

Exploring Factors for Establishing an Aviation Biofuel Supply Chain

An Agent Based Modelling Approach

Master Thesis

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Abstract

The aviation industry is looking for ways to reduce its carbon footprint; as the use of fossil fuel kerosene is the largest direct cause of this footprint the ambition which follows is the implementation of biofuels for the aviation sector (biokerosene). However, the price associated with biokerosene in comparison with regular kerosene is much higher; it is assumed that this aspect will improve as the scale of biokerosene production increases. However, initiating this very up scaling of biokerosene has proven to be very challenging.

This thesis explores the above mentioned problem by using an Agent Based Modelling (ABM) approach to investigate under which conditions, biokerosene supply chains can emerge. The choice for ABM is based on the fact that the actors involved in a biokerosene setting can be represented as agents, and the interaction between these agents is expected to cause emergent and self-organizing system behaviour. An existing, large-scale biofuel market is chosen as the main setting for the exploration of biokerosene implementation with the Agent Based Model. The Brazilian bio-ethanol market is chosen as the case study topic; it is the oldest large scale biofuel market which has already attracted significant attention from academia, policy makers and industry players around the world and it is seen as a successful market model for biofuel (ethanol can be used as a transport fuel) implementation.

The research steps which are conducted in order to give an insight into the main research question,

“What measures are necessary to establish a bio-ethanol based aviation kerosene supply chain within the existing bio-ethanol market in Brazil and what projected impact might these have on the bio-ethanol market behaviour?”,

consist of the following:

- i. An ABM (base model) is devised of the existing Brazilian bio-ethanol market; the exploration of this bio-ethanol model shows how the market is volatile due to constant changing demand and production volumes of ethanol which itself is due to different internal (demand and production flexibility) and external (commodity prices) factors. Furthermore, it is shown that the flexible nature of the bio-ethanol market has a positive impact on biofuel refinery profits and also lowers biofuel prices in comparison to a non-flexible situation.
- ii. The ABM is expanded (BioJet model) with the addition of a proposed biokerosene production stream. The exploration of this model shows how the competition for the feedstock (sugarcane) dominates the actual consumer price of biofuel in relation to the actual production cost of the fuel. Furthermore, it is shown how government induced policies and external commodity price changes, significantly affect the production volumes and price levels of both road transport and aviation biofuels.

A deliverable of this thesis is the development of a working simulation tool which can be used to explore different scenarios in the field of biofuels, particularly when the market is characterized by flexible behaviour on both the demand and supply side. Furthermore, the results which are obtained by the model exploration show that as long as current government policies regarding the use of biofuels for road transport are left unchanged, the implementation of large scale biokerosene production will come at a significant price premium; even when considering a maturation of the technical issues regarding biokerosene production and economies of scale effects. The main reason for this premium is the fact that government policies enforce a competing demand for biofuel (at all costs). A shift in government policy which discourages road-transport biofuel use in favour of aviation biofuel use can significantly reduce the price premiums which are necessary for biokerosene supply. Furthermore, the model results show how the Brazilian bio-ethanol market is still dependent on government policies in order to maintain a price competitive advantage over regular fossil fuels; this is in contrast to what is often claimed to be a free-market biofuel “success” story. It is important to note that essentially all biofuel markets around the world possess the same, if not stronger, degree of government intervention.

Given the added technical complexity of aviation biofuels and the corresponding higher production costs together with the low level of possible government induced kerosene price controls, the successful, price competitive, large scale implementation of aviation biofuels without any institutional changes in the existing fuel (automobile and/or aviation) markets seems a highly unlikely proposition. This thesis shows the necessity of further insights from an academic and industry perspective regarding the implementation of biokerosene in a government policy making and supply and demand market setting to compliment the already undergoing extensive exploration of biokerosene production and consumption in a technological and sustainability sense. This thesis makes an initial foray into the actual investigation of biokerosene price behaviour in such an institutional setting.

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...to switch or not to switch...



