The impact of reducing carbon dioxide emission in the aviation sector on biofuel demand and market growth

Term paper: Energy Economics and Policy

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1. Introduction

As of 2008, the whole airline industry was one of the largest contributors to global GDP creation with 8% and $3.5 trillion in relative and absolute terms, respectively (Steele, IATA). The whole sector provided employment to 32 million people while served 2.4 billion passengers (Steele, IATA). The sector is admittedly a major driver in technology innovation, tourism, trade, and global infrastructure. The broadly-defined airline sector consists of numerous participants such as the airlines, airfreight providers, manufacturers, repair and maintenance companies, OEMs, ground handling service companies, airports, air traffic controllers, and several other types of service companies. This heavily interlinked system of participants is largely dependent on the airlines' performance, which is subject to economic volatility, natural hazards, and regulatory control. The latter has imposed significant pressure on the sector in terms of delay and cancellation refund policies, emission abatements, security measures, and other strict requirements. Compliance with new regulations usually requires substantial investments or restructured operations. The fragmented nature of the regulatory environment hampers the sector's ability to give a uniform response to various challenges. The aviation sector is regulated by the Department of Transportation in the United States and similarly by the Transport and Tourism Committee of the European Commission in the European Union. In Asia, South America, Africa, and Australia, regulation is practiced on state level in all countries.

The last two decades in Europe and the United States brought several open skies agreements, which replaced the system of bilateral agreements to authorize and control scheduled commercial airline operation between two countries. Open skies agreements and increasing demand brought fierce competition for passengers and airport slots among carriers throughout the world. This competitive environment, not surprisingly, drove airline margins down substantially. According to IATA (International Air Transport Association), member airlines' total net loss amounted to $9.9 billion in 2009, which suggests that the industry operates under enormous economic pressure. Consolidation has been a remarkable theme in the sector during the last five years due to financial difficulties, strategic benefits, and expected synergies.

There has been increasing political pressure on the airline industry since 2005, the start of the European Union Emission Trading Scheme (ETS), to mitigate climate change effects by reducing carbon dioxide and greenhouse gas (GHG) emissions. Commercial aviation is responsible for 2% of the total carbon dioxide emissions worldwide. Due to high altitude flights, carbon and GHG emissions contribute disproportionately to climate change, as a result of higher radiative forcing. In 2010, ICAO (International Civil Aviation Organization), an international umbrella organization of the airline sector, established a global framework to stabilize carbon emissions. This approach is the first of its kind in all sectors of the world economy. All 190 member countries agreed to a framework that sets the goal to improve fuel efficiency by 2% annually until 2050, achieve carbon neutral growth from 2020, and establish a global carbon dioxide standard for aircraft engines by 2013 (ICAO Environmental Report). From 2012 onward, the airline industry will be part of the ETS, which puts increased weight on necessary emission reduction. Apart from automatically allocated quotas, additional emission credits will be auctioned off for airlines. All carriers operating flights to, from, and within member states of the European Union will have legal obligations to comply with the trading system, buy emission credits, pay levies, and obey emission caps.

This compliance appears to be extremely challenging because the aviation sector is already in a very stiff economical situations. On the long term, there are promising possibilities to reduce carbon dioxide emissions by utilizing new technologies which might trigger paradigm shifts. However, on the short term, meaning the next 10-15 years, the only plausible solution appears to be biofuel. This paper focuses on certain aspects of the feasibility and the economics of algae biofuel usage in commercial aviation.

2. Research question with analysis framework

This paper investigates the impact of the ICAO's ACT GLOBAL CO_2 and GHG emission reduction commitment on algae biofuel production, examining growth of market share, production volumes, and most importantly related emission reductions.

The airlines have to find alternative fuels for two main purposes: cost and emissions reduction. Rising crude oil prices imply that jet fuel prices will also surge with a short delay which will hit airlines hard given that fuel costs account for 30-50% of airline spending depending on the flight length, aircraft type, and other factors (IATA Fact Sheet: Industry Statistics, 2011). High oil prices can easily push even the most profitable companies into the red, as it happened in 2009 when crude oil price reached $140 a barrel. Fuel efficiency goals set by ICAO cannot be reached without the application of biofuels. The advantage of these biofuels relative to fossil fuels lays either in carbon capturing during cultivation phase or in reduced carbon emissions in flight.

