those two purposes, however in the short term it could also serve the first and the third ones, due to the slight increase in price on jet fuel that would likely be passed on to the passengers. Should a decision to introduce a quota obligation be passed into law, it would be a highly controversial step. The aviation industry, through IATA, has stated that a blend mandate is not a preferred route from their perspective, due to the fear of increased operating expenses. Their preference has instead been focusing on a global MBM, due to its high cost efficiency (Loran, 2013).

The two major points that will be considered for the introduction are the following:

- Who will be the obliged party?
- What should the initial quota be and how much should it increase over time?

The first question aims at deciding who the responsibility of fulfilling the quota requirements will fall on. The number of plausible options are limited and can be narrowed down to three options; the producer or importer of a fuel, the seller of a fuel or the user of a fuel. The users will be disregarded as an option in this case, due to the distribution infrastructure of fuel. Consumers of fuel generally do not place orders for fuel, they purchase the fuel that is available from the pump. Requiring these customers to fulfill a certain quota requirement over the course of a year would likely bring with it difficulties in terms of accounting and sheer management of the system. The large amount of customers compared to suppliers would appear to create a system much more complex and intricate than needed. The focus will then shift to producers and importers. The majority of aviation fuel consumed in Sweden is imported from producers outside the borders of Sweden (SPBI, 2013). As no other country currently has a quota system in place, demanding for all fuel to be exported to the Swedish market to contain a specific amount of renewables could prove a logistic problem for foreign companies, and also accounting problems for Swedish authorities as the verification of the renewable content could become more difficult to examine. The remaining entity is then the sellers/suppliers of aviation fuel, which for the Swedish aviation market generally means traditional oil companies. This corresponds with the proposed Swedish quota obligation for fuels for road use previously mentioned in section 6.1, in which whoever is responsible for the taxation obligation is also responsible for fulfilling the quota requirement, which in general would mean the seller of fuels or very large consumers of fuel (Energimyndigheten, 2013). In the case of aviation, taxation is of course not applicable as fuel is exempt from taxes. As will be discussed in the next section, it is likely for renewable fuel to be introduced upstream of the aircraft, effectively taking it out of the hands of airlines as they generally do not handle fuel themselves in Sweden. The quota obligation for road fuels previously being proposed as a policy measure has not yet been introduced in practice, but since fuel suppliers would have been required to abide by it, they likely have some amount of familiarity with it. The aviation system would function similarly, albeit with a smaller quota requirement. As the systems would be, there would be less of a learning curve than if a completely new type of system was introduced.

An important factor in the successful introduction of a quota obligation is the annual percentual requirements. If set too high, the cost penalty might disrupt the market excessively and if set too low, it might not achieve the desired effect. The annual requirements proposed in this project are presented in Table 1. These percentages have been chosen to grow the required amount exponentially, in order to give the aviation industry a low quota at first, which is subsequently ramped up in later years. As will be shown in section 6.5.4, these quotas would enable the use of renewable fuels without causing an increase in ticket prices from a no-action scenario by more than 3% for most fuel production routes. These calculations have been made using the projected baseline fuel prices, the projected costs of CO_2 emissions under the EU-ETS and the projected renewable fuel costs. The renewable fuel costs are projected for when fuels have reached maturity, which might not quite be the case for the 2015 scenario. The small amounts required are however still not likely to be enough to cause a sharp increase in ticket prices.

Table 1. Proposed quota requirements in %

Quota requirements (%)	
2015	2
2020	5
2025	10
2030	18
2035	29
2040	40

With these quotas and the projected CO_2 and fuel prices, at year 2040 renewable fuels have a chance of bearing their own costs at that point in time. The EU has set out an aspirational goal of using 40% low carbon fuels by 2050, but if projected prices of fuel and CO_2 are an accurate indication of future scenarios, renewable fuels could become economically viable before that, which could be an opportunity Sweden could take advantage of. It is unlikely for quotas to be put into legislation this far ahead in time, but for the purpose of illustration and as a base for calculations, these are the quotas that will be used in this report.

6.4.2 Introducing renewable fuel in the distribution network

One of the questions that need to be addressed when investigating a blending requirement is where the renewable fuel is to be mixed with conventional fuel. An important point to consider when examining this issue is the accountability aspect. To comply with a quota obligation, the obliged parties need to be able to account for their fuel to contain the appropriate amount of renewable fuel. Being able to accurately measure the renewable quantity is crucial for the successful implementation of a blending requirement.

There are several points in the supply chain of aviation fuel where renewable fuel could be introduced. It could be done directly at the refinery, called initial blending, or it could be done further downstream for individual airports fuel depots, called secondary blending (Oh, 2011). Where the fuel is optimally mixed in largely has to do with logistics costs. To date, biofuels have been introduced at the very last step in the supply chain, directly into the airplanes. They have never been intermixed in the conventional fuel infrastructure due to the small number of users. Introducing renewable fuels this late in the distribution chain would not be plausible should a quota obligation become a reality. Storing and distributing the renewable component completely separate from the conventional supply chain would cause logistics to cost more than if the renewable and conventional fuels were transported together. The renewable fuel is therefore best mixed in further upstream than it currently is.

Airport fuel handling

Aviation fuel at an airport is generally stored in a so called “fuel farm”, which in layman terms can be best described as large cisterns. These fuel farms are located in proximity to the airfield which it serves. The transport of the fuel from the fuel farm to the airplanes is usually done in two different ways. The first alternative is for tanker trucks to drive to the fuel farm, fill its tank and drive to the airplane which is to be refueled. This is a fairly straightforward operation and is often done at smaller airports but also at larger airports for aircraft that cannot park adjacently to the terminal buildings. The alternative method of distributing aviation fuel is using a hydrant system. This consists of a system of underground pipes distributing the fuel to “wells” located around the airport area. The wells are points where a hose is connected and then attached to the aircraft in order to transfer the fuel into (or from) the airplanes tanks by a dispenser truck. This hydrant system is connected to the fuel farm, making the use of tanker vehicles redundant, reducing the risk associated with transporting jet fuel around and airport in vehicles. In Sweden, Arlanda is the only major airport utilizing a hydrant system. Most other airports use tanker trucks for refueling. In many refueling operations, the ownership of a tank farm is shared between different actors on the market. In some cases it is owned by airlines, in some by the airport and in some cases by companies supplying fuel to the fuel farm. In these cases where there is a joint ownership, the amount of fuel each actor supplies and then subsequently sells needs to be carefully monitored. It can be compared to an electricity grid where there are several suppliers feeding the market with an interchangeable product. Customers purchase their product from a specific supplier, even though everyone withdraws their purchases from the same pool (Oh, 2011).

Arlanda

Arlanda is interesting to examine further since roughly 62% of Sweden's total deliveries of jet fuel takes place here (SPBI, 2013; Westman, 2014). The infrastructure to deliver fuel to this airport is also more sophisticated than most other airports in Sweden. The fuel farm at Arlanda is owned by a conglomerate of fuel suppliers. The company managing the fuel farm, AFAB, is not in the business of purchasing or selling fuels, but merely act as an intermediate, managing and distributing the fuel to the end consumers. They keep track of the amount of fuel each company supplies to the airport and how much is delivered by the fuelling company to the end consumers. The oil companies are then billed a small administrational fee based on the amount of fuel they have sold to end consumers, in order to cover operating expenses. In the upstream supply chain, the fuel is first delivered by ship to the harbor in Gävle where it is stored in oil depots. Each fuel company stores their products separately. The fuel is then loaded onto trains chartered by the specific fuel companies which take it to Märsta, which lies close to Arlanda airport. Here it is discharged into a pipeline and transported to the fuel farm at Arlanda (Swedavia, 2011). The fuel farm is the first place where the different fuel companies' products are mixed with each other, and the amounts are carefully monitored to ensure correct accounting. In an interview with AFAB's CEO Bengt Westman in March of 2014, he explained AFAB's operations. He did not believe that accounting for renewable fuels and the ability to measure how much had been sold for each individual fuel company would be a problem, seeing as how they already measure this. This view was resonated in the study by Värmeforsk (Ekbom, Hjerpe, Hagström, & Hermann, 2009).

ASTM compliance

The ASTM fuel specification prohibits the mixing of conventional jet fuel and renewable fuel to higher proportions than 50%. This could potentially place a constraint on where fuel is mixed in, should there be a possible risk of exceeding the 50% threshold. For example, a fuel farm receives fuel from several different suppliers who are obliged to fulfill the quota requirements. If all suppliers use secondary blending and deposit shipments of renewable fuel into the fuel farm at the same time, there could be a risk of overshooting the 50% maximum if the current fuel levels are not carefully monitored and communicated. Due to the fact that the proposed amount of renewable fuel is fairly small compared to the consumption of conventional fuel, this might not pose a big problem however. It is likely that most of the renewable fuel will be consumed on airports close to established infrastructure in place in order to minimize costs, should secondary blending be utilized. The quota requirement would not require all fuel to contain the exact minimum amount of renewable fuel at all times, but merely that the volumes amount to a certain percentage of the total amount of Jet A-1 delivered on an annual basis by all of the fuel suppliers. Based on this fact, it does not seem reasonable for obliged parties to spend money transporting renewable fuels to airports far from the bulk delivery infrastructure if there is no requirement for fuel to contain renewables. The airports located far from the large delivery routes by train and ships will still require fuel to maintain operations but they may not receive a significant amount of renewable fuel as long as these fuels are not cost competitive. Should renewable aviation fuels become economically viable to a larger extent, they could be distributed strategically by fuel sellers to counter fluctuations in conventional fuel price throughout Sweden. As of today, this is not the case however.

The fact that synthetically produced fuels are not allowed to be mixed in to a percentage higher than 50% states the case for initial blending. This would likely reduce the risk of any miscommunications between fuel suppliers depositing fuel into a jointly owned fuel farm. If the renewable component was deposited further upstream than the fuel farm, the fuel companies are likely to have better insight into the contents of their own storage facilities, giving them full control over the quota of sustainable fuel. Most aviation fuel used in Sweden is delivered to bulk oil depots by ship. From these depots, the oil is then distributed to airports using trains or trucks. The fuel suppliers could deposit the renewable contents they are obliged to provide directly into the central storage facilities and then be assured that the limitations set out by fuel standards are not exceeded. In the case of Arlanda, the fuel passes through bulk storage in Gävle harbor before it is loaded onto trains for further transport. Oil companies manage their own cisterns and fuel depots, giving them exact knowledge regarding the volumes currently in storage. They would then know the exact percentage of renewable content in the fuel delivered to airports. These depots are in the size range of 45 000 – 100 000 m^3 (Westman, 2014). For these volumes, exceeding the 50% maximum would require simultaneous deposits of quantities that would exceed the initial total annual targets for all of Sweden. Initial blending therefore appears to be the most convenient route for fuel suppliers to use. As there is currently no production of renewable aviation fuels in Sweden, it would need to be imported initially, unless significant strides are made domestically. The fuel would likely arrive by ship and pass through an oil depot, making these terminals a suitable place for renewable products to enter the conventional fuel infrastructure.

Fuel quality assurance

The quality of conventional fuel is controlled continuously throughout the operation. Before the fuel is unloaded from whatever mode of transport used to bring it to the fuel depot, the fuels qualities are inspected in order to ensure that the given fuel standards are met. Should a contaminated fuel be put into the system and intermixed with the existing fuel it could prove disastrous since there would be no way of removing the contamination. The fuel is then controlled while in storage and at several points from the time it leaves the depot until it is pumped into an aircraft (Swedavia, 2011). The control procedure in place for conventional jet fuel coupled with the careful controls necessary to classify a renewable aviation fuel as compatible and adherent to standards should provide a solid safety measure against contamination. For all intents and purposes, once the alternative fuel has been classified according to ASTM D7566 it is to be considered a fuel adhering to ASTM D1655 as mentioned in chapters 3.1 and 4.1. Should renewable aviation fuels for some reason be found to be of a lesser quality than conventional fuels, it could severely damage their reputation and make fuel purchasers hesitant to purchase these fuels. The flights performed on biofuels so far have largely been done in order to attract publicity. Needless to say, should for some reason renewable fuels be causing a safety hazard, it is not the type of publicity the fuel or aviation industries wishes to attract. This should however not be an issue unless significant errors are made in the supply chain, just as for conventional fuels today.

6.5 Economic impact

The main reasons alternative fuels for aviation are not utilized at scale today is the high cost associated with them. The price discrepancy compared to conventional petroleum-based fuels differs between the various production methods, but at present they can generally be said to be more expensive. Some production routes have been estimated to price ranges, where the lower end of cost spectrum may not be competitive now, but could become competitive in the future (IATA, 2013b). Due to the present immaturity of the technology, it is however difficult to accurately estimate these future production costs. Further, the estimated price ranges can be shifted slightly if any cost of emitting CO_2-equivalents is included. Production of renewable fuels also requires a readily available supply of raw materials. A large part of estimating future production costs consist of estimating the feedstock costs (European Commission, 2013). Biofuels generally emit less GHG than conventional fuels and are therefore in some circumstances exempt from the carbon taxation levied on conventional fuels in some locations (for example the EU-ETS, even though it is not a specific tax on fuel).

6.5.1 Prices at present

The viability of alternative aviation fuels is inherently intertwined with the price development of conventional petroleum-based fuels and, to a significant extent, the price of crude oil. The aggregate price of jet fuel consists mainly of the cost of acquiring crude oil, and their relationship can be seen clearly in Figure 3. Fuel costs have increased for airlines in recent years. These expenses represented 30% of airlines operating costs in 2011, up from only 17% in 2004 (IATA, 2013a). In their 2013 annual reports, SAS and Norwegian reported fuel costs comprising 24.5% and 32%, respectively, of the two groups' operating expenses (SAS Group, 2013; Norwegian Air Shuttle ASA, 2013).