Illustrator : Michael Sloan

Chapter 1

Introduction

In this chapter:

- 1.1 Fuelling the Aviation Industry
- 1.2 Biofuels for Aviation
- 1.3 Brazilian Bio-Ethanol
- 1.4 Bio-Ethanol Literature
- 1.5 Biokerosene Market Implications
- 1.6 Research Gap
- 1.7 Sustainability and Resource
Dependency

1.1 Fuelling the Aviation Industry

The aviation industry is characterized by the fact that it is an energy intensive industry. As a matter of fact, the cost of energy constitutes over thirty percent of the overall airline operating costs (*IATA Fuel, 2014*). In addition to the economic costs, the corresponding high volume of greenhouse gas emissions associated with current day kerosene use has moved the industry towards looking for alternatives for current fossil fuel based sources of energy (*ATAG, 2009; IATA, 2013*). As a result from the strict safety regulations which are present in the industry, any alternative fuel source must be compatible with current day aircraft (so-called drop-in fuels). Given these facts, the industry as a whole has set its eye on using biofuels, as a future source of energy for powering jet aircraft (*ATAG, 2009; IATA, 2013*). The technological and economic capacity of the biofuel sector to produce biokerosene at the moment is lacking, this is due primarily to a lack of confidence in biokerosene from conventional producers of kerosene and biofuels alike, and from a lack of financial resources from the aviation sector.

1.2 Biofuels for Aviation

The implementation of biofuels throughout different industries has been proven to be a complex matter; many governments and private institutions are in the midst of trying to establish commercial supply chains and markets, yet it has been proven to be difficult to compete with the established fossil fuel supply chain (*EC, 2013; IATA, 2013*). The most well-known case of large scale biofuel implementation is in Brazil. As of 2013, more than half of all cars in Brazil run on a biofuel blend (*ANFAVEA, 2013*). The Brazilian case has been initiated through a long series of governmental policy interventions (*ANFAVEA, 2013; Banse, Kemfert & Sorda, 2010; Cortez & Rosillo-Calle, 1998*). The Brazilian case represents a special case in that it has been initiated over a long period of time (since 1970), it has undergone significant shifts in government interference (from ethanol subsidies towards tax leverage) and it has been subject to significant external shocks (harvest crises leading to severe ethanol supply shortages). Moreover, in recent years the introduction of so-called flex fuel vehicles has presented the average Brazilian car consumer the autonomous freedom to choose his or her ethanol usage based on market principles (*ANFAVEA, 2013*). This latter fact makes the Brazilian ethanol case unique; there is a relatively liberal biofuel market which has proven to be capable of growing significantly.

For an industry which strives to implement biofuels based on economic principles, it is imperative to investigate possible lessons which may be learnt from the Brazilian bio-ethanol case. Research into the Brazilian case and the possible linkages and analogies with aviation biofuel implementation can significantly increase the effectiveness of industry and government policy making in this regard through the shared knowledge and understanding which may be gained by all sectors (*De Bruijn & Ten Heuvelhof, 2008*). Specifically what is required is that this knowledge be made available regarding the question of *what* and *how* for bio-ethanol based kerosene (referred to as biokerosene from now on) in Brazil.

1.3 The Brazilian Bio-Ethanol System

In view of learning about the implementation of bio-ethanol in Brazil, to further gain an understanding of implementing biofuels in general, it is necessary to consider the area of interest in the bio-ethanol field which is relevant for this research. The overall level of interest is in the increase of the total production of the biofuel, which in this case is bio-ethanol fuel. The total production of bio-ethanol is composed of the sum of the individual production units within the market. Therefore, the output of the total bio-ethanol market, is determined by the sum of the individual *system* parts. A system can be regarded as (Maani & Cavana, 2000):

“..a collection of parts that interact with another to function as a whole. However, a system is more than the sum of its parts, it is the product of their interaction. A system subsumes its parts and can itself be part of a larger system.”

In terms of the bio-ethanol market or any other commodity market for that matter, the “parts” can be composed of the production units, the distribution units and the consumer units. Furthermore, the “interaction” between these parts is related to the supply and demand of the commodities throughout the system. It is this supply and demand, and particularly the *change* in the composition of the volume and prices of the products, which will be the core area of interest with regards to the analysis of the bio-ethanol market in Brazil.

The bio-ethanol system does not remain fixed over time; indeed as explained already, the introduction of the Flex Fuel Vehicles has added another level of interaction in the existing bio-ethanol system. The demand side of the market can change much more quickly now as users can at any given moment switch their fuel commodity demand entirely (between two different types of ethanol).

An illustration of the core elements and interactions in the system under study, the Brazilian bio-ethanol system, is shown in Figure 1.