The airlines seek to leverage technological innovations in order to be able to cope with regulatory requirements and stay in the business. Winglets, claimed to be the most significant innovation of the industry in the last 20 years, brought for the airlines fuel savings of 4-6% depending on flight characteristics (Turner, NASA). However, these processes are slow compared to the industry's usual dynamics. Complete development of a new aircraft takes more than 10 years; development of new generation engines requires a comparable amount of time. Redesigned airline routes, coordinated air traffic control in Europe, new take-off and landing procedures, and weight reductions on board all help to save fuel and achieve profitability target but all come short to solve the problem without a paradigm shift.

Such a shift might come from alternative fuels that are suitable to replace the currently used crude-oil based JET-A fuel. Biofuels appear to be a plausible alternative to fossil fuels; however, details of application are not clear yet.

According to the Air Transport Action Group, the currently considered so-called second-generation biofuels include:

- Jatropha: "[Jatropha] is a plant that produces seeds containing inedible lipid oil that can be used to produce fuel. Each seed produces 30 to 40% of its mass in oil. Jatropha can be grown in a range of difficult soil conditions, including arid and otherwise non-arable areas, leaving prime land available for food crops. The seeds are toxic to both humans and animals and are therefore not a food source" (Air Transport Action Group).

- Camelina: "[Camelina] is primarily an energy crop, with high lipid oil content. The primary market for camelina oil is as a feedstock to produce renewable fuels. The left over "waste" from the oil extraction can also be used as feed for chickens in small proportions. Camelina is often grown as a rotational crop with wheat and other cereal crops when the land would otherwise be left fallow (unplanted) as part of the normal crop rotation programme" (Air Transport Action Group).

- Halophytes: "[Halophytes] are salt marsh grasses and other saline habitat species that can grow either in salt water or in areas affected by sea spray where plants would not normally be able to grow" (Air Transport Action Group).

The most promising biofuel is, however, a third generation one: algae. The Air Transport Action Group claims that algae are suitable for producing jet biofuel for the whole industry. They yield more than 10 times more oil per surface area than any other biofuel plant. As large amount of carbon dioxide is necessary for algae growth, carbon emissions from nearby power plants can be fed to the ponds. This way, algae are carbon neutral after burning the biofuel in flight. Algae can be cultivated in using either seawater or wastewater; farms can be set up as ponds in invaluable areas or sea plantations close to the shore. Therefore, there is no conflict with areas used for food growth.

Other than biofuels, there is one more alternative fuel: waste. Waste mass is fed into a large reactor heated up to 4000-5000°C, where solid waste is transformed into syngas. The syngas is cleaned and cooled down, then transformed into jet fuel through an undisclosed technology, called Fischer-Trops method (Kagan 2010). Waste-based fuel production requires large amount of energy invested, which in most cases also brings additional carbon and GHG emissions. Some areas might still prefer this method due to lower total cost and relatively low level of land use.

Nevertheless, algae are expected to be dominant in most areas. Algae biofuel production is largely dependent on the efficiency and possibility of scaling up laboratory and test environment cultivation of algae, as well as extraction of oil. Airline tests are currently performed with trial fuel mixes containing 20% and 50% algae biofuel and JET-A as the remaining part. The Defense Advanced Research Project Agency of the United States started construction and development work of algal ponds in order to begin large-scale production of algae oil. The refinery of this project is scheduled to start production in 2013 (Goldenberg on guardian.co.uk). In Europe, the Cranfield University runs two projects with the aim of determining the prerequisites and methods of mass-production (IATA: Aviation Biofuels).

This present study calculates demand for algae biofuel per year taking into account the industry growth, the emission reductions, and the fuel necessities. The framework proposed only considers algae as sustainable biofuel, in order to simplify kerosene equivalent efficiency of various biofuels. For the reasons outlined in the previous section, this limitation is not entirely arbitrary; the possibility that algae will provide the vast majority of biofuel is rather high. In the following sections, the simulation with the model yields the required land/water surface in order to elaborate on the conflict between cultivation of feedstock for fuels and for human consumption.

For the sake of simplicity, the model is based on the assumption that airlines reached their limits of reducing their carbon dioxide emission by all other means. Technology, route planning, air traffic control optimization, and other techniques are all considered outside options.

3. Model

The proposed model is built on two major data sets:

- Historical airline traffic data in terms of number of passengers, revenue, passenger kilometer (RPK), airline seat kilometers (ASK), amount of jet fuel burnt, amount of carbon dioxide emitted, average capacity of aircraft, average load factor, and price of kerosene used. The proposed ICAO reduction plan is also taken into account to determine yearly reduction totals. This starts from a base of 637 million tons in 2005. Figures are projected for the coming years based on IATA's growth forecast.

- Algae biofuel production data with expected large-scale production figures. This includes specific energy of biofuel, specific energy of JET-A (most widely used conventional jet fuel), amount of carbon dioxide emitted during burning, amount of carbon dioxide captured during cultivation, surface area required for cultivation, and production price of algae biofuel.