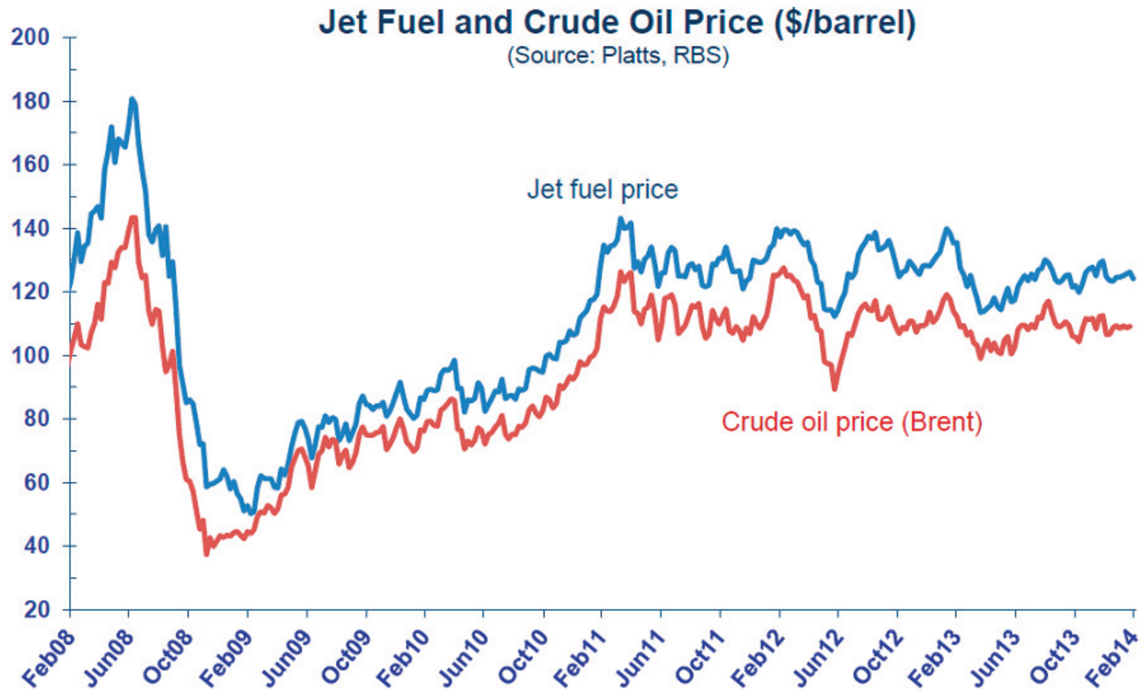

Figure 3. Price development of Jet fuel and crude oil. (IATA, 2014)

The price of jet fuel in Europe varies similar to any other petroleum product. The prices shift depending on current supply, forecasted supply, historic consumption, forecasted consumption and so on. During the period March 11th 2013 until March 10th 2014, the average price of jet fuel sold in Rotterdam in the Netherlands was 730 €/ton (European Commission, 2014a). The entire year and its fluctuations can be seen in Figure 4. Jet fuel is measured in several different units and currencies around the world, for example m^3, gallons, liters and tons. For the sake of comparison, the average price will be converted to USD/liter. When converted to this unit using the average exchange rate between € and USD for the year 2013, and the average density for Jet A-1, the European price comes to 1.20 USD/liter (Ministry of Defence (UK), 2011; Credit Suisse, 2014). The actual price differs slightly between the various countries in Europe naturally, but serves as an indicator as there is no publically available aggregated price data for the Swedish aviation fuel market. The price information found for the US market indicates lower price levels than in the EU. The average retail price of conventional jet fuel in the US was 0.82 USD/liter during 2012 (EIA, 2014). Due to the majority of the fuel projections, conventional and renewable, coming from North America, this is the figure that will be used for comparison of future prices.

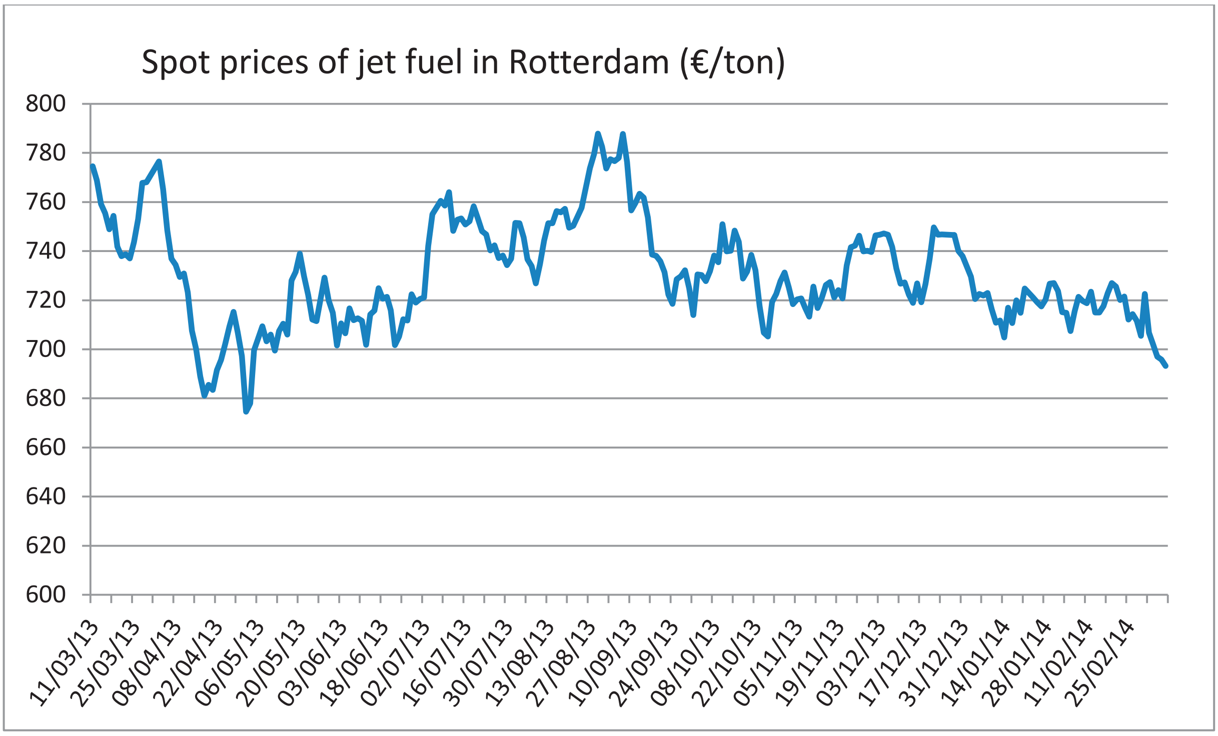

Figure 4. Spot prices of jet fuel in Rotterdam (European Commission, 2014).

So far, one of the largest purchasers of alternative aviation fuel has been the U.S. armed forces through the DLA[16]. Part of the motivation for this is planning for a future scenario where renewable aviation fuels may be on equal fiscal footing with conventional fuels, but the question of energy security also plays a significant part (Blakeley, 2012). The prices at which they have purchased fuels are presented below in Table 2.

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[16] Defense Logistics Agency

Table 2. Alternative aviation fuel prices, purchased by US Department of Defense (DOD) from 2007 to 2012 (IATA, 2013b; Blakeley, 2012).

Fuel type	Quantity purchased (l)	Average cost ($/l)	Min	Max
HEFA	4 108 428	10.11	7.07	39.37
FT[17]	2 763 050	0.99	0.90	1.85
ATJ	352 005	15.59	15.59	15.59
DSHC	162 755	6.80	6.80	6.80

[1] Produced from coal and natural gas, not from renewable feedstock

As can be seen in these figures, these fuels are in general more expensive than their petroleum counterpart. An exception to this are the FT-fuels purchased from companies Shell and Sasol. In some purchases these fuels have been bought at prices similar to that of conventional fuels. There is however a caveat when examining the pricing of these fuels. As stated in chapter 4.1.1, life cycle emissions of GHG are generally larger for FT fuels produced from coal and natural gas than they are from conventional petroleum-based fuels. This would effectively mean that allowing these fuels to be included in a quota obligation could increase the aviation sector's environmental impact instead of decreasing it. Reducing the lifecycle GHG emissions by using carbon capture could be a possibility, but these fuels will not be considered further in this report.

Presently, HEFA fuels are the most readily available and most of the available renewable fuel on the market consists of this. The price range for HEFA fuels stretches very widely, which stems from the several different processes used to produce these fuels. In the most expensive batch of HEFA fuel purchased by the US DOD, algal oil was used as feedstock. The cheapest batch is also produced partly from algal oil, but it is intermixed with used cooking oil (Blakeley, 2012). In another purchase in 2011, aviation operator Alaska Airlines purchased 105 980 liters HEFA fuel produced from used cooking oil at a price of 4.49 USD/l, which is in the same range as the DOD's average price for HEFA fuel (The Seattle Times, 2011).

When refining different types of bio-crude into fuel grade products, the processes are tailored to optimize the yield of a certain type of hydrocarbon. Other hydrocarbons can however be obtained as byproducts. If a process is optimized to maximize production of diesel for example, some amounts of jet fuel and gasoline can often be extracted. Often these processes are designed to give as high a yield as possible of the most economically beneficial product. If producing diesel is more advantageous, the system will likely be adapted to increase diesel's proportion of the total production, thereby reducing yield of the other products (Natural Resources Canada, 2014). This could work against gearing production facilities specifically for production of renewable jet fuel, if production of biodiesel for road use is more beneficial. This may not necessarily be a problem for investors however, as they will not be as reliant on just one product. If the profit margins for one type of fuel decreases it could make other types of fuel more economically beneficial.

In Sweden, and most other parts of the world where a blending requirement of renewable fuels has been proposed or introduced, the focus of legislators has been on road fuels. Aviation fuels can be

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included voluntarily, as is the case in the US and the Netherlands, but there is generally not a mandatory requirement. This provides a direct incentive for fuel producers to gear their operations towards maximizing the yield of renewable diesel and other fuels falling directly under the quota obligation. The fact that aviation fuels are not being premiered in the same manner could cause them to not be prioritized as much as road fuels (IATA, 2013b). Currently, biodiesel has a stronger support system in place for encouraging its use, making it more difficult for production of renewable jet fuel to acquire feedstock material (Pearlson, Wollersheim, & Hileman, 2012). This economic imbalance makes technology development more difficult than it would be under other circumstances. The “valley of death”-problem discussed in chapter 6.1 is prevalent for renewable aviation fuels.

6.5.2 Projected price developments

As renewable aviation fuels can be considered to be in their infancy, their current prices may not be representative of what they will be in the future. As production methods are refined and technology evolves, the hope of the aviation industry is for prices of renewable jet fuel to decrease. There are naturally several factors that will influence the price development of renewable fuel going ahead, some of which can be projected with more accuracy than others. Much of the variability in the projections depends on prices of feedstock, capital expenditures and process optimization. Introduction of policy instruments affecting the renewable fuel arena in general is also a factor influencing price development as it can influence the market. The projected values for renewable fuels are most commonly stated as a minimum selling price, or MSP, for producers to cover the expenses associated with production facilities and feedstock. Slight differences between the timeframes for the various projections exist. While some aim to project the prices at a specific time or period of time in the future, other projections are given for a time when technologies have reached a steady state, i. e. when the MSP is not decreasing significantly for every new production facility. The price projections aggregated in Table 3 can be seen in their full scope in Appendix A, where the assumed time frame can also be seen. The number of studies used in the average is included for reference. It depicts to some extent how much attention the different production routes are generating and how well researched they currently are. Average values of the examined price projections made are presented below in Table 3. For comparison, projected conventional jet fuel prices without the cost of CO_2 included can be seen in Table 4.

Table 3. Average values of price forecasts for high, baseline and low price developments in 2009-2014 USD/liter, the sources are available in Appendix A.

Fuel type	Average of High	Average of Baseline	Average of Low	# of studies
ATJ	3.69	2.12	1.51	5
DSHC	3.41	1.56	0.69	4
FT	1.46	1.23	0.91	6
HEFA	2.30	1.37	1.15	8
PTJ	0.84	0.67	0.49	1

Table 4. Projected conventional jet kerosene retail prices for the US market in 2012 USD/liter, cost of CO_2 not included (EIA, 2014).

Fuel Type	Year	High	Baseline	Low
Petroleum	2015	0,95	0,70	0,58
Petroleum	2020	1,07	0,76	0,51
Petroleum	2025	1,19	0,85	0,54
Petroleum	2030	1,31	0,92	0,55
Petroleum	2035	1,45	1,02	0,56
Petroleum	2040	1,59	1,11	0,58

As can be seen when comparing Table 3 and Table 4, a discrepancy in price is projected to exist for most technologies even when renewable fuels have reached a steady state. In practice, this means that sustainable fuels will need some form of subsidy or policy measure to be able to compete with conventional petroleum-based fuels. Where this subsidy is to come from remains to be seen, but it could prove to be a problem for the successful deployment of alternative fuels on the market. A few words of caution are necessary when comparing these tables. Firstly, the price of conventional jet fuel in these projections is expected to decrease slightly from its current level of 0.82 USD/liter. The decrease is noticeable, but it is likely still reasonable considering the fluctuations in crude oil prices. The projections for renewable fuels are not all from the same source and therefore do not use the same assumptions. Further, they are not all done at the same time or in the same region. When the price estimates have been given in other currencies than USD, they have been converted using the average conversion rate for the specific year the study was published. On the positive side, the projected price developments are most commonly given in, for example, 2012 USD. The projections have then attempted to give a comparison of what the equivalent future cost could be in current day currency. The alternative would be to state the prices in nominal dollars, or what they would actually cost in year X in year X currency. This would make comparisons between today and future scenarios more difficult as factors such as inflation would have to be considered.