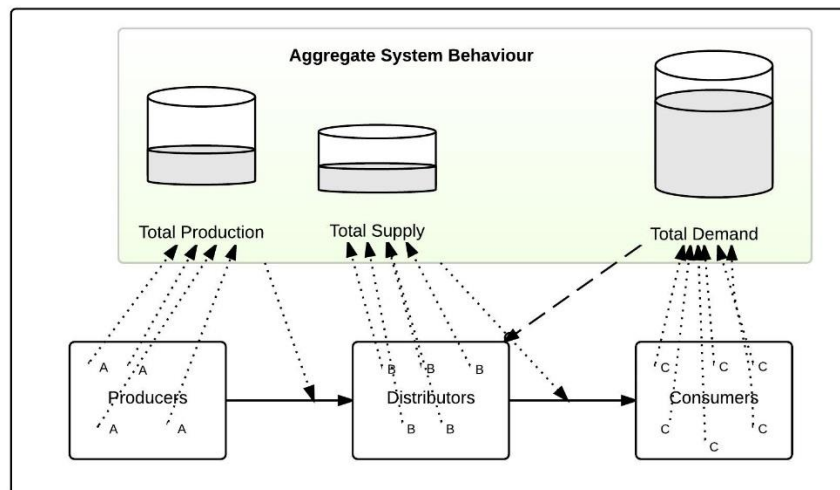


Figure 1: A Study of the Bio-Ethanol Demand and Supply System

Figure 2 shows the Brazilian output of sugarcane products relative to each other together with the global prices for oil and sugar. As the prices for sugar and oil are affected on a global scale, only observations can be made regarding correlations between an increase/decrease in the price of a good and the increase/decrease in the relative production of a good. Nevertheless, it seems likely that there is to some degree a positive effect of higher oil prices on hydrous ethanol production; this is supported by the corresponding relative increase of hydrous ethanol in conjunction with an increase in the global oil price. An interesting observation is the fact that the production of all products shows a sharp decrease in the same year (2011); this shows how the supply of sugarcane can vary significantly between years. After this year the ethanol market shows a strong recovery while the sugar market has stagnated; there is a possible correlation between the stagnant sugar market and the ethanol market growth.