Airline traffic data is given by IATA's industry forecast analysis. Annual RPK (revenue passenger kilometer) and ASK (airline seat kilometer) is calculated according to the growth forecast outlined by IATA. Amount of fuel consumed is estimated by taking into account yearly ASK data, average airliner consumption, and average capacity. From fuel burnt carbon dioxide emission is calculated by multiplying by typical CO_2/fuel burnt ratio given by ICAO.

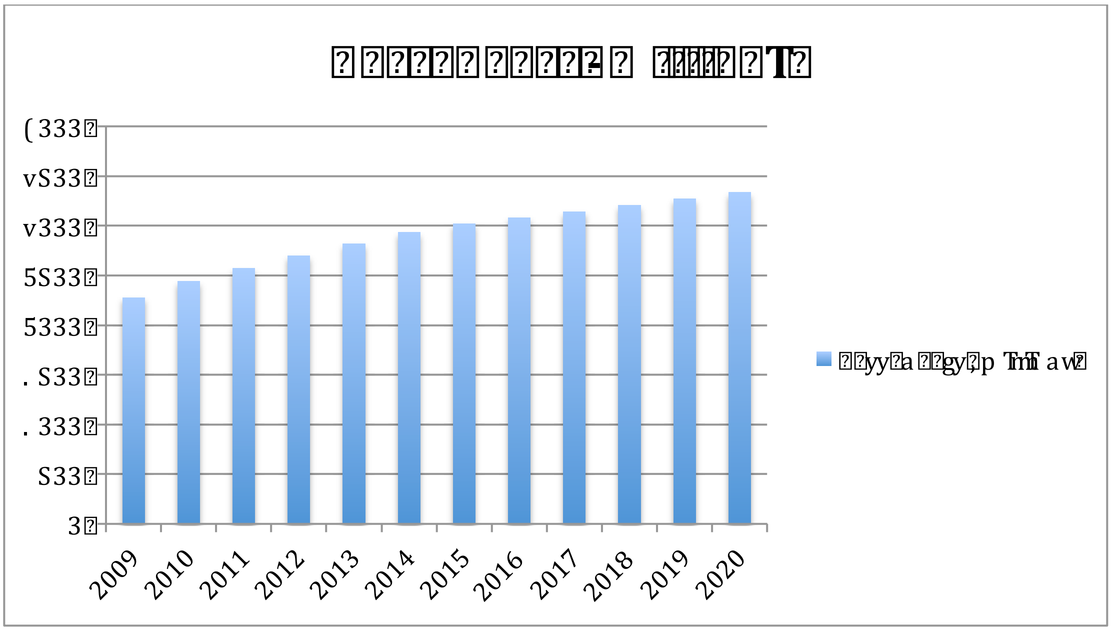
The model takes into account the proposed 1.5% fuel efficiency improvement outlined by the 2010 ICAO agreement. Given the linear relationships, this translates into a reduction of 1.5% of carbon dioxide emissions worldwide. According to the assumption made above, that the airline industry reached its limit of reducing emissions by all other means, this has to be achieved directly by carbon neutral biofuels, such as algae-based products. Algae-relevant data was obtained from the Air Transport Action Group and from Campbell (2010).

4. Limitations

This section intends to examine the validity of the assumptions on which the model is built. These limitations might alter the results but will not affect industry trends and magnitude of emission reduction effects.

The most important assumption used in this study, that airlines are not able to reduce their carbon emissions in any other way but using biofuels, is certainly not entirely realistic; nevertheless, it is not far from the actual situation. Technological innovations have a very long throughput time that is inherent from the safety requirements of the aviation sector. Harmonization of air traffic control requires coordinated high-level political decision, which is hard to achieve even in the European Union. Route planning methods reached an advanced level from which currently it seems hard to progress further. Improvement of take-off, approach, holding, taxi, and landing procedures might eventually contribute to higher fuel efficiency. Taking into account that the latter being the only feasible technique, the proposed assumption approximates the current situation with relatively high accuracy.

Aggregated air traffic data can also lead to lower precision of the forecast. This problem can be addressed with using premium detailed data provided by research and analysis firms. Average consumption is largely dependent on flight procedures, weather phenomena, cruising velocity, aircraft loads, and most importantly aircraft types. Large number of new aircraft to be put in the service in the following years might lower industry-wide average fuel consumption figures.