Many factors have not been included in these projections however, for example the potential cost of emitting CO_2. With the inclusion of aviation in the EU-ETS and ongoing talks of a global MBM in ICAO, these costs may help bridge the gap between renewable and conventional fuels. As mentioned in Chapter 2, biofuels used in aviation are currently considered to emit no lifecycle GHG under the EU-ETS. For a theoretical flight powered by 100% biofuels, the operating airline would be required to surrender no permits for the emissions caused by that particular flight. What the emission reductions will be counted as in ICAO’s global MBM have not yet been decided upon, but it could have an effect on the viability of renewable aviation fuels. Aviation biofuels in the EU are today required to be certified as sustainable according to a set of criteria given in Article 17 of Directive 2009/28/EC. One of the minimum requirements is for the life cycle GHG emissions to provide at least a 35% decrease compared to conventional fuels. This minimum reduction is then scheduled to be 50% in 2017. Beyond this specific threshold, more sustainability criteria exist which will not be discussed in depth in this report. The fuels to be used for the purpose of fulfilling the proposed quota obligation will be assumed to fulfill these criteria and be usable as biofuels in the EU.

Under the EU-ETS and also the MBM to be proposed by ICAO, emissions of CO_2 will come at a price. The ICAO measure has not yet been finalized and the costs it will impose on airlines have therefore not yet been decided upon. The EU system on the other hand has been functional since 2005. During this time the price of carbon emissions has fluctuated greatly. Prices are currently very low (About 5

€/ton CO_2 on 5/5-2014) compared to the initial price of between 20 and 25 €/ton CO_2. Global economic hardship in 2008 has caused an abundance of allowances to be available on the market, effectively reducing the price of emissions (The Economist, 2013). The EU publishes price projections for the expected development of allowance prices under the ETS. These can be seen in Figure 5. According to this projection, the price of carbon allowances is currently at a low point compared to the initial prices at the onset of the latest trading period (The Economist, 2013). Prices are expected to increase significantly above the current levels as time progresses. This appears to be a plausible scenario considering the decreasing amount of emissions allowed under the system's cap (European Commission, 2014).

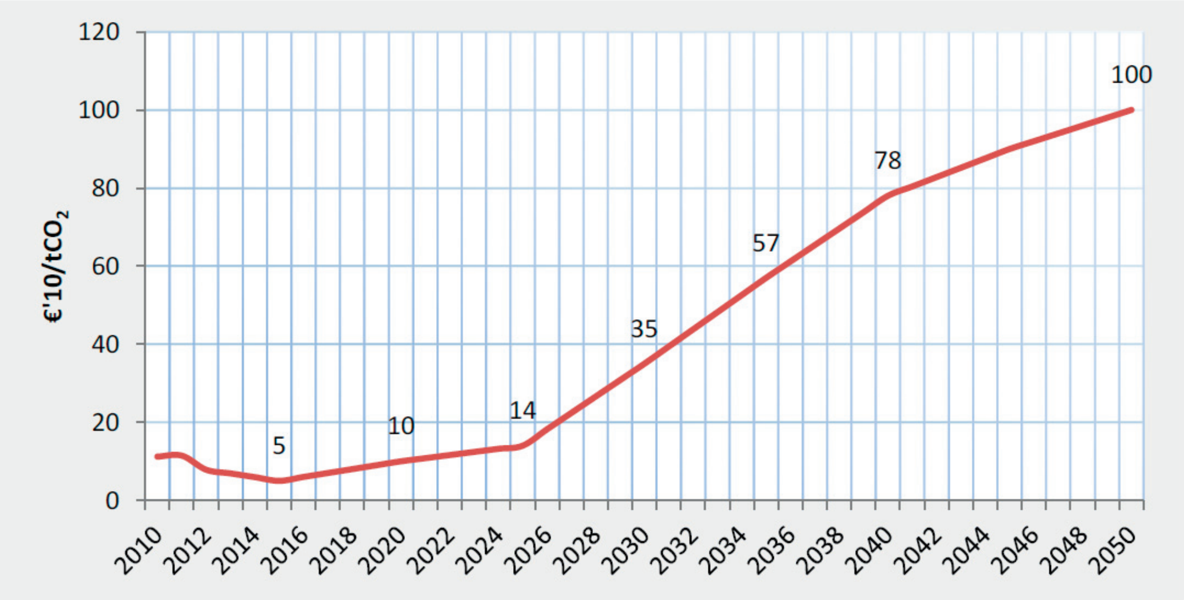

Figure 5. Projected price development under the EU-ETS in 2010 €/ton CO_2 (European Commission, 2014b)

Aviation is somewhat of a special case in the EU-ETS however. As mentioned in Chapter 2, aviation's presence in the EU-ETS is certain until 2016. Speculating further ahead in time is difficult as much will depend on the outcome in the ICAO, but it seems likely that emissions of CO_2 will have a cost. The cap for the EU-ETS in general will gradually decrease, but this is not the case for aviation. Aviation's cap will remain stable at 95% of the average annual emissions during 2004-2006 levels until 2020. Obliged airlines will also be awarded the majority, or 82%, of allowances for free, but 15% will be sold through auctions. The remaining 3% are kept in a special reserve reserved for new and rapidly expanding airlines (European Commission, 2014). The allowances airlines receive for free cannot be used to cover emissions from non-aviation sources, but conventional allowances from other sectors can be used to cover emissions from aviation. This is currently not a very strong incentive to implement biofuels now. If the amount of allowances allocated for free is reduced and the price of them increases, it could be. With the projected changes in the price of conventional jet fuel coupled with the projected price of carbon emissions, low carbon fuels could become viable. Conventional fuels appear likely to become more expensive to use in the long term and the price of renewable fuels are conversely expected to decrease in price compared to today. If the cost of emission allowances increases, it can help bridge the gap between conventional and sustainable fuels.

6.5.3 Calculating effect on price of air transport

If a quota obligation for aviation would become a reality, it would likely have an effect on the price of airline tickets from Sweden. This section will estimate the change in cost for one typical long distance and two short distance routes, one international and one domestic, under certain conditions. The figures attained in the previous section 6.5.2 will be used as the base for calculating the projected price change. The long haul route examined will be Stockholm – New York, as it was the most trafficked intercontinental route from Sweden. The international short haul route examined will be Stockholm – London as it was the most trafficked intracontinental route from Sweden. The domestic short haul route examined will be Stockholm – Gothenburg as it was the most trafficked route within Sweden (Swedavia, 2013b). The price change will be calculated for a round-trip economy fare ticket. Due to the often non-transparent pricing strategies of airlines, some of the price components will have to be estimated and simplified.

There is a certain degree of difficulty in estimating fuel consumption for specific routes owing to the fact that most routes are not trafficked by solely one operator operating just one specific type of aircraft. There is a vast amount of aircraft of different sizes and engine configurations, which have been produced at different points in time. To simplify this problem, the ICAO Carbon Emissions Calculator will be used. The calculator contains data on what types of aircraft operate on specific routes, how many seats they have and what their fuel consumption is. It is by no means a perfect tool, but it should provide a fairly accurate average for the different routes. The fuel consumption will be divided on the number of seats given for the average aircraft in the ICAO tool and divided by the cabin factor[18], or CF, to determine the fuel consumption per passenger/ticket. For simplicity it will be assumed that every passenger causes the same amount of fuel to be used. Due to business and first class seating often taking up more space per passenger on an aircraft operating long haul, this is not entirely correct. The majority of the cabin room on aircraft operating the specific routes is however used for economy class type seating (Seatguru.com, 2014). Premium class passengers also pay for a number of services not directly tied to fuel consumption, for example lounges and priority boarding.

Once the fuel consumption per passenger has been determined, this can be tied to a direct cost for that amount of aviation fuel. It can also be tied to the amount of CO_2 stemming from every passenger, as well as the associated cost of emissions, as fuel consumption and CO_2 emissions are directly related. No cost for emissions of CO_2 will be levied on the 2015 projection of the NYC-route as flights out of Europe are not covered by the EU-ETS. In the 2020-2040 projections, a cost of emissions is included for the full scope of all three routes. The projected price of emissions of CO_2 will be based on the projections given for the EU-ETS. This is only a reasonable estimation until 2020, when the global ICAO MBM is scheduled to become active and likely replace EU-ETS. There is however no information for what the cost of emissions will be under the ICAO system, and the EU-ETS projections will therefore be used beyond its planned scope. Conventional fuel cost will be estimated using the projections stated in Table 4. Renewable fuels will be priced according to the projections in Table 3. These values are estimated for when fuels have reached a plateau in production cost. This will likely not be the case for 2015 as that is very soon, but reliable current price information is difficult to find. It will also be assumed that renewable fuel will only be used on the segment of a trip departing from a destination within Sweden. For New York and London, the

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[18] Cabin factor – A metric describing the degree of occupancy on an airplane. $CF = \frac{\#\ of\ passengers}{\#\ of\ seats}$

required quota will be divided by two as no renewable fuel has to be used on the returning segment. The price change per unit aviation fuel stemming from the introduction of a quota obligation can then be used to estimate the price change per passenger/ticket on a given flight compared to a no-action scenario. In the no-action scenario, no renewable fuel is required to be used. Assumptions for this scenario is that prices of conventional jet fuel will change according to their projections, and carbon emissions will have a cost following the projected prices for the EU-ETS. It will also be assumed that 100% of the change in fuel price will be passed on to the passenger purchasing the airline ticket. This will be assumed for both increases and reductions in price. Of the total ticket price, only a certain share is directly related to fuel costs. The remaining part consists of costs for labor, airport fees, maintenance of aircraft, purchases of new aircraft and such. These costs will be assumed to remain constant over time as including them would add several degrees of complexity to the calculations.

The fuel use will be assumed to remain constant over time. ICAO has an aspirational goal of increased fuel efficiency, but since it is not binding there are currently no repercussions if the commitment is not lived up to. The initial prices of tickets will be estimated based on information received from various price comparison websites on May 6th 2014. Prices are meant to be seen as reasonable assumptions for what a round-trip ticket on the specific route could cost and are not a definitive average. The data received from the ICAO calculator as well as assumptions made will be stated below in Table 5.

Table 5. Starting data and initial assumptions

Route	Price (USD)	Distance (km)	Fuel used (kg)	Seats	CF[1]	Fuel used / Pass. (kg)
Stockholm - New York	922	12602	70092	269	0,74	352,11
Stockholm - London	215	2920	11472	175	0,74	88,59
Stockholm - Gothenburg	170	788	4424	152	0,69	42,18

[1] (Swedavia, 2013a)

The variables that will be examined are the following:

- Price of conventional fuel – Projections presented in Table 4 will be used
- Price of renewable fuel – Projections presented in Table 3 will be used
- Quota percentage – Percentages proposed in section 6.4.1 will be used
- Price of CO_2 – Projections presented in section 6.5.2 will be used

In the projected scenarios for fuels where a high, a baseline and a low price exists, these will be used. In the projections for cost of CO_2 which only provides one value for each point in time, this value will be considered the baseline while this value ±50% will be considered the high and low scenarios. For the purpose of calculating the GHG savings for biofuels and the associated reduction in required allowances under the EU-ETS, the renewable fuels used will be considered to have a 100% reduction. This is currently the case and it is not an unreasonable assumption that this system could continue on in the ICAO MBM.

The formula that will be used when calculating the price in each specific scenario for the international destinations is described beneath:

$$TFC_Q = \frac{100 - \frac{Q_P}{2}}{100} * V_{TF} * C_{CF} + \frac{\frac{Q_P}{2}}{100} * V_{TF} * C_{RF} + \frac{100 - \frac{Q_P}{2}}{100} * V_{TF} * M_{CO_2} * C_{CO_2}$$

Q_P = Quota percentage at time t, as stated in section 6.4.1
V_{TF} = Volume of total fuel used per passenger, conventional and renewable (liter)
C_{CF} = Cost of conventional fuel at time t (USD/liter)
C_{RF} = Cost of renewable fuel at time t (USD/liter)
M_{CO_2}= Mass of CO_2 emitted per volume fuel consumed (2.56 tons CO_2/m^3 fuel)
C_{CO_2} = Cost per mass unit of CO_2 emitted at time t (USD/ton)
TFC_Q = Total fuel cost per passenger with quota requirement at time t (USD)

The formula used for the domestic destination is very similar and can be found beneath. The only difference is that renewable fuel is assumed to be used on both segments of the journey:

$$TFC_Q = \frac{100 - Q_P}{100} * V_{TF} * C_{CF} + \frac{Q_P}{100} * V_{TF} * C_{RF} + \frac{100 - Q_P}{100} * V_{TF} * M_{CO_2} * C_{CO_2}$$

The cost estimations received through the use of the above formulas will be combined with the costs not related to fuel to a new ticket price at for the time t. These costs will be been calculated using the following formula:

$$TC_{NF} = TP_I - TFC_I$$

TC_{NF} = Total costs not related to fuel (USD)
TP_I = Initial ticket price for year 2014 (USD)
TFC_I = Total initial fuel costs (USD)

Once these non-fuel related costs are known, they can be combined with the calculated fuel costs to estimate the ticket prices for every scenario using the following formula:

$$TP_{QP} = TFC_Q + TC_{NF}$$

TP_{QP} = Ticket price at time t with quota obligation (USD)

This new ticket price will be compared to the calculated ticket price in a no-action scenario at the same point in time, where no quota obligation has been factored in. The no-action scenario only factors in the conventional fuel price and a cost for CO_2 emissions. The formula used for this calculation reads as follows:

$$\Delta TP_{QP} = \frac{TP_{QP}}{TP_{NA}} * 100$$

ΔTP_{QP} = Ticket price with quota obligation at time t as percentage of ticket price in no-action scenario at time t
TP_{NA} = Total fuel cost at time t in a no-action scenario (USD)

The projected ticket prices will also be compared to 2014 levels using the following formula:

$$\Delta TP_{QI} = \frac{TP_{QP}}{TP_I} * 100$$

ΔTP_{QI} = Ticket price at time t with quota obligation as percentage of ticket price in 2014.