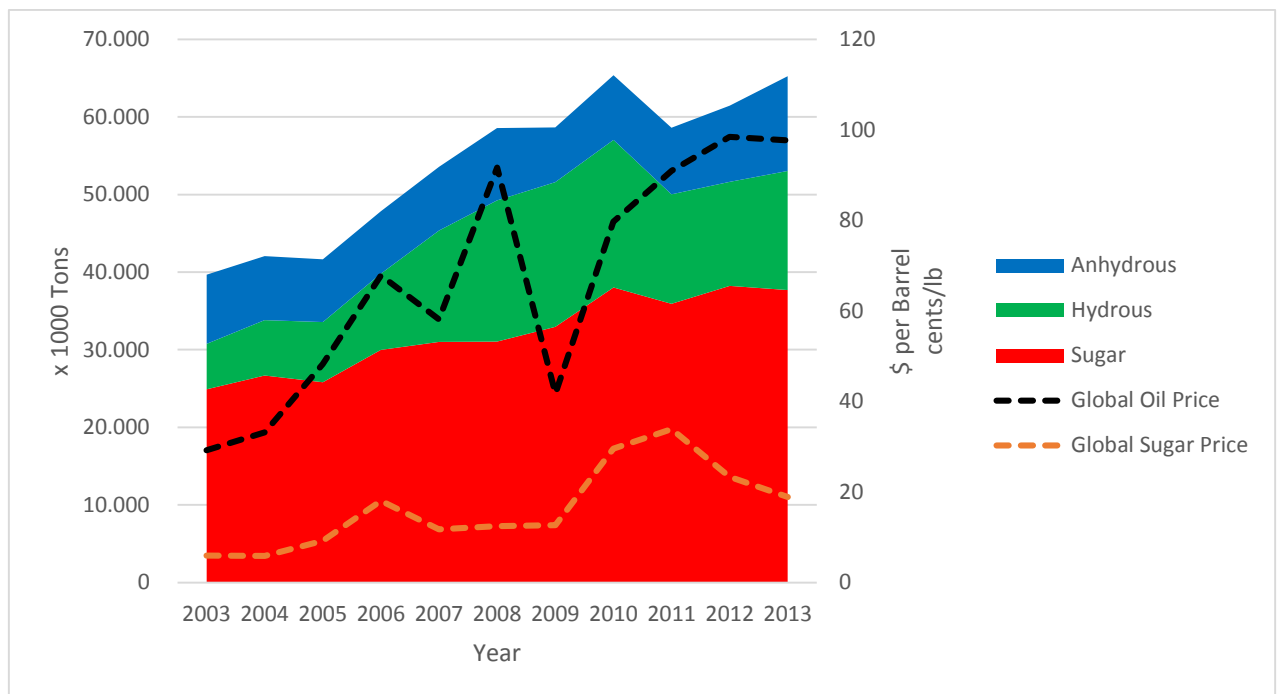


Figure 2: Production Output (stacked area) of Sugarcane Products and Global Commodity Prices (UNICA, 2014)

From Figure 3 it can be seen that there is a significant increase in sugarcane output from the year 2000 onwards. This can be attributed, in part, to the introduction of flex fuel vehicles (ANFAVEA, 2013). The study of the Brazilian market aggregate behaviour will be focussed on the period after the flex fuel introduction due to the considerable shift in the market demand for hydrous ethanol (Flex Fuel market transition).

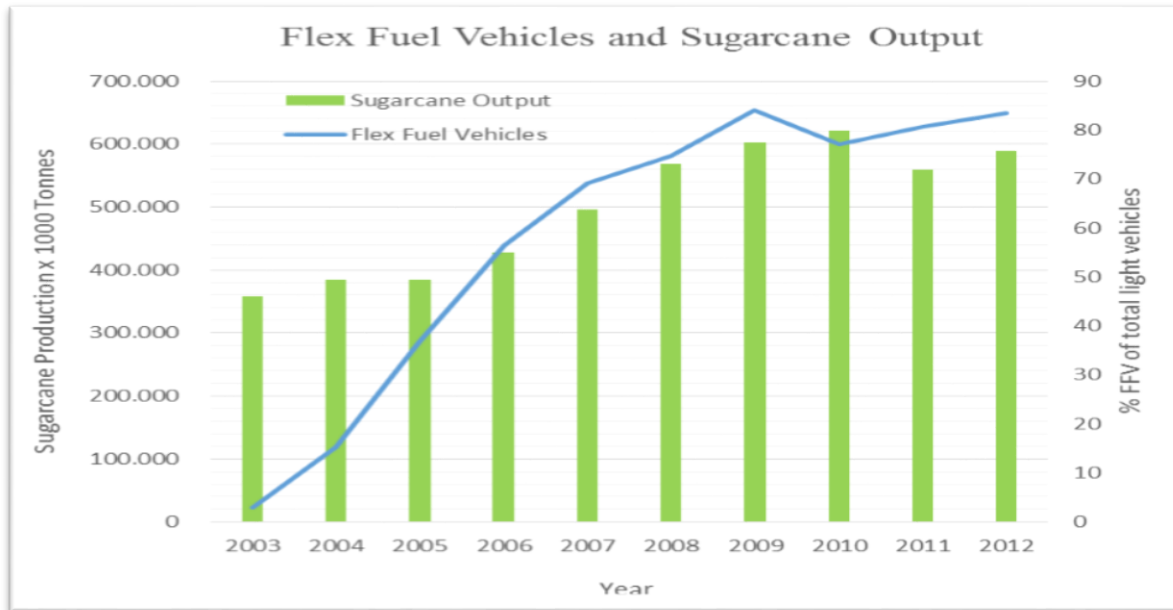


Figure 3: Brazilian Sugarcane Output and Flex Fuel Vehicle Diffusion (UNICA, 2014)

1.4 Bio-Ethanol Literature

Part of the existing literature regarding the Brazilian bio-ethanol market consists of an analysis of both the demand (Charlita de Freitas & Kaneko, 2011; Pacina & Silveira, 2011) and supply (Junginger, Faaij, Poot, Van den Wall Bake & Walter, 2009) side of the bio-ethanol market. In a recent paper by De Gorter, Drabik, Kliauga & Timilsina (2013), an analysis is made using an in-depth *economic* model of the total bio-ethanol market in Brazil.