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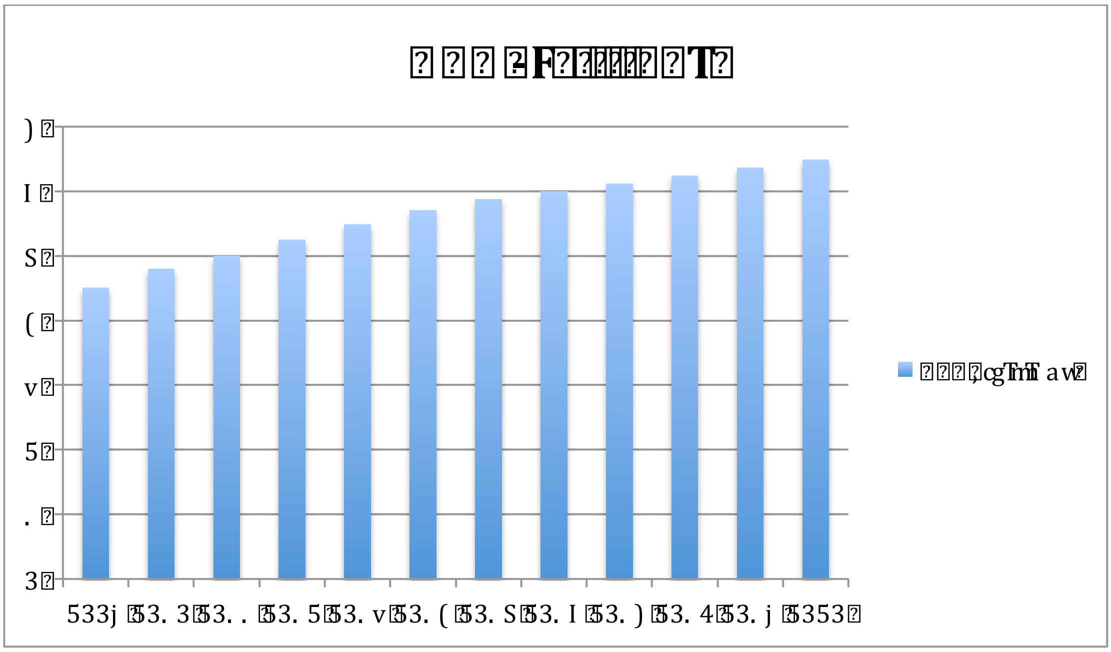