6.5.4 Results

When calculations of fuel prices and ticket prices have been made for all of the scenarios described in the previous chapter, a vast amount of data has been made available. Not all of this data will be presented in this chapter as it would be overwhelming. For the full scope of the calculations, these are available in Appendix B where the calculations of fuel costs are presented for all considered scenarios for all three destinations. A few excerpts of the comparison will be presented below. In Figure 6, Figure 9, Figure 10, Figure 13, Figure 14 and Figure 17, the estimated ticket prices in the no-action scenario and when using a quota obligation are broken down. These calculations combine the baseline projections for conventional fuel price, renewable fuel price and costs of emitting CO_2. For the quota obligation scenarios, HEFA-type fuels were used for the calculations depicted in these figures. The forecasts for the price of airline tickets in USD as a percentual increase or decrease from 2014 prices are shown in Figure 8, Figure 12 and Figure 16. As can be seen, ticket prices are expected to initially decrease from today's prices due to jet fuel's projected decrease in price. After 2020, ticket prices are however expected to become relatively more expensive than they are today. By 2040, ticket prices are expected cost 15% to 36% more compared to 2014 levels when examining the projected baseline scenarios.

Figure 7, Figure 11 and Figure 15 displays how scenarios when a quota obligation is introduced compares to a no-action scenario where strictly conventional fuel is used. The X-axis in these graphs depict the no-action scenario, and any deviation from it represents increased or decreased ticket prices when using specific fuels under a quota obligation. It can be seen that a quota obligation in general will bring with it a ticket price increase for some time ahead when compared to the no-action scenario. In practice, it means that with a quota obligation aviation tickets in general will be more expensive than in a no-action scenario. For the international routes, the initial price increase over the no-action scenario is estimated at between 0.2% and 0.7%, while the reduction in absolute currency compared to 2014 is between a 2.3% and 2.8% decrease. The domestic route displays an initial price increase over the no-action scenario between 0.3% and 0.9%. The decrease compared to 2014 levels is between 2.3% and 2.8%, like for international route. Due to the small volumes required to be mixed in, a higher or lower price of emitting CO_2 does virtually nothing to affect the price. Once the combination of higher conventional fuel prices, higher quota percentages and higher CO_2 costs become more noticeable around 2030. The gap between the no-action scenario and the proposed quota obligated scenarios peaks in 2030 for HEFA and FT. After 2030 until 2040, the gap decreases in size and is eventually inverted, meaning ticket prices are cheaper with renewable fuel than they would be using purely conventional fuel. The international and the domestic scenarios depict similar developments over time, with the domestic scenario being slightly more exaggerated due to the need to use renewable fuel on both the outbound and inbound segments of the trip.

The various renewable fuel production techniques display differentiated capabilities to achieve viability. The fuel projected to be commercially competitive under the most number of circumstances is fuel produced from the FT route. Close behind is the DSHC route, followed by HEFA and ATJ. Comparing the projected ticket prices to reach a conclusion of which fuel will reach viability first is likely not a reasonable approach considering the prices are average values of a larger amount of projections. Different assumptions and timeframes have been used in the calculation of these projections. It is also not likely for just one fuel to be used under a quota requirement. All fuels will likely be used to some extent if the proper technical certifications are passed. It does however provide some indication of when and under what circumstances the different fuels potentially could bear their own costs under a quota obligation with a specific set of quota percentages, as well as what the changes in ticket prices could be.

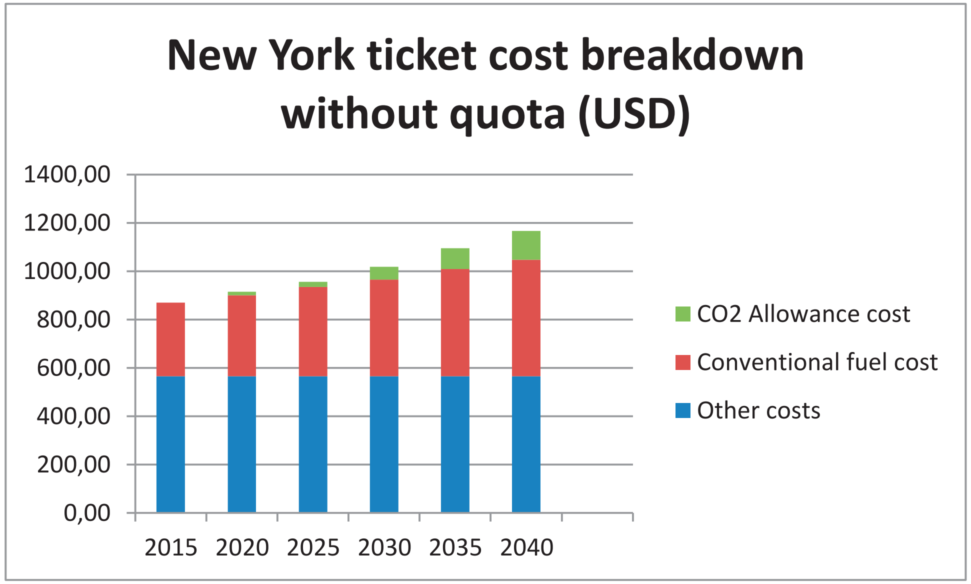

Figure 9. New York ticket price breakdown in no-action scenario, baseline projections

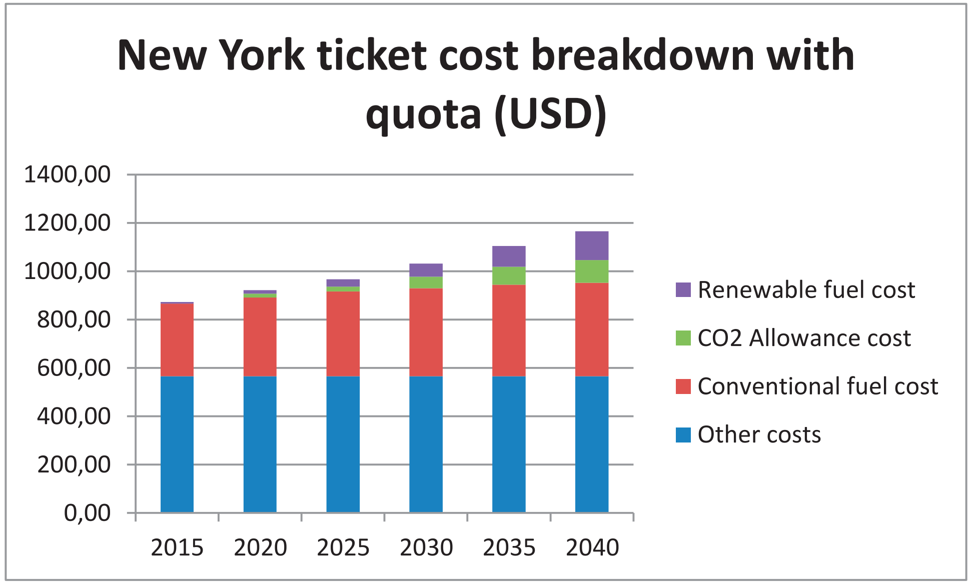

Figure 6. New York ticket price breakdown with HEFA-fuel with quota obligation, baseline projections

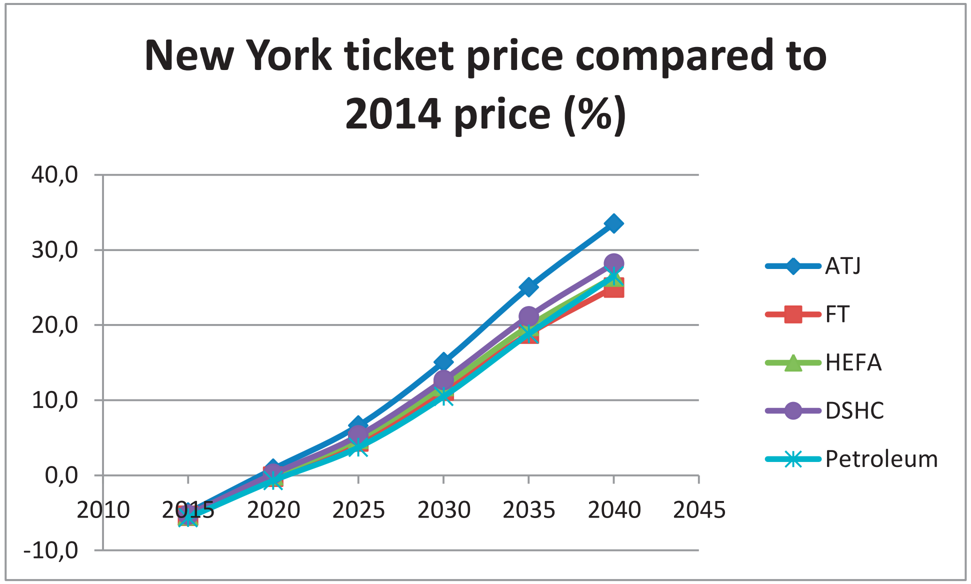

Figure 8. New York ticket price compared to 2014 price, baseline projections

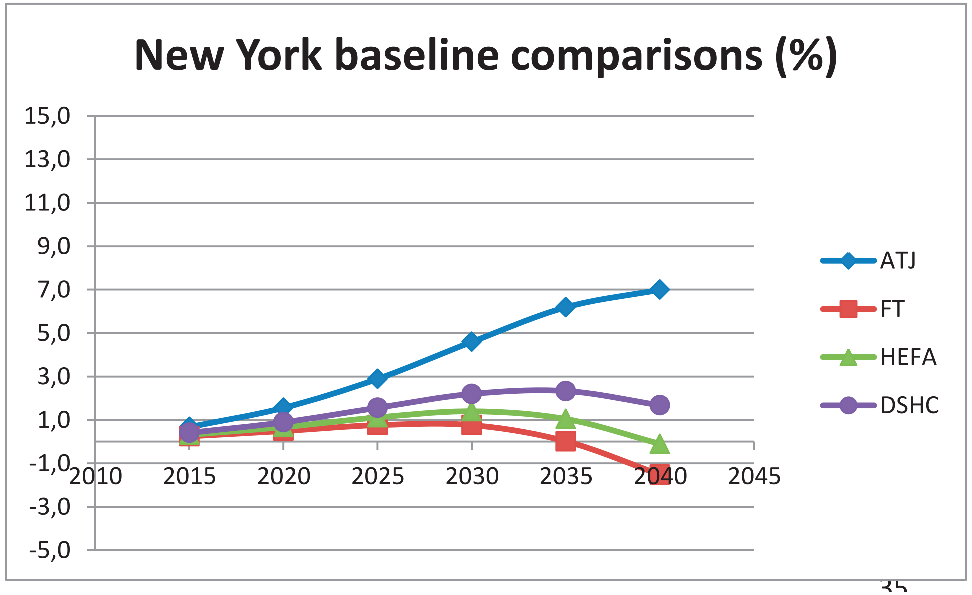

Figure 7. New York ticket price with quota obligation compared to no-action scenario, baseline projections

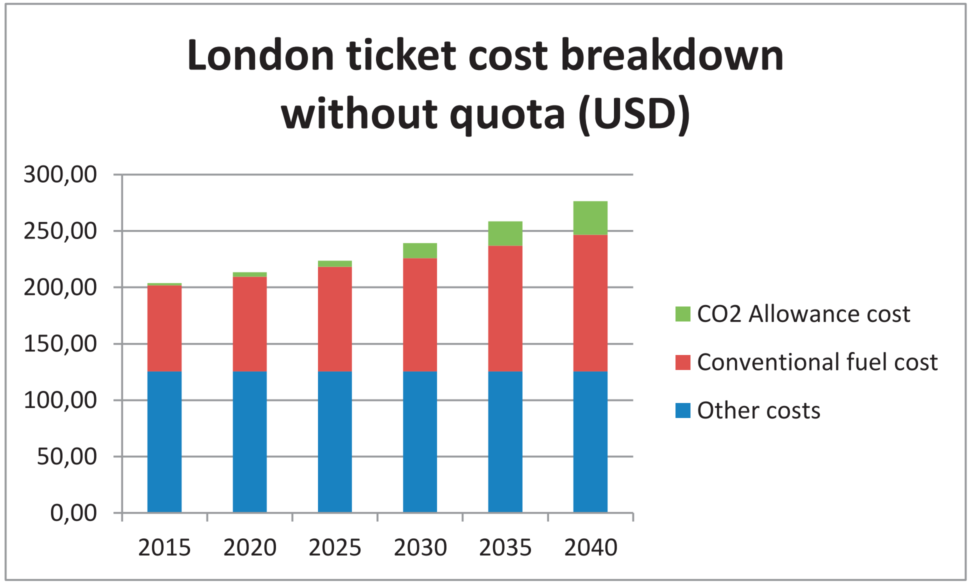

Figure 13. London ticket price breakdown in no-action scenario, baseline projections