Junginger *et al.* (2009) show using an experience curve approach how the Brazilian ethanol production costs have declined. It is shown that these costs are lowered as a function of cumulative production; this aspect is for a large part the underlying reason that the aviation industry is arguing for an up scaling of biofuel production (IATA, 2013). One of the significant recommendations made by Junginger *et al.* (2009) is to explore how the Brazilian implementation can be exported to other countries with sugarcane potential; this recommendation is made in light of the already initiated “riding down” ethanol experience curve.

De Gorter, Drabik, Kliauga & Timilsina (2013) show in their report that the Brazilian bio-ethanol market is essentially an isolated market in that sense that the government controls market prices. In great detail, an empirical economic analysis is carried out on the bio-ethanol market and the major finding is that government policies in fact have raised the price of ethanol in Brazil in the last few years; a clear understanding of this is however lacking and De Gorter *et al.* (2013) recommend further research on this behavioural aspect through analysing demand dynamics in terms of supply shocks and demand developments such as the introduction of the export market and the diversification of bio-ethanol to alternative markets.

Furthermore, on the demand side, *Pacina & Silveira. (2011)* show that for a further penetration of the global bio-ethanol market, policies will be needed to nurture a multitude of bio-ethanol markets in order for bio-ethanol to be able to withstand supply shocks which typify mono supply markets as is the case with the Brazilian market. In conjunction with this, *Charlita de Freitas & Kaneko. (2011)* argue that supply shortages in bio-ethanol severely impact future demand of bio-ethanol as has been the case in recent years in Brazil. It is therefore imperative that the supply and demand of bio-ethanol are maintained relatively stable; this may be done by exploring further use of bio-ethanol in different capacities. Both *Charlita de Freitas & Kaneko. (2011)* and *Pacina & Silveira. (2011)* recommend further research into short term expansion of ethanol use; the existing literature surrounding the Brazilian market lacks an in-depth exploration of alternative bio-ethanol usage from a market and policy making perspective.

1.5 Biokerosene Market Implications

In terms of implementing the jet kerosene market into the existing Brazilian bio-ethanol supply chain, the crucial phases arise after the feedstock phase; the feedstock remains fixed as sugarcane. The core aspects of the bio-ethanol based jet kerosene implementation will consist of inducing producers and/or distributors to enter the kerosene market and creating a clear supply for this fuel in the face of traditional automobile bio-ethanol use and fossil fuel use. More specifically, the road transportation sector is increasingly making use of biofuels; this increase is very much driven by government policies (*Banse, Kemfert & Sorda, 2010*). From the CAS perspective, the implementation of the biokerosene supply chain will have the effect of an additional end-user segment (aviation) and an extension in the conditional rules of bio-ethanol producers and distributors.

At the current time, in the technical sense, biofuel production for road transportation is a much more efficient pathway than the processing of the fuel into jet kerosene (*IATA, 2014; Qantas, 2013*). This fact plays a significant role in the aviation biofuel debate; from the perspective of biofuel producers, at the moment, it makes no economic sense to produce biofuel kerosene (*Boeing, Embraer, FAPESP & UNICAMP, 2013*). A significant characteristic however of the kerosene market is the high level of centralization; airports represent a highly concentrated area of kerosene use as opposed to the dispersed gasoline market for cars (*IATA, 2009*). This may pose a substantial advantage for the aviation case as in Brazil, a significant portion of total bio-ethanol costs is derived from logistic aspects (*BNDES & CGEE, 2008*).

1.6 Research Gap

From the literature review on the bio-ethanol market in Brazil it is clear that there is a significant gap regarding the exploration of an alternative end-use of bio-ethanol in this market; no major studies are available in this respect. Combined with the aviation's necessity to investigate biofuel implementation policies, a research into combining these two elements is prompted. This thesis gives an outline of the research project which has been carried out, for understanding how the Brazilian bio-ethanol market can be expanded through establishing an aviation biofuel market and through which policies and incentives this may be possible.

The understanding of starting up biokerosene markets in Brazil can act as a springboard for further research into the technological aspects (biofuel conversion), logistic and supply chain aspects and demand market aspects such as the impact an existing biokerosene market will have on airlines. Furthermore, there may be significant consequences to the total bio-ethanol market in the long run which will have implications on the existing knowledge of the market. This research can thus be seen as taking a first step in the research void regarding the market dynamics (pricing and volume changes) of biokerosene.