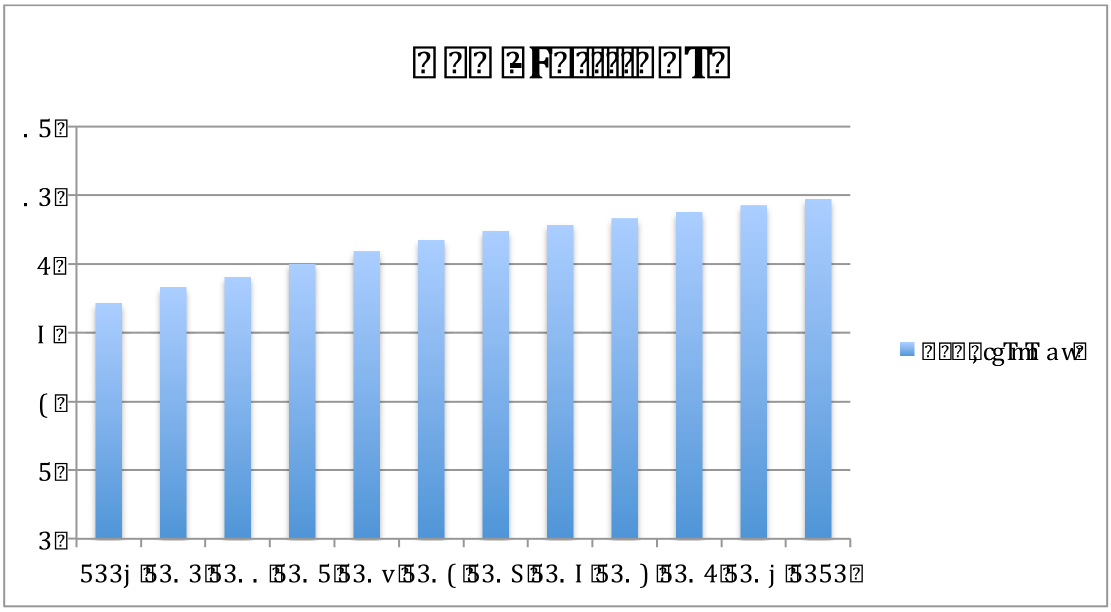

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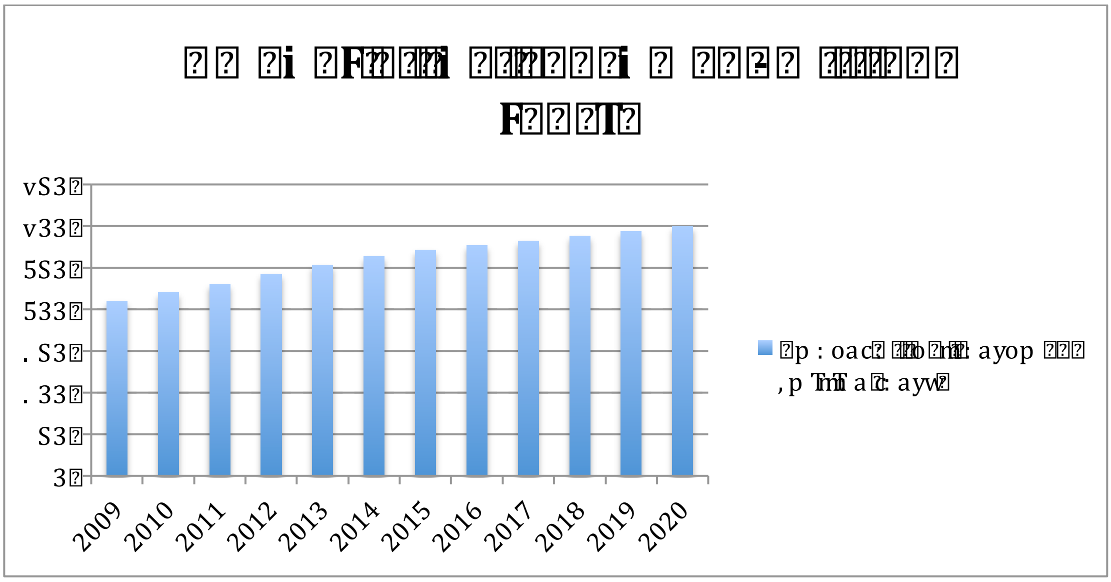
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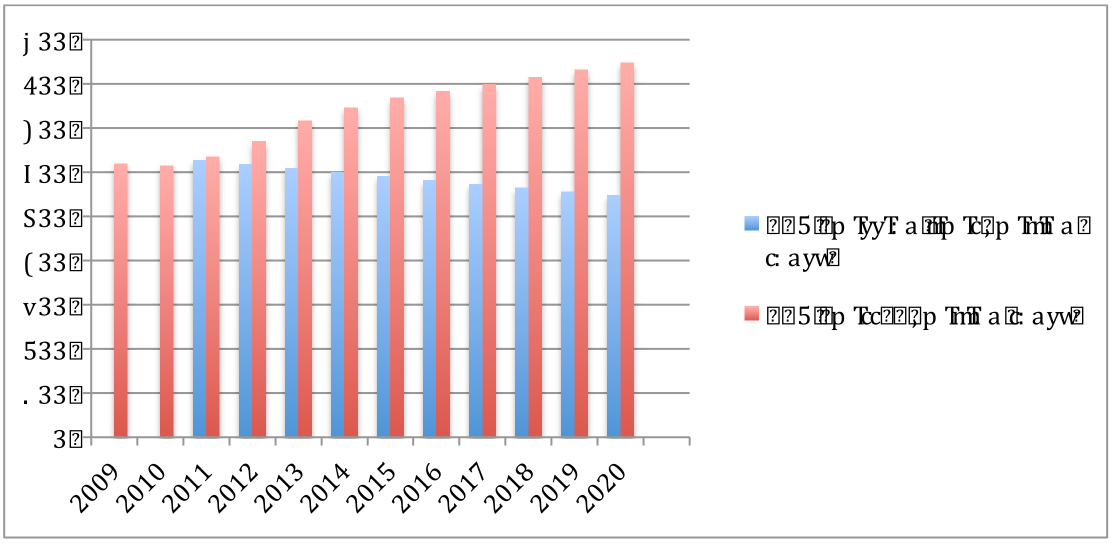
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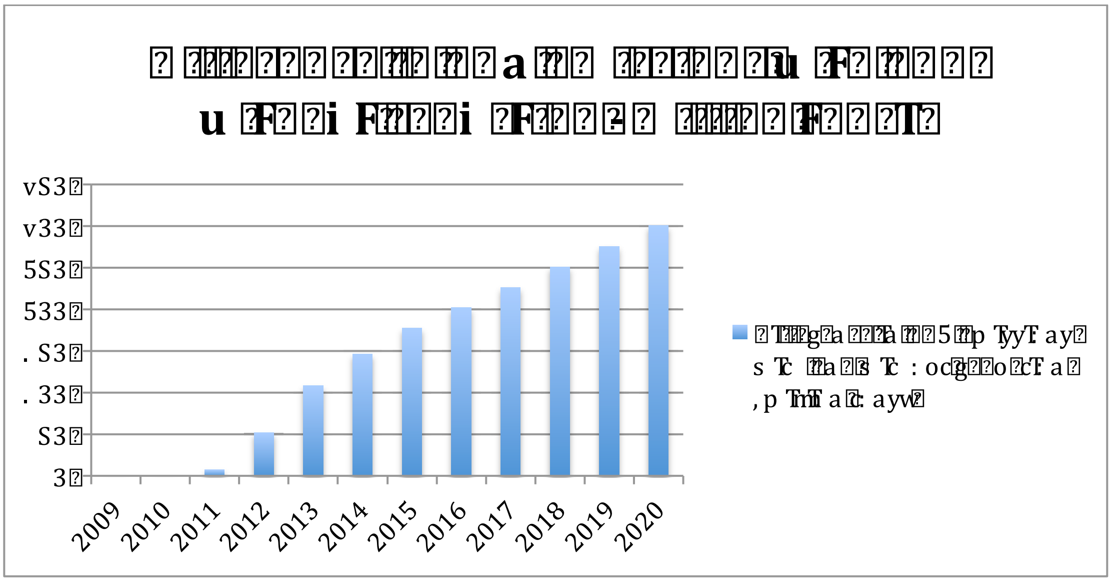