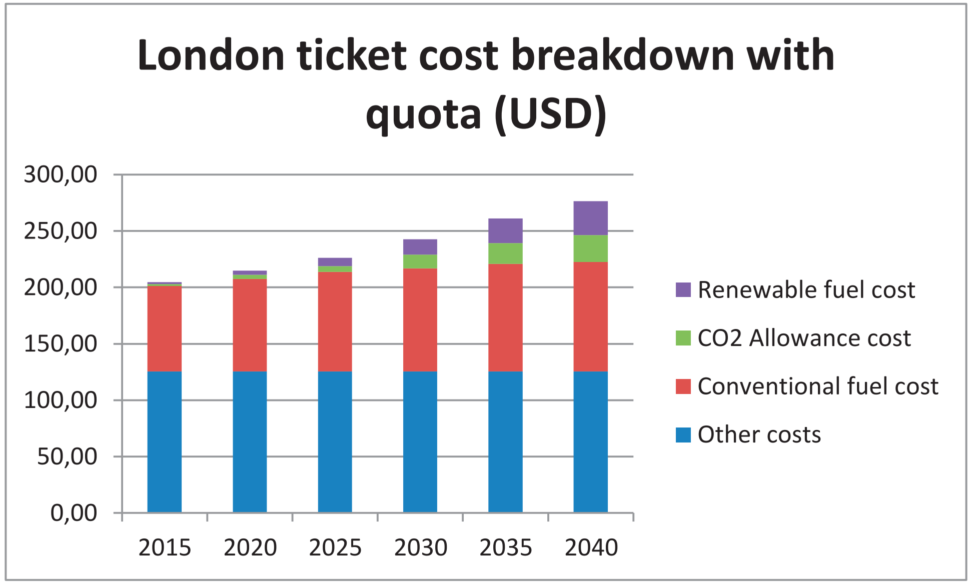

Figure 10. London ticket price breakdown with HEFA-fuel with quota obligation, baseline projections

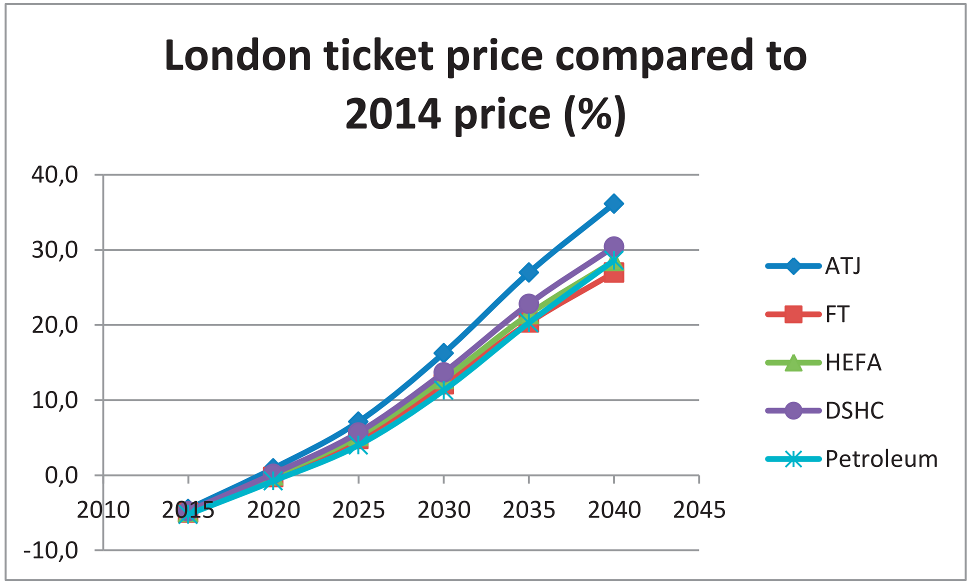

Figure 12. London ticket price compared to 2014 price, baseline projections

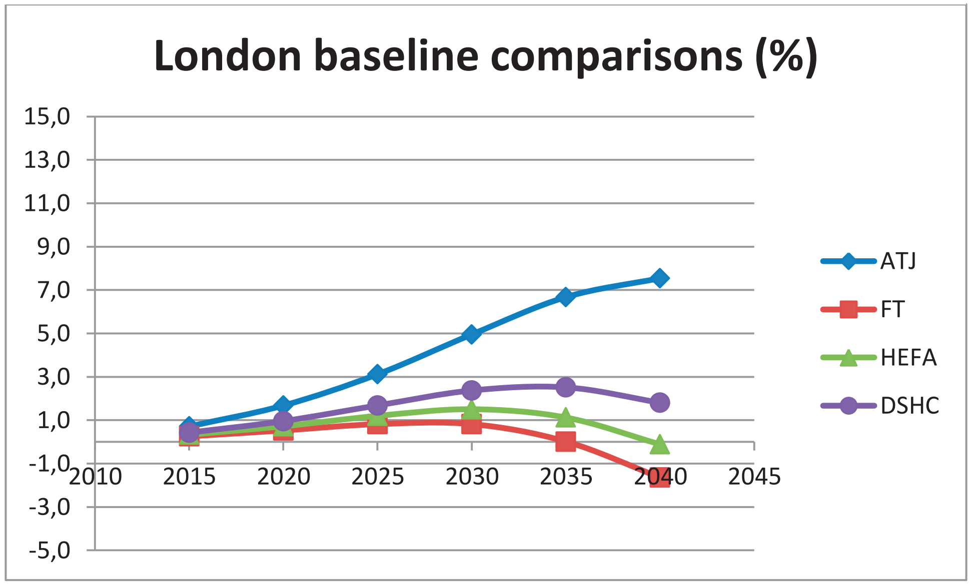

Figure 11. London ticket price with quota obligation compared to no-action scenario, baseline projections

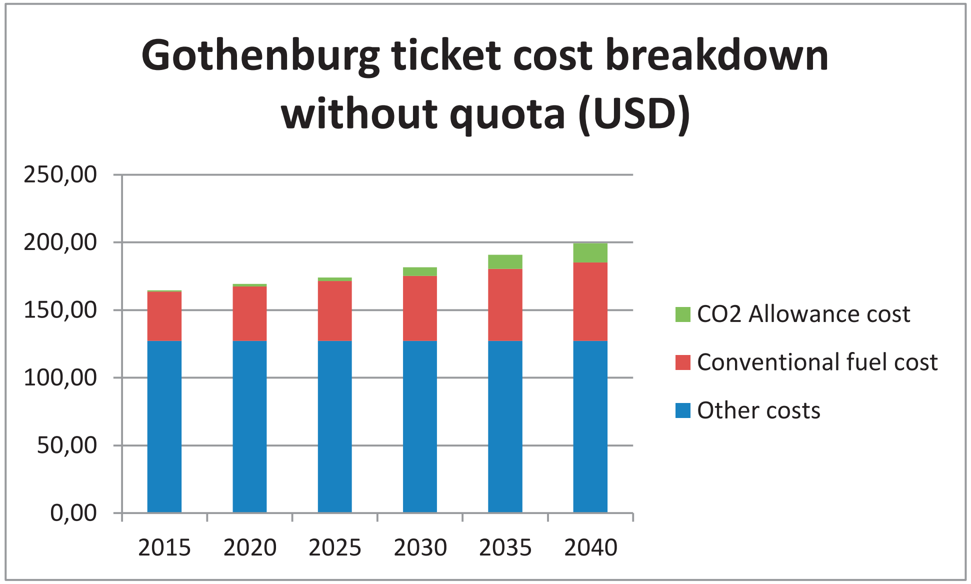

Figure 17. Gothenburg ticket price breakdown in no-action scenario, baseline projections

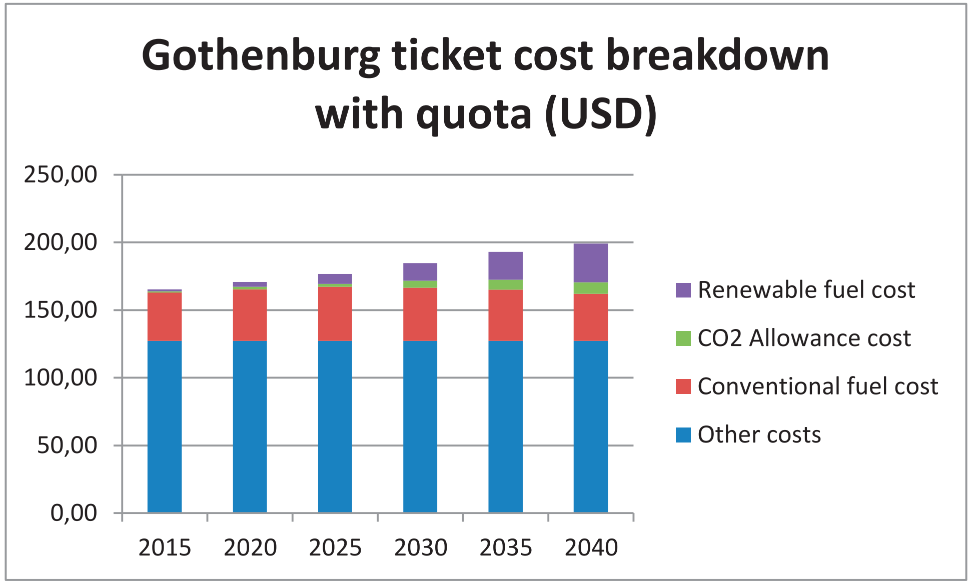

Figure 14. Gothenburg ticket price breakdown with HEFA-fuel with quota obligation, baseline projections

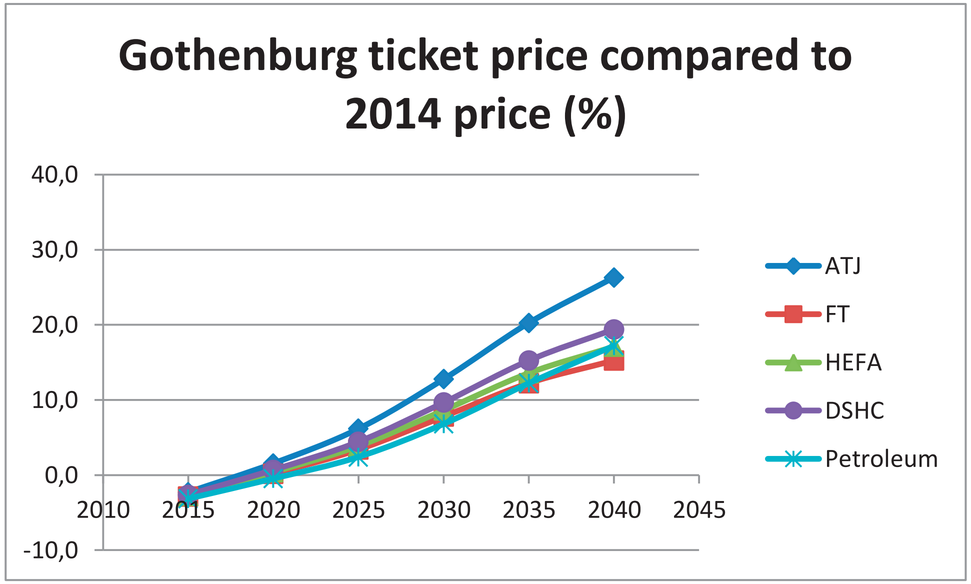

Figure 16. Gothenburg ticket price compared to 2014 price, baseline projections

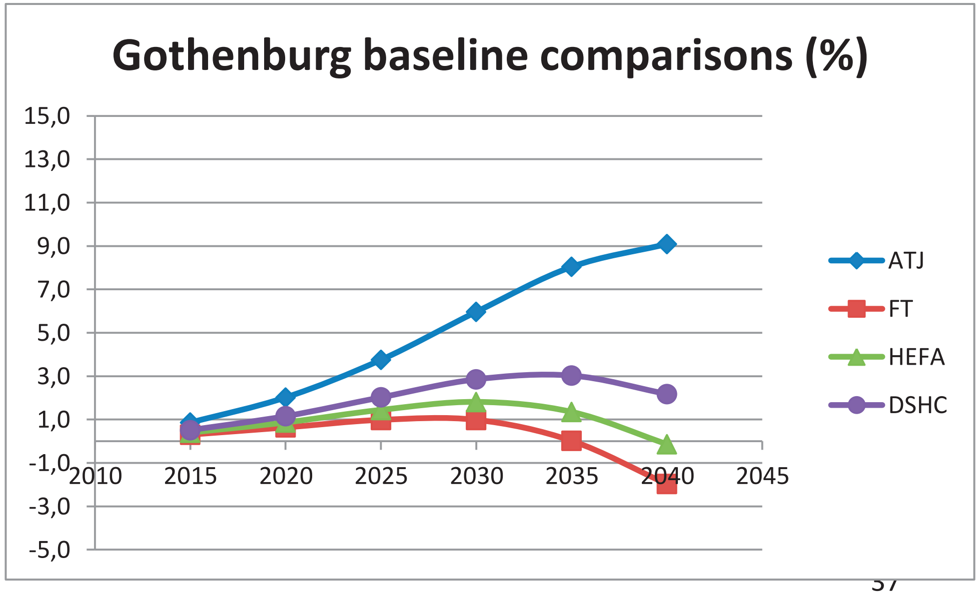

Figure 15. Gothenburg ticket price with quota obligation compared to no-action scenario, baseline projections

Chapter 7. Discussion

This study has shown that the introduction of a quota obligation for the Swedish Jet A-1 market could be feasible under a specific set of conditions. It is however not without obstacles, which will be discussed in this section.

7.1 Price changes

The calculations show that introducing a quota requirement would likely mean an increase over a no-action scenario in Jet A-1 price, and consequently ticket price, until at least 2035. At this point, given an increase in CO_2 costs and conventional jet fuel price, renewable fuels could become economically viable. As can be seen in Appendix B, there are also many combinations of scenarios where this is not the case and renewable fuels still requires subsidizing.

For the baseline scenarios, the total ticket price increases compared to 2014 levels are by 2040 expected to be between 34% and 25% for NY, 36% and 27% for London and 26% and 15% for Gothenburg. Compared to a no-action scenario where the only commodities changing in price are conventional fuel and CO_2, the quota obligated scenarios in 2040 ultimately have a price difference of -1,5% and +7% for NY, -1,6% and +7,5% for London and -2,0% and +9% for Gothenburg. In the year 2040, there are two baseline scenarios for each destination where the price using renewables is projected to decrease compared to that of conventional fuels, for the FT and HEFA routes.