The practical contribution of bridging this knowledge gap consists of giving policy makers and industry leaders alike an insight into how both parties can act towards initiating an aviation biofuel market. This in turn can have the social implication of making possible an early step into actual sustainable flying and resource independency from fossil fuels. Furthermore, this research can be exported to other sources of biofuel feedstock which show similarities to the sugarcane supply chain. This is especially relevant for future generation feedstock which are projected to be available in the medium term.


This research has been carried out as part of a master graduation project at the Schiphol Group; the operator of Amsterdam Airport. Schiphol Group is a partner in different international initiatives to establish a biofuel supply chain for aviation in Europe (*BioPort Holland, 2013; Climate-KIC, 2014*). The results of this research are relevant for Schiphol Group both in terms of gaining additional insights for implementing biofuels in Europe and as being the aviation representative in this project. An understanding of biokerosene market dynamics will give Schiphol Group and its partners more confidence in decision making on biofuel strategies and it may enhance their communication towards other actors in this field (*De Bruijn & Ten Heuvelhof, 2008*).

1.7 Sustainability and Resource Dependency

The main driver for implementing biofuels in aviation is to be able to mitigate the greenhouse gas emissions caused by flying on regular fossil fuel kerosene. The overall scope of sustainability is thus the climate change issue. However, in terms of the biofuel debate, opponents of biofuels have noted the unintended significant impacts in terms of land use and the projected rise in prices of foods in general and particularly of food directly competing with fuel use; such as wheat, corn, sugarcane; the so-called first generation biofuels (*ATAG, 2009*). The aviation sector is committed to avoid this debate altogether by maintaining a position of using only those biofuels which are composed of non-edible feedstock; the second generation biofuels (*ATAG, 2009; Qantas, 2013; SkyNRG, 2014*).

This report is concerned with the bio-ethanol production from sugarcane feedstock in Brazil; it is therefore centred on first-generation biofuels which are not accepted by a large portion of the aviation industry. However, the scope of this research is to explore the economics of biofuel kerosene production in an existing setting (Brazil). Therefore the sustainability debate will not be further discussed; however it is important to realize that the sustainability and technical aspects of biofuel use are also major requirements for any supply chain to be realized for aviation. There is a high level of uncertainty regarding these aspects, this will be dealt with and explained further on in the report. Additionally a discussion of the sustainability of biofuel use in the aviation industry is presented in Appendix A.

Regarding another important driver for biofuel use is the fact that fossil fuels are a finite source. The increasing scarcity in the future of this commodity (and the expected increase of prices) presents the aviation industry with opportunity to influence its dependency on fuel; particularly from an economical point of view this may be an important factor in the biofuel debate. Also in light of government policies which are aimed at securing fuel supplies, biofuels may be the only realistic method in which this can be achieved in the near future for aviation (*US Department of Defense, 2014*).



Chapter 2 Research Formulation

In this chapter:

- 2.1 Problem Statement
- 2.2 Research Questions
- 2.3 Research Methodology
- 2.4 Research Steps and Thesis Outline

2.1 Problem Statement

The underlying assumption in the aviation industry and other related industries with an interest in biofuel use is that cost reductions in biofuels will be achieved through developments in technology and from up scaling effects in the production (ATAG, 2013; IATA, 2013; Junginger, Lako, Lensink, van Sark & Weiss, 2008; Rosillo, Teelucksingh, Thraen & Seiffert, 2012). Figure 4 shows the proposed cost-reduction cycle for biokerosene production. The current high cost of the fuel however, prohibits this cycle; as a consequence there is no formalized supply and/or demand. Specifically, the question is how one can influence the conditional rules within the system towards producing biokerosene.