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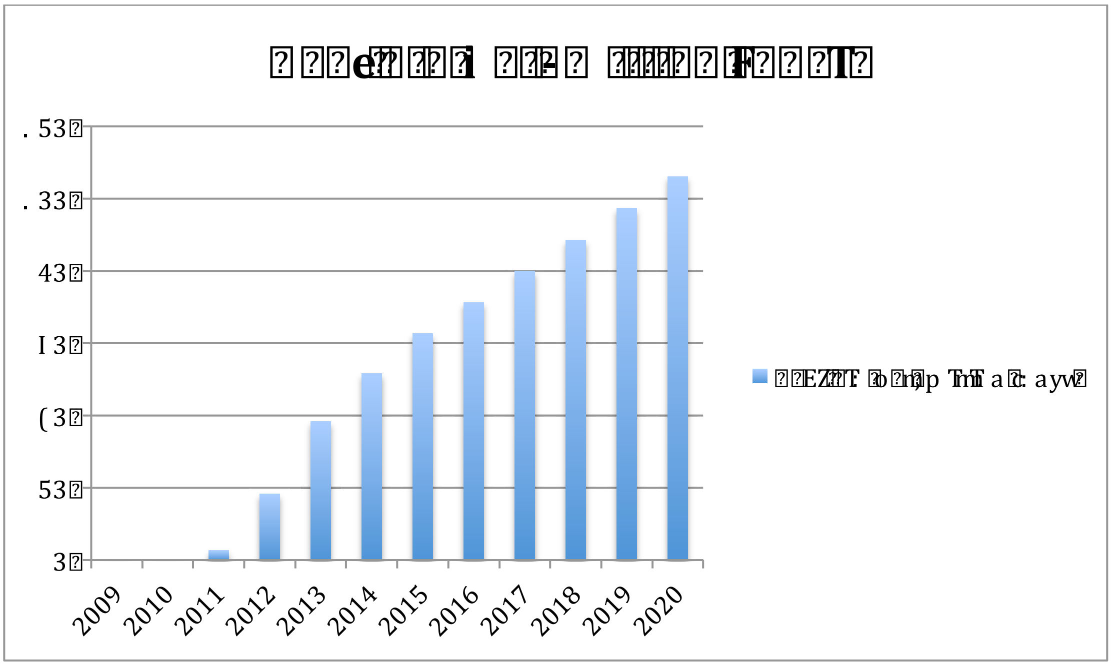