When using certain combinations of the high and low projected prices of renewable and conventional fuels, the ticket price under a quota obligation when compared to the no-action scenario in 2040 is between a 34,8% increase to a 14,4% decrease. When low conventional fuel prices are combined with high renewable fuel prices and low costs of CO_2, the resulting ticket price is generally an increase. If conventional fuel is expensive, renewable fuel is cheap and CO_2 emissions are expensive, the ticket price under a quota obligation is often cheaper than in the no-action scenario. The baseline changes in price, while not miniscule, are likely not enough to drastically change the aviation industry. It could serve to drive passengers to use railroads and cheap road transport on short trips to a larger extent, but to what extent requires further research.

It can be seen in the graphs that the cost of CO_2 emissions will likely play a part in the total ticket prices, but is it not the most significant. Fuel costs are more important for the final price than emission prices are at the projected prices. The EU-ETS and the expected ICAO MBM may therefore not be the best drivers for stimulating production of aviation biofuel. They play some part, but it could be that more specific targeted incentives are needed for biofuels to be used to a greater extent.

7.2 Projections

The price differences of a baseline no-action scenario and the baseline scenarios using renewables are all in the same range. No baseline scenario under a quota obligation has a deviation of more than 10% from the same no-action scenario. As making forecasts that are supposed to be valid for a point in time 25 years ahead is immensely difficult and almost impossible, renewable fuels could well become viable before or even after when these calculations show they will.

The forecasted prices varied between the different fuels production routes, some more than others. Part of the variation can likely be attributed to when in time these projections were made as the global landscape changes rapidly due to conditions in the global economy, introduction of policy measures in different regions and socio-political conditions around the world. The region in which the projection is made likely has some bearing on the estimations as different assumptions can be made about costs of resources, willingness to invest and potential market uptake of the produced goods. Use of various feedstocks also yield slightly different MSP estimations.

An effort has been made to find as many sources for estimated MSPs as possible in order to produce a reasonable estimate for what the actual price of renewable fuels could amount to once the technologies have reached a steady state. It needs to be understood that projections are very difficult to make. In the case of bioenergy, the price of biomass plays a huge role in the final price. Policy measures stimulating a certain kind of bioenergy can limit the access of another technology to affordable feedstock. Technologies using vegetable oils are facing this problem today, with production of certain fuels being much more economically beneficial due to policies and methods of stimulating production. Some studies used in the estimation of production cost correlate well while others can be considered slight outliers.

Not all estimations have been made purely with aviation fuels in mind, but are more general estimations of what liquid hydrocarbons produced from that particular route of production could cost to produce. While the cost difference may not be significant, it needs to mentioned. Another fact that is important to have in mind is that once technologies have been developed and refined, it does not seem likely for just one single fuel to be used. The fuel used does not have to be only FT because it is currently projected to be the cheapest to produce. It could come from a mixture of FT, DSHC, HEFA and ATJ as a result of available production capacity, fluctuations in feedstock price and so on. In general the projected prices can be considered to all be in the same range, which is reassuring for producers of renewable fuel as there is no single production route that is vastly superior. All production routes have potential for playing a role in the future of aviation.

The vast amount of variables affecting the MSP is too large for all possibilities to be covered. This is not only valid for the estimations of renewable fuel, but also for the projected prices of conventional fuel and CO_2. The cost of CO_2 allowances under the EU-ETS is a good indication of the difficulty of designing and forecasting the price of a commodity in these cases. An unforeseen change in the global economy can upend the most extensively analyses and projections. With the amount of estimations used to generate the average projections presented in this report, all scenarios will still not have been covered, but hopefully more than if just one or two projections had been used. Using an average value does not generate an exact estimation, but it likely reduces the level of insecurity slightly.

7.3 Effect on aviation in Sweden

Aviation does however provide a service that is virtually irreplaceable in many cases, for example intercontinental travel over long distances. Travelling to NY by any other transport mode is currently very tedious and would be an ordeal for the passengers. A ticket price increase of 34% may cause some passengers to not make New York their destination, but a significant amount of people will likely still make the trip. The price changes could have an effect on the rate at which air travel is utilized but it appears more likely for it to have an effect on the way airlines design their route strategies. Swedish airports are currently nodes of a couple of non-stop long haul routes. The fierce competition among airlines could hamper the effectiveness of a quota obligation if it is only introduced on the Swedish market. Airlines could choose to route travel through a hub outside of Sweden if the increased cost of fuel makes flying long haul routes less competitive. As the price increases would be small to begin with, it is not sure if this would be the case in practice, but it is a possibility.

Depending on where an incoming flight is arriving from and then departing to, they may avoid refueling in Sweden altogether. There is a maximum landing weight limit for aircraft and if enough fuel is retained onboard without exceeding the limit, this could become a way for airlines to avoid buying fuel in Sweden. These qualms are however theoretical and are not sure to come to fruition. Aviation fuel differs in price across airports not only on an international level, but also domestically.

On the short haul routes, such as domestic, a price change could drive passengers to use railroad or road transportation instead of aviation. As with international travel, aviation has the advantage of taking less time than road and rail transportation, but the difference is smaller for shorter routes. An alternative if it is deemed impossible for international use is designing a system purely for Sweden's domestic market. As it would then not effect international aviation, the potential legal obstacle would become a non-issue. In practice, due to the fuel infrastructure being designed the way it is, all fuel users would still be using some amount of renewable fuel, but only airlines with domestic traffic would be paying the premium for it. The accounting procedure would be slightly more difficult as fuel sellers would be required to know the destination of the purchasing aircraft in order to make sure the quota obligation is fulfilled. As the amounts required for the domestic market would be significantly smaller than for the international market, the positive effects of a quota obligation in terms of stimulating renewable fuel production would be diminished by a large amount.

Judging from the fact that the most travelled aviation route in Sweden is Stockholm to Gothenburg is however an indication that a slight increase in price might not change much. Stockholm and Gothenburg already have several alternatives for transportation and aviation still exists. It fills an important role that is sometimes overlooked, namely that passengers may not have Stockholm or Gothenburg as their point of origin. Travelling from Gothenburg through Stockholm may just be a layover en route to a destination much further away. The alternative of taking the train still exists in these cases, but travelling by air for the entirety of the trip is often much more convenient as the transfer situation is simplified. At some price level, casual travellers may however find the cost of air travel intolerable and will instead choose other modes of transportation. Investigating the price elasticity and the willingness to pay for air travel has not been a part of this project, but is an area that will need further investigation if the Swedish Transport Agency wishes to further proceed with this policy measure.

7.4 Quota obligation effectiveness

Another topic in need of more research is the current production capacity. It was assumed in the projections for ticket prices that the steady state-price of renewable fuel would be in effect for 2015. This will likely not hold true as it would require the production technology to develop very rapidly. The low percentage of blending required should however do little to affect the final ticket price. By 2020 the rate of production will hopefully have picked up and prices might have decreased.

The rate at which prices fall from their currently high levels will to some extent depend on how big the demand for renewable fuels will be. Estimating this demand is difficult as there are currently no binding legislation within the EU or the world in general requiring the use of renewable fuels for aviation. It can be assumed that if more legislation and binding targets would be put in place the demand for biofuels would be likely to grow. Introducing a quota obligation on an EU-ETS level would serve this purpose even better than doing it on just a Swedish scale. For Sweden, 2% of the total amount of jet fuel sold in 2012 would be equal to about 22000 m^3 (SPBI, 2013). The same amount on an EU-ETS scale would be roughly 1.2 million m^3, a substantially larger amount (Eurostat, 2014a). Circumventing the obligation by avoiding refueling within the countries covered by the EU-ETS would be much more difficult in a larger system. Putting up with extra travel time in order to get cheaper tickets is something travellers do today, but there is likely a limit to how far they are willing to go. Should a trip to New York for example be cheaper to route through Dubai, the travel time could effectively more than double.

Introducing environmental legislation affecting aviation and its economy is often ill received as evidenced by the EU-ETS. A quota obligation seems to be permissible under current legislation, something the EU asserted the EU-ETS also was. Discussions would have to take place to gauge the international aviation community’s reception of this suggestion for a policy instrument from a legal perspective. This policy measure could serve as a complement to the EU-ETS but it could also be redundant in a way, since it would force a specific measure of reducing aviation’s emission on airlines. The synergy effects between emission MBMs and a quota obligation would need to be looked at closer should a quota obligation be introduced. They do not serve the exact same purpose though, as a quota obligation would not only have as a target to reduce the emissions from aviation but also to stimulate a development of the renewable fuel industry. This could come as a side effect of an MBM, but it is not the main target.

Chapter 8. Conclusions

This study has shown that the introduction of a quota obligation for the Swedish Jet A-1 market could be feasible under a specific set of conditions. The two conditions that seem to have the most effect on the viability of renewable fuels are the price developments of conventional and renewable fuel production. Should an obligation be introduced, airline ticket prices are likely to increase by a higher amount than they would in a no-action scenario. In the projected baseline cases, the increase in ticket prices stemming from increased fuel costs would generally be at most 9% in the year 2040 according to calculations. The total price increase compared to 2014 levels would be at most 36% in the year 2040 at a 40% quota obligation using baseline projections and assumptions. A scenario with no quota obligation is expected to have a price increase of 29% at the same point in time. An increase of 36% is not likely to have huge ramifications for the usage rate of aviation in general, but as discussed in Chapter 7, it could have an effect on the Swedish aviation market if the price increases in Sweden are higher than in surrounding countries. As pricing of air travel tickets is very competitive, even small changes in fuel prices could cause long haul routes from Sweden lose competitiveness when compared to routes from other nearby countries. Feeder routes to other European hubs would likely become more prevalent.

Introducing a quota obligation system on an EU or EEA level makes more sense, as it would be more difficult to bypass the requirement through altering the route network. The amounts required to fulfill a quota would also be much greater than if a quota is solely applied to Sweden, likely driving technology development more rapidly than it would just for Sweden. This has not been discussed in depth on the international arena and due to the difficulties the EU-ETS has faced, placing further environmental regulation on aviation appears to be an unlikely turn of events before ICAO presents its global MBM. A quota obligation does appear to be permissible under current bi- and multilateral conventions and agreements, but whether the international aviation community would agree remains to be seen until it would actually be passed into legislation.

Assuming the baseline projections are accurate, renewable fuels will eventually become the most economically viable traditional aviation fuel. When this point in time comes will to some extent depend on how quickly renewable fuels are adopted. At present, this is however not the case. Significant investments will need to be made in production facilities, something which could be facilitated through the use of a quota obligation and other policy measures. For this reason a quota obligation appears to serve its purpose. As aviation is the only reasonable mode of transportation for intercontinental travel, and will continue to be so for the foreseeable future, renewable fuels are not only useful, but absolutely necessary. This point could be seen as an incentive to introduce a quota obligation. The Swedish market may suffer slightly in the short term, but it could be helpful to get a head start in the long term.

Should a quota obligation be introduced, placing the obligation on the fuel sellers appears to be the most functional route. It would likely reduce the amount of administration required when compared to placing the obligation on the fuel users, due to the much lower amount of actors on the fuel supplier market. The fuel companies also control the fuel infrastructure and, and as discussed, the further upstream in the distribution network the fuel is introduced, the easier it is. Fuel depots at harbor hubs are likely a suitable place for fuel to be introduced, partly because it makes compliance with fuel standards easier, and partly because much of the fuel passes through these hubs.

From a pragmatic perspective, the penalties of introducing a quota obligation on jet fuel in Sweden appear to outweigh the benefits at present time. The system risks not producing desired effects while making Swedish aviation less competitive. One of the arguments for a quota obligation is that of Sweden blazing the trail and showing other countries that using renewables within aviation is possible. If other countries with larger stake in the international aviation industry would follow is unclear, but at present it does not seem likely. Given more time for aviation biofuels to mature and if introduced on a larger scale, a quota obligation could become a more viable policy measure, but at present it does not appear to have the required qualities.