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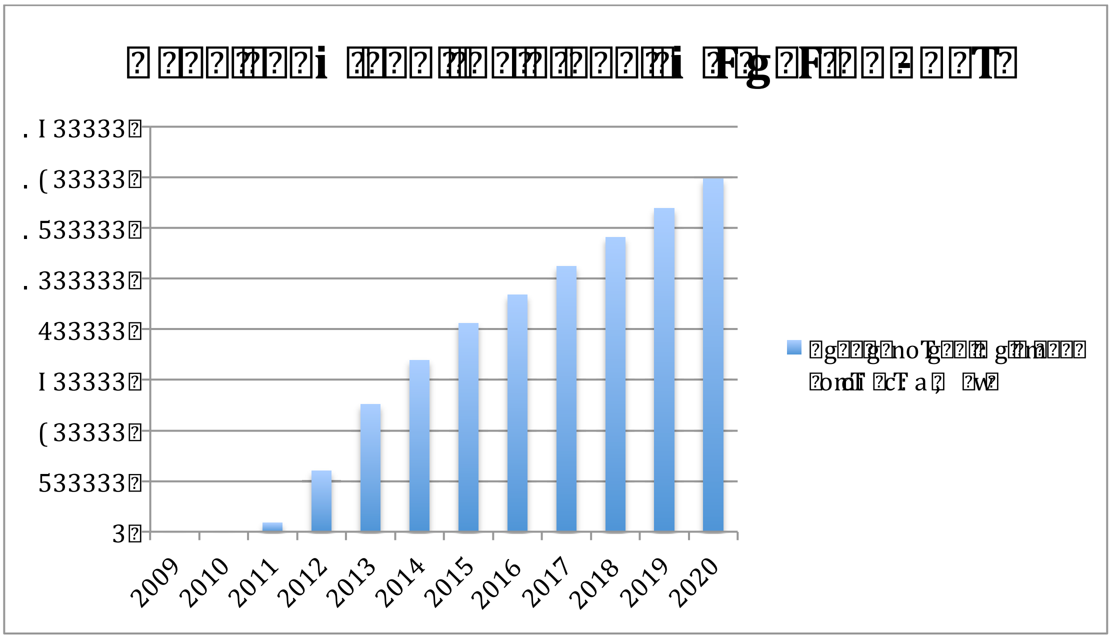
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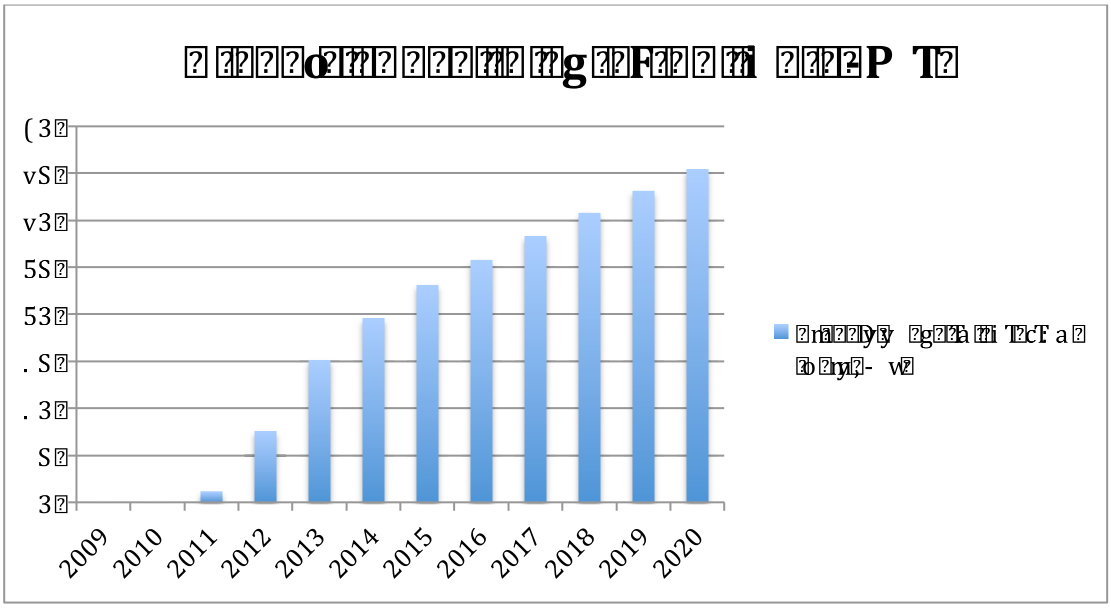
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6. Conclusion

The results given by our model described in Sections 3, 4, and 5 have four main implications.

First, the rapidly increasing traffic will cause an increase of 30% in fuel demand and in carbon dioxide emissions in the next 10 years. Due to the increasing crude oil prices, which was estimated to grow with an unusually low pace, and widening crack spreads (cost of refining crude oil into jet fuel) this increase elevates the fuel spending even more than 30%. The low margins of the industry imply that this additional cost substantially drives the bottom line in a negative direction, pushing some carriers into heavy losses.

Second, the large difference in unrestricted and reduced carbon dioxide emission indicates that it is not possible to avoid a paradigm shift in fuel use as mentioned in Section 1. Biofuels are capable to fill the gap between the ICAO limits and the business-as-usual numbers due to their zero emission characteristics. ICAO's commitment is in effect from 2011, which means that mass-introduction of biofuels cannot be delayed, because the industry is not able to tackle the carbon dioxide emission challenge in any other faster way.

Third, the forecasted market share suggests the economic feasibility of large-scale algae biofuel production. A market share of 35% in 10 years certainly pays off the large initial investments. Algae jet fuel is also supported by the estimates of EQ2 Insight which puts the additional carbon costs incurred due to the ETS at $0.21 per gallon of conventional jet fuel, which is not applicable to biofuels.

Fourth, the area required for algae production, with algae jet fuel as the final goal, is multiple orders of magnitude less than those of other alternatives. The total surface area is also substantially smaller than the land used for wheat production in the United States. In addition, it does not need freshwater or valuable pieces of land. Wastewater, seawater, or deserts and rural areas can easily accommodate algae plantations. Hence, there is marginal conflict with human food production.

It is important to note that the whole model is based on IATA's traffic growth forecast, which might prove to be inaccurate in the future. Most of the traffic growth will come from Asia and mainly China, while above average growth is expected in South America. The European and US market are mature; it is not likely that these areas generate substantial growth or significant decline by nature. However, carbon taxes levied on commercial flights in Europe, rising fuel prices, changed corporate travel policies unexpected financial downturns, or lengthier safety procedures at the airport might affect passengers' willingness to fly. These phenomena are unlikely in Asia but there is another credible threat there: railway. High-speed railway networks or bullet trains between major cities are competitors of the so-called point-to-point markets. Nonetheless, IATA's numbers can still be considered as best indications, given that the threats mentioned might also be balanced by positive forces e.g. upbeat in corporate travel fueled by Chinese corporate giants.

7. Outlook

Realizing the importance of biofuels, most importantly algae, the aviation sector and related industries, i.e. oil producers, have been investing heavily into research and development of large-scale biofuel production during recent years. As a result, price parity with fossil fuels is expected to be reached by 2017 or 2018 (Feldman, Reuters).

IATA urges governments to introduce policies, research grants, and tax benefits that favor biofuel production. These measures can accelerate the pace in order to reach price parity faster, which in turn helps reducing CO_2 emissions.

Numerous airlines, supported by aircraft and engine manufacturers, perform flight tests with different types of biofuels to evaluate to short and long term effects of biofuel on jet engines and aircraft fuselages. However, these trials will take months to yield useful results. The next step is the certification of biofuels for commercial airline use. For the purpose of certification, biofuels have to be standardized first, assuring stable quality and characteristics. This process will occur in multiple phases and for multiple engine types until reaching 100% certified biofuel operations.

Airlines are considering algae and other biofuel products as drop-in-fuels used together with conventional fossil fuels. This means that aircrafts will burn a mixture of conventional fuel and biofuel. The latter will have an increasing share over time, starting from 20%. Based on this application ratio, IATA estimates a 6% market share of biofuels by 2020 (IATA: Aviation and Environment). Given that this market share is not sufficient to bridge the gap, the introduction process can be promoted and accelerated, staying within limits of safe operations, by the aforementioned government policies. Tax credits for investments in biofuel, promotion of a truly global emission reduction framework, and involvement of other participants of the transportation sector can help to achieve certain economies of scale much faster which would translate into possibly rewarding business opportunities and safer investments in biofuel development and production.

Appendix – Key calculations used

Calculations listed here were modified in order to account for differences in units of measurement.

ASK: $$ASK = \frac{RSK}{LF}$$

Fuel consumed: $$f_{burnt} = \frac{ASK \cdot con}{c_{avg}}$$

CO_2 emitted: $$e = f_{burnt}\, ftc$$

Fuel consumed: $$c_{fuel} = (p_{oil} + cr) f_{burnt}$$

Fuel gap to bridge: $$gap = \frac{(e_l - e)}{ftc}$$

Difference between restricted and unrestricted CO_2 emissions:
$$diff = e_l - e$$

Area required for algae cultivation: $$A = gap \cdot y$$

Market share of aviation biofuels: $$s = \frac{gap}{f_{burnt}}$$

<u>Notations:</u>

LF – load factor
e – CO_2 emitted
e_l – allowed CO_2 emission
c_{avg} – average capacity of aircraft
p_{oil} – price of oil
cr – crack spread of jet fuel
ftc – fuel to carbon dioxide ratio
ASK – Average Seat Kilometer
RSK – Revenue Seat Kilometer
con – consumption
A – surface area
y – algae yield per hectare (in tons)

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