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Appendix A. Price projections

Fuel type	Year	Region	Feedstock	Source	Price estimate (USD/l)		
					High	Baseline	Low
Jet A-1	2013	EU	Petroleum	(European Commission, 2014a)	-	1.20	-
Jet kerosene	2012	USA	Petroleum	(EIA, 2014)	-	0.82	-
Jet kerosene	2020	USA	Petroleum	(EIA, 2014)	1.04	0.70	0.51
Jet kerosene	2030	USA	Petroleum	(EIA, 2014)	1.18	0.85	0.55
Jet kerosene	2040	USA	Petroleum	(EIA, 2014)	1.38	1.00	0.58
FT	-	-	Switchgrass	(IATA, 2013b)	2.52	1.97	1.42
FT	-	-	Natural gas	(IATA, 2013b)	1.28	1.03	0.77
FT	-	Sweden	Wood chips	(Ekbom, Hjerpe, Hagström, & Hermann, 2009)	1.18	-	0.71
FT	2020-2025	-	Lignocellulose	(IPCC, 2012)	0.88	0.65	0.42
FT	2020	Norway	Wood products	(Ramböll, 2013)	1.62	1.48	1.37
FT	2030	Norway	Wood products	(Ramböll, 2013)	1.27	1.03	0.76
HEFA	-	-	Soybean	(IATA, 2013b)	1.27	1.20	1.16
HEFA	-	-	Tallow	(IATA, 2013b)	1.16	1.09	1.05
HEFA	-	-	Yellow grease	(IATA, 2013b)	0.99	0.92	0.88
HEFA	-	-	Soybean	(Pearlson,	1.95	1.19	0.97

Fuel type	Year	Region	Feedstock	Source	Price estimate (USD/l)		
				Wollersheim, & Hileman, 2012)			
HEFA	2020	USA	Soybean/Camelina/Pennycress	(Winchester, McConnachie, Wollersheim, & Waitz, 2013)	1.65	1.43	0.99
HEFA	2020-2025	-	Vegetable oil	(IPCC, 2012)	1.04	0.79	0.53
HEFA	2020-2025	-	Algae oil	(IPCC, 2012)	4.90	2.98	1.04
HEFA	-	USA	Algae oil	(Milbrandt, Kinchin, & McCormick, 2013)	5.43	-	2.60
ATJ	-	-	Sugar cane	(IATA, 2013b)	2.34	1.37	0.61
ATJ	-	-	Corn grain	(IATA, 2013b)	3.65	1.57	0.71
ATJ	-	-	Switchgrass	(IATA, 2013b)	6.28	2.01	1.09
ATJ	2020	Norway	Bioethanol	(Ramböll, 2013)	3.61	3.44	3.26
ATJ	2030	Norway	Bioethanol	(Ramböll, 2013)	2.58	2.23	1.89
DSHC	-	-	Sugar cane	(Staples, o.a., 2014)	2.63	1.56	0.61
DSHC	-	-	Corn grain	(Staples, o.a., 2014)	3.65	1.75	0.84
DSHC	-	-	Switchgrass	(Staples, o.a., 2014)	6.30	2.30	1.09
DSHC	2020-2030	-	Lignocellulose	(IPCC, 2012)	1.04	0.63	0.21
PTJ	2020-2030	-	Lignocellulose	(IPCC, 2012)	0.84	0.67	0.49

Appendix B. Relative price changes

B.1 Total ticket cost with quota obligation relative to ticket cost without quota obligation

In the following tables, the calculated fuel costs once a quota obligation has been introduced is compared with the calculated fuel costs for the no-action scenario. Each destination is displayed on three pages, one for each CO_2 allowance cost scenario. The fuel costs under a quota obligation are displayed in the larger table and the fuel costs in a no-action scenario are displayed in the smaller table. The costs are given in 2012 USD.

A red cell indicates that the total fuel cost per passenger is more expensive than in the corresponding no-action scenario, while a green cell indicates that the fuel cost is less expensive. The vertical columns indicates projections for conventional jet fuel at specific stated points in time. H, B and L indicate the projected High, Baseline and Low price projection for the given year. The horizontal rows indicate the high, baseline and low projected minimum selling price for the four renewable fuels examined in this price evaluation. The cell where a row and column intersect represents that combination of scenarios' total fuel-associated cost for the given route. If a cell for example contains "602.1" and is colored green, this means that for the given set of circumstances, the total costs of fuel and emissions of CO_2 amount to are lower than in the no-action scenario at that point in time.

Stockholm – New York, total fuel cost per passenger with quota obligation, baseline CO_2 cost scenario

		2015			2020			2025			2030			2035			2040		
		H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
ATJ	High	424,9	317,3	265,7	508,4	381,3	275,3	591,8	451,4	323,4	711,0	556,7	410,3	845,5	685,7	514,7	968,5	801,6	617,3
	Baseline	418,1	310,5	258,8	491,4	364,2	258,3	557,8	417,4	289,4	649,6	495,4	349,0	746,8	586,9	416,0	832,3	665,4	481,1
	Low	415,4	307,8	256,2	484,7	357,6	251,6	544,5	404,1	276,1	625,7	471,5	325,1	708,2	548,4	377,5	779,2	612,2	427,9
FT	High	415,2	307,6	255,9	484,1	357,0	251,0	543,3	402,9	274,9	623,6	469,3	322,9	704,8	544,9	374,0	774,4	607,4	423,1
	Baseline	414,2	306,6	255,0	481,7	354,5	248,6	538,4	398,0	270,0	614,7	460,5	314,1	690,5	530,7	359,7	754,7	587,8	403,5
	Low	412,8	305,2	253,6	478,2	351,0	245,1	531,4	391,0	262,9	602,1	447,8	301,4	670,1	510,3	339,3	726,6	559,7	375,4
HEFA	High	418,8	311,2	259,6	493,3	366,1	260,2	561,6	421,2	293,2	656,5	502,2	355,9	757,8	598,0	427,0	847,5	680,6	496,3
	Baseline	414,8	307,2	255,6	483,2	356,1	250,1	541,4	401,0	273,0	620,2	465,9	319,6	699,3	539,5	368,5	766,9	599,9	415,6
	Low	413,9	306,3	254,6	480,8	353,7	247,7	536,7	396,3	268,2	611,6	457,4	311,0	685,5	525,7	354,7	747,8	580,9	396,6
DSHC	High	423,6	316,1	264,4	505,3	378,2	272,2	585,6	445,2	317,2	699,8	545,5	399,1	827,5	667,7	496,7	943,7	776,7	592,4
	Baseline	415,6	308,0	256,4	485,3	358,1	252,1	545,5	405,1	277,1	627,6	473,3	326,9	711,2	551,4	380,4	783,3	616,3	432,0
	Low	411,8	304,2	252,6	475,8	348,6	242,7	526,6	386,2	258,1	593,4	439,2	292,8	656,2	496,4	325,4	707,4	540,5	356,2

Stockholm – New York, total fuel cost per passenger without quota obligation, baseline CO_2 cost scenario

	2015			2020			2025			2030			2035			2040		
	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
Conventional	413,0	304,3	252,1	480,3	349,9	241,2	538,5	390,7	256,0	622,6	453,0	292,2	716,8	529,9	329,9	809,5	600,9	370,5

Stockholm – New York, total fuel cost per passenger with quota obligation, high CO_2 cost scenario

		2015			2020			2025			2030			2035			2040		
		H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
ATJ	High	424,9	317,3	265,7	515,8	388,7	282,7	601,9	461,5	333,5	735,1	580,8	434,5	882,5	722,7	551,7	1015,9	849,0	664,6
	Baseline	418,1	310,5	258,8	498,8	371,6	265,7	567,9	427,5	299,4	673,8	519,5	373,2	783,7	623,9	452,9	879,6	712,7	528,4
	Low	415,4	307,8	256,2	492,1	365,0	259,0	554,6	414,2	286,2	649,9	495,6	349,3	745,2	585,4	414,4	826,5	659,6	475,3
FT	High	415,2	307,6	255,9	491,5	364,4	258,4	553,4	413,0	285,0	647,7	493,5	347,1	741,7	581,9	410,9	821,7	654,8	470,5
	Baseline	414,2	306,6	255,0	489,1	361,9	256,0	548,5	408,1	280,0	638,9	484,6	338,3	727,5	567,7	396,7	802,1	635,1	450,8
	Low	412,8	305,2	253,6	485,6	358,4	252,5	541,5	401,0	273,0	626,3	472,0	325,6	707,1	547,3	376,3	774,0	607,0	422,7
HEFA	High	418,8	311,2	259,6	500,7	373,5	267,6	571,7	431,3	303,3	680,7	526,4	380,0	794,8	635,0	464,0	894,9	727,9	543,6
	Baseline	414,8	307,2	255,6	490,6	363,5	257,5	551,5	411,1	283,1	644,4	490,1	343,7	736,3	576,5	405,5	814,2	647,3	463,0
	Low	413,9	306,3	254,6	488,2	361,1	255,1	546,8	406,3	278,3	635,8	481,5	335,2	722,5	562,7	391,7	795,2	628,2	443,9
DSHC	High	423,6	316,1	264,4	512,7	385,6	279,6	595,7	455,3	327,3	723,9	569,6	423,3	864,5	704,7	533,7	991,0	824,1	639,8
	Baseline	415,6	308,0	256,4	492,7	365,5	259,5	555,6	415,2	287,2	651,7	497,5	351,1	748,2	588,4	417,4	830,6	663,7	479,4
	Low	411,8	304,2	252,6	483,2	356,0	250,1	536,7	396,2	268,2	617,6	463,3	317,0	693,2	533,4	362,4	754,7	587,8	403,5

Stockholm – New York, total fuel cost per passenger without quota obligation, high CO_2 cost scenario

	2015			2020			2025			2030			2035			2040		
	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
Conventional	413,0	304,3	252,1	487,9	357,5	248,8	549,2	401,4	266,6	649,1	479,6	318,8	760,1	573,1	373,2	868,7	660,1	429,7

Stockholm – New York, total fuel cost per passenger with quota obligation, low CO_2 cost scenario

		2015			2020			2025			2030			2035			2040		
		H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
ATJ	High	424,9	317,3	265,7	501,0	373,9	267,9	581,8	441,3	313,3	686,8	532,5	386,1	808,6	648,7	477,8	921,2	754,3	570,0
	Baseline	418,1	310,5	258,8	484,0	356,8	250,9	547,7	407,3	279,3	625,5	471,2	324,8	709,8	550,0	379,0	785,0	618,0	433,7
	Low	415,4	307,8	256,2	477,4	350,2	244,2	534,4	394,0	266,0	601,6	447,3	300,9	671,3	511,4	340,5	731,8	564,9	380,6
FT	High	415,2	307,6	255,9	476,8	349,6	243,6	533,2	392,8	264,8	599,4	445,1	298,8	667,8	508,0	337,0	727,0	560,1	375,8
	Baseline	414,2	306,6	255,0	474,3	347,1	241,2	528,3	387,9	259,9	590,6	436,3	289,9	653,5	493,7	322,8	707,4	540,5	356,1
	Low	412,8	305,2	253,6	470,8	343,6	237,7	521,3	380,9	252,8	577,9	423,6	277,3	633,2	473,3	302,4	679,3	512,3	328,0
HEFA	High	418,8	311,2	259,6	485,9	358,7	252,8	551,5	411,1	283,1	632,3	478,1	331,7	720,8	561,0	390,0	800,2	633,3	448,9
	Baseline	414,8	307,2	255,6	475,8	348,7	242,7	531,3	390,9	262,9	596,0	441,8	295,4	662,4	502,5	331,6	719,5	552,6	368,3
	Low	413,9	306,3	254,6	473,4	346,3	240,3	526,6	386,2	258,1	587,5	433,2	286,8	648,6	488,7	317,8	700,5	533,6	349,2
DSHC	High	423,6	316,1	264,4	497,9	370,8	264,8	575,5	435,1	307,1	675,6	521,3	375,0	790,5	630,7	459,7	896,3	729,4	545,1
	Baseline	415,6	308,0	256,4	477,9	350,7	244,7	535,4	395,0	267,0	603,4	449,1	302,8	674,2	514,4	343,4	735,9	569,0	384,7
	Low	411,8	304,2	252,6	468,4	341,2	235,3	516,5	376,1	248,0	569,3	415,0	268,6	619,2	459,4	288,4	660,1	493,1	308,8

Stockholm – New York, total fuel cost per passenger without quota obligation, low CO_2 cost scenario

	2015			2020			2025			2030			2035			2040		
	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
Conventional	413,0	304,3	252,1	472,7	342,3	233,6	527,9	380,1	245,4	596,0	426,5	265,6	673,6	486,6	286,7	750,4	541,7	311,3

Stockholm – London, total fuel cost per passenger with quota obligation, baseline CO_2 cost scenario

		2015			2020			2025			2030			2035			2040		
		H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
ATJ	High	108,8	81,7	68,7	127,9	95,9	69,3	148,9	113,6	81,4	178,9	140,1	103,2	212,7	172,5	129,5	243,7	201,7	155,3
	Baseline	107,1	80,0	67,0	123,6	91,6	65,0	140,3	105,0	72,8	163,4	124,6	87,8	187,9	147,7	104,7	209,4	167,4	121,0
	Low	106,4	79,3	66,3	122,0	90,0	63,3	137,0	101,7	69,5	157,4	118,6	81,8	178,2	138,0	95,0	196,0	154,0	107,7
FT	High	106,4	79,4	66,4	122,0	90,0	63,4	137,1	101,8	69,6	157,6	118,8	82,0	178,5	138,3	95,2	196,4	154,4	108,1
	Baseline	106,1	79,0	66,0	121,2	89,2	62,5	135,4	100,1	67,9	154,6	115,7	78,9	173,6	133,4	90,3	189,7	147,7	101,3
	Low	105,7	78,7	65,7	120,3	88,3	61,6	133,7	98,3	66,1	151,4	112,6	75,8	168,5	128,3	85,3	182,7	140,7	94,3
HEFA	High	107,3	80,2	67,2	124,1	92,1	65,5	141,3	106,0	73,8	165,2	126,4	89,5	190,7	150,4	107,4	213,2	171,2	124,9
	Baseline	106,2	79,2	66,2	121,6	89,6	62,9	136,2	100,9	68,7	156,0	117,2	80,4	175,9	135,7	92,7	192,9	150,9	104,6
	Low	106,0	78,9	65,9	121,0	89,0	62,3	135,0	99,7	67,5	153,9	115,1	78,2	172,5	132,3	89,2	188,1	146,1	99,8
DSHC	High	108,5	81,4	68,4	127,1	95,1	68,5	147,3	112,0	79,8	176,0	137,2	100,4	208,2	168,0	125,0	237,4	195,4	149,0
	Baseline	106,5	79,4	66,4	122,1	90,1	63,4	137,2	101,9	69,7	157,9	119,1	82,3	178,9	138,7	95,7	197,1	155,1	108,7
	Low	105,5	78,4	65,4	119,7	87,7	61,1	132,5	97,2	64,9	149,3	110,5	73,7	165,1	124,9	81,9	178,0	136,0	89,6

Stockholm – London, total fuel cost per passenger without quota obligation, baseline CO_2 cost scenario

	2015			2020			2025			2030			2035			2040		
	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
Conventional	105,8	78,5	65,3	120,8	88,0	60,7	135,5	98,3	64,4	156,6	114,0	73,5	180,3	133,3	83,0	203,7	151,2	93,2

Stockholm – London, total fuel cost per passenger with quota obligation, high CO_2 cost scenario

		2015			2020			2025			2030			2035			2040		
		H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
ATJ	High	109,7	82,7	69,7	129,8	97,8	71,1	151,4	116,1	83,9	184,9	146,1	109,3	222,0	181,8	138,8	255,6	213,6	167,2
	Baseline	108,0	80,9	68,0	125,5	93,5	66,8	142,9	107,5	75,3	169,5	130,7	93,9	197,2	157,0	114,0	221,3	179,3	132,9
	Low	107,3	80,3	67,3	123,8	91,8	65,2	139,5	104,2	72,0	163,5	124,7	87,9	187,5	147,3	104,3	207,9	165,9	119,6
FT	High	107,4	80,3	67,3	123,9	91,9	65,2	139,6	104,3	72,1	163,7	124,9	88,0	187,8	147,6	104,5	208,3	166,3	120,0
	Baseline	107,0	80,0	67,0	123,0	91,0	64,4	137,9	102,6	70,4	160,6	121,8	85,0	182,9	142,7	99,6	201,6	159,6	113,2
	Low	106,7	79,6	66,6	122,1	90,2	63,5	136,2	100,9	68,7	157,5	118,7	81,9	177,8	137,6	94,6	194,6	152,6	106,2
HEFA	High	108,2	81,1	68,1	126,0	94,0	67,3	143,8	108,5	76,3	171,2	132,4	95,6	200,0	159,7	116,7	225,1	183,1	136,8
	Baseline	107,2	80,1	67,1	123,4	91,4	64,8	138,8	103,4	71,2	162,1	123,3	86,5	185,2	145,0	102,0	204,8	162,8	116,5
	Low	107,0	79,9	66,9	122,8	90,8	64,2	137,6	102,2	70,0	160,0	121,1	84,3	181,8	141,6	98,5	200,1	158,1	111,7
DSHC	High	109,4	82,3	69,4	129,0	97,0	70,3	149,9	114,5	82,3	182,1	143,3	106,5	217,5	177,3	134,3	249,3	207,3	161,0
	Baseline	107,4	80,3	67,3	123,9	92,0	65,3	139,8	104,5	72,3	164,0	125,2	88,3	188,2	148,0	105,0	209,0	167,0	120,6
	Low	106,4	79,4	66,4	121,6	89,6	62,9	135,0	99,7	67,5	155,4	116,6	79,7	174,4	134,2	91,2	189,9	147,9	101,5

Stockholm – London, total fuel cost per passenger without quota obligation, high CO_2 cost scenario

	2015			2020			2025			2030			2035			2040		
	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
Conventional	106,8	79,4	66,3	122,7	89,9	62,6	138,2	101,0	67,1	163,3	120,7	80,2	191,2	144,2	93,9	218,6	166,1	108,1

Stockholm – London, total fuel cost per passenger with quota obligation, low CO_2 cost scenario

		2015			2020			2025			2030			2035			2040		
		H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
ATJ	High	107,8	80,8	67,8	126,0	94,1	67,4	146,4	111,0	78,8	172,8	134,0	97,1	203,4	163,2	120,2	231,8	189,8	143,4
	Baseline	106,1	79,1	66,1	121,8	89,8	63,1	137,8	102,5	70,3	157,4	118,5	81,7	178,6	138,4	95,3	197,5	155,5	109,1
	Low	105,5	78,4	65,4	120,1	88,1	61,4	134,5	99,1	66,9	151,3	112,5	75,7	168,9	128,7	85,7	184,1	142,1	95,7
FT	High	105,5	78,4	65,4	120,1	88,2	61,5	134,5	99,2	67,0	151,5	112,7	75,9	169,2	129,0	85,9	184,5	142,5	96,1
	Baseline	105,1	78,1	65,1	119,3	87,3	60,6	132,9	97,5	65,3	148,5	109,7	72,8	164,3	124,1	81,0	177,7	135,7	89,4
	Low	104,8	77,7	64,7	118,4	86,4	59,8	131,1	95,8	63,6	145,3	106,5	69,7	159,2	119,0	76,0	170,8	128,8	82,4
HEFA	High	106,3	79,3	66,3	122,2	90,3	63,6	138,8	103,4	71,2	159,1	120,3	83,4	181,4	141,1	98,1	201,3	159,3	112,9
	Baseline	105,3	78,2	65,2	119,7	87,7	61,1	133,7	98,4	66,1	150,0	111,1	74,3	166,6	126,4	83,4	181,0	139,0	92,7
	Low	105,1	78,0	65,0	119,1	87,1	60,5	132,5	97,2	64,9	147,8	109,0	72,2	163,2	123,0	79,9	176,2	134,2	87,9
DSHC	High	107,5	80,5	67,5	125,3	93,3	66,6	144,8	109,5	77,3	170,0	131,2	94,3	198,9	158,7	115,7	225,5	183,5	137,1
	Baseline	105,5	78,4	65,4	120,2	88,2	61,6	134,7	99,4	67,2	151,8	113,0	76,2	169,6	129,4	86,4	185,1	143,2	96,8
	Low	104,6	77,5	64,5	117,8	85,8	59,2	129,9	94,6	62,4	143,2	104,4	67,6	155,8	115,6	72,6	166,1	124,1	77,7

Stockholm – London, total fuel cost per passenger without quota obligation, low CO_2 cost scenario

	2015			2020			2025			2030			2035			2040		
	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
Conventional	104,9	77,5	64,4	118,9	86,1	58,8	132,8	95,6	61,7	150,0	107,3	66,8	169,5	122,4	72,1	188,8	136,3	78,3

Stockholm – Gothenburg, total fuel cost per passenger with quota obligation, baseline CO_2 cost scenario

		2015			2020			2025			2030			2035			2040		
		H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
ATJ	High	53,2	40,5	34,3	64,3	49,4	37,1	77,3	61,4	46,8	95,8	79,1	63,3	116,7	100,8	83,8	135,1	120,1	103,5
	Baseline	51,6	38,8	32,7	60,2	45,4	33,0	69,1	53,2	38,7	81,1	64,4	48,6	93,0	77,1	60,1	102,4	87,4	70,9
	Low	50,9	38,2	32,1	58,6	43,8	31,4	65,9	50,0	35,5	75,3	58,7	42,9	83,8	67,9	50,9	89,7	74,7	58,1
FT	High	51,0	38,2	32,1	58,6	43,8	31,4	66,0	50,1	35,6	75,5	58,9	43,1	84,1	68,2	51,2	90,1	75,1	58,5
	Baseline	50,6	37,9	31,8	57,8	43,0	30,6	64,4	48,5	34,0	72,6	56,0	40,2	79,4	63,5	46,5	83,6	68,6	52,1
	Low	50,3	37,6	31,4	57,0	42,2	29,8	62,8	46,8	32,3	69,6	53,0	37,2	74,6	58,7	41,7	77,0	62,0	45,4
HEFA	High	51,8	39,0	32,9	60,6	45,8	33,4	70,0	54,1	39,6	82,7	66,1	50,3	95,7	79,8	62,8	106,1	91,1	74,5
	Baseline	50,8	38,0	31,9	58,2	43,4	31,0	65,2	49,3	34,7	74,0	57,4	41,6	81,7	65,8	48,8	86,8	71,8	55,2
	Low	50,6	37,8	31,7	57,7	42,8	30,5	64,1	48,1	33,6	72,0	55,3	39,5	78,4	62,5	45,5	82,2	67,2	50,6
DSHC	High	52,9	40,2	34,0	63,5	48,7	36,3	75,8	59,9	45,3	93,1	76,4	60,6	112,4	96,5	79,5	129,1	114,1	97,6
	Baseline	51,0	38,2	32,1	58,7	43,9	31,5	66,2	50,3	35,7	75,8	59,1	43,3	84,5	68,6	51,6	90,7	75,7	59,1
	Low	50,1	37,3	31,2	56,5	41,6	29,2	61,6	45,7	31,2	67,6	50,9	35,1	71,4	55,5	38,4	72,5	57,5	41,0

Stockholm – Gothenburg, total fuel cost per passenger without quota obligation, baseline CO_2 cost scenario

	2015			2020			2025			2030			2035			2040		
	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
Conventional	50,4	37,4	31,1	57,5	41,9	28,9	64,5	46,8	30,7	74,6	54,3	35,0	85,9	63,5	39,5	97,0	72,0	44,4

Stockholm – Gothenburg, total fuel cost per passenger with quota obligation, high CO_2 cost scenario

		2015			2020			2025			2030			2035			2040		
		H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
ATJ	High	53,7	40,9	34,8	65,1	50,3	37,9	78,4	62,5	48,0	98,4	81,7	65,9	120,4	104,5	87,5	139,3	124,3	107,8
	Baseline	52,0	39,3	33,1	61,1	46,2	33,8	70,3	54,3	39,8	83,7	67,0	51,2	96,7	80,8	63,8	106,7	91,7	75,1
	Low	51,4	38,6	32,5	59,5	44,6	32,3	67,1	51,2	36,6	77,9	61,3	45,5	87,5	71,6	54,6	94,0	79,0	62,4
FT	High	51,4	38,7	32,5	59,5	44,7	32,3	67,2	51,2	36,7	78,1	61,5	45,7	87,8	71,9	54,9	94,3	79,3	62,8
	Baseline	51,1	38,3	32,2	58,7	43,9	31,5	65,6	49,6	35,1	75,2	58,6	42,8	83,1	67,2	50,2	87,9	72,9	56,3
	Low	50,8	38,0	31,9	57,9	43,0	30,7	63,9	48,0	33,4	72,2	55,6	39,8	78,3	62,4	45,4	81,2	66,3	49,7
HEFA	High	52,2	39,5	33,3	61,5	46,7	34,3	71,2	55,2	40,7	85,3	68,7	52,9	99,4	83,5	66,5	110,3	95,3	78,8
	Baseline	51,2	38,5	32,4	59,1	44,3	31,9	66,4	50,4	35,9	76,6	60,0	44,2	85,4	69,5	52,5	91,0	76,0	59,5
	Low	51,0	38,3	32,1	58,5	43,7	31,3	65,2	49,3	34,7	74,6	57,9	42,1	82,1	66,2	49,1	86,4	71,5	54,9
DSHC	High	53,4	40,6	34,5	64,4	49,5	37,2	76,9	61,0	46,5	95,7	79,0	63,2	116,1	100,2	83,2	133,4	118,4	101,8
	Baseline	51,4	38,7	32,6	59,6	44,7	32,4	67,3	51,4	36,9	78,4	61,7	45,9	88,2	72,3	55,3	94,9	79,9	63,4
	Low	50,5	37,8	31,7	57,3	42,5	30,1	62,8	46,9	32,3	70,2	53,6	37,8	75,0	59,1	42,1	76,8	61,8	45,2

Stockholm – Gothenburg, total fuel cost per passenger without quota obligation, high CO_2 cost scenario

	2015			2020			2025			2030			2035			2040		
	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
Conventional	50,8	37,8	31,6	58,4	42,8	29,8	65,8	48,1	31,9	77,8	57,5	38,2	91,1	68,7	44,7	104,1	79,1	51,5

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Stockholm – Gothenburg, total fuel cost per passenger with quota obligation, low CO_2 cost scenario

		2015			2020			2025			2030			2035			2040		
		H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
ATJ	High	52,8	40,0	33,9	63,4	48,6	36,2	76,1	60,2	45,7	93,1	76,5	60,7	113,0	97,1	80,1	130,8	115,8	99,3
	Baseline	51,1	38,4	32,3	59,3	44,5	32,1	68,0	52,0	37,5	78,5	61,8	46,0	89,4	73,5	56,5	98,2	83,2	66,6
	Low	50,5	37,7	31,6	57,7	42,9	30,5	64,8	48,9	34,3	72,7	56,1	40,3	80,1	64,2	47,2	85,4	70,5	53,9
FT	High	50,5	37,8	31,6	57,8	42,9	30,6	64,9	49,0	34,4	72,9	56,2	40,4	80,4	64,5	47,5	85,8	70,8	54,3
	Baseline	50,2	37,4	31,3	57,0	42,1	29,8	63,3	47,3	32,8	70,0	53,3	37,5	75,7	59,8	42,8	79,4	64,4	47,8
	Low	49,9	37,1	31,0	56,1	41,3	28,9	61,6	45,7	31,2	67,0	50,4	34,6	70,9	55,0	38,0	72,7	57,7	41,2
HEFA	High	51,3	38,6	32,4	59,8	44,9	32,6	68,9	53,0	38,4	80,1	63,4	47,6	92,0	76,1	59,1	101,8	86,8	70,3
	Baseline	50,4	37,6	31,5	57,4	42,5	30,2	64,1	48,1	33,6	71,4	54,7	39,0	78,0	62,1	45,1	82,5	67,5	50,9
	Low	50,1	37,4	31,2	56,8	42,0	29,6	62,9	47,0	32,5	69,4	52,7	36,9	74,7	58,8	41,8	77,9	62,9	46,4
DSHC	High	52,5	39,7	33,6	62,7	47,8	35,5	74,7	58,7	44,2	90,5	73,8	58,0	108,7	92,8	75,8	124,9	109,9	93,3
	Baseline	50,6	37,8	31,7	57,9	43,0	30,7	65,0	49,1	34,6	73,2	56,5	40,7	80,8	65,0	47,9	86,4	71,4	54,9
	Low	49,6	36,9	30,8	55,6	40,7	28,4	60,5	44,6	30,0	65,0	48,3	32,5	67,7	51,8	34,8	68,3	53,3	36,7

Stockholm – Gothenburg, total fuel cost per passenger without quota obligation, low CO_2 cost scenario

	2015			2020			2025			2030			2035			2040		
	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L	H	B	L
Conventional	49,9	36,9	30,7	56,6	41,0	28,0	63,2	45,5	29,4	71,4	51,1	31,8	80,7	58,3	34,3	89,9	64,9	37,3