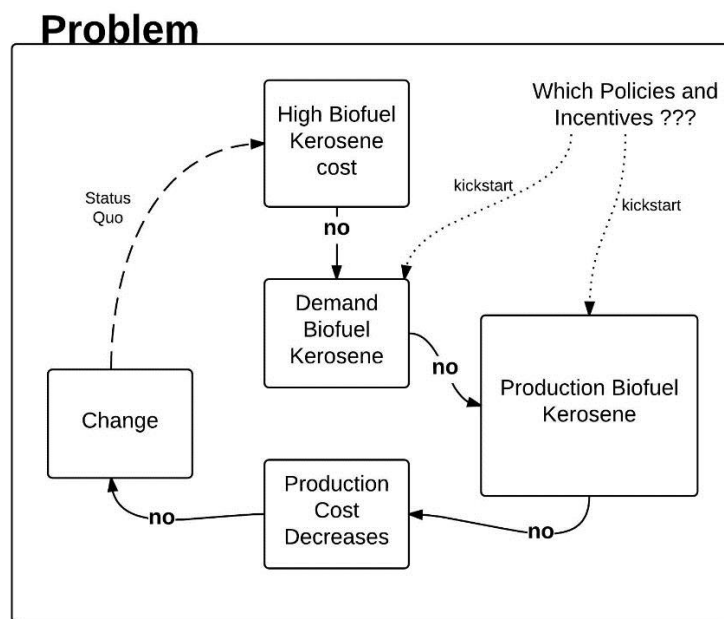


Figure 4: Biokerosene Production and Demand Dilemma

The lack of in-depth knowledge or research into how policy makers can undertake action to stimulate the establishment of this supply and/or demand means that currently there is a public and private inaction in this respect. In concrete terms one must think towards the implementation based on blending mandates, subsidies, taxes and other financial incentives. Also additionally one can think of the current policies regarding road transportation fuels; a change in these policies may have significant impacts on the financial attractiveness of biokerosene production and consumption. The uncertainty regarding the impacts of these measures constitutes the overall research problem which will be addressed in this research project. The thesis will aim to provide an initial step towards the in-depth knowledge which is necessary to understand how measures may stimulate biokerosene production, which can in turn achieve further bio-ethanol and biokerosene production cost reductions.

This thesis will address the research problem (biokerosene implementation) by exploring the research gap (lack of understanding of bio-ethanol market expansion).

2.2 Research Questions

Following from the introduction, the higher level objective of this research is clear; gaining an insight into how biokerosene production may arise and under what market conditions (pricing). This insight can be obtained by the lower level objective of exploring how the Brazilian bio-ethanol market can be expanded through the establishment of an aviation biofuel market and through which policies, incentives and other measures this may be possible. Based on this underlying notion the following main research question is formulated:

What measures are necessary to establish a bio-ethanol based aviation kerosene supply chain within the existing bio-ethanol market in Brazil and what projected impacts might these have on the bio-ethanol market behaviour?

To be able to clearly achieve these two aspects in this research, the following sub-questions are formulated:

1. *What typology of actors are present within the bio-ethanol market in Brazil and what conditional rules characterize the interaction between these actors?*
2. *How does the interaction between the actors in the bio-ethanol market affect the aggregate behaviour of the market?*
3. *What are the implications of introducing bio-ethanol based kerosene production within the existing bio-ethanol market in Brazil?*
4. *What production and consumption patterns arise of bio-ethanol based kerosene in Brazil in terms of volume and pricing relative to fossil fuel kerosene as a function of different policy measures?*
5. *What factors may significantly increase the production of bio-ethanol based kerosene?*

2.3 Research Methodology

The research approach which is used and the reasoning behind this approach to find the answers to the research questions is described in the following section.

2.3.1 Choice of Analysis Tools

The underlying goal of this research is to gain an insight into what can *drive* the implementation of a bio-ethanol based aviation kerosene supply in Brazil and *how*. With this in mind, supply (production) and demand (price) behaviour is therefore the single most important viewpoint for this research. Particularly from the industries and governmental viewpoint, it is very important to be able to explore different policies in a realistic environment (Carley, Carrol, Harrison & Lin, 2007; Holland, 1992).

This presumption naturally leads to simulation techniques as the preferred tool in order to investigate the research problem (Borshchev & Filippov, 2004; Robinson, 2003; Sterman, 2002).

A Complex Adaptive System

The nature of the Brazilian bio-ethanol market is complex; that is, there is no single definitive way to describe it or define its behaviour. To be more specific, the system can be considered to be a Complex Adaptive System (CAS). A definition for a CAS is given below which has been formulated by Holland, 1992:

“A Complex Adaptive System (CAS) is a dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behaviour in the system, it has to arise from competition and cooperation among agents themselves. The overall behaviour of the system is the result of a huge number of decision made every moment by many individual agents.”

Referring to the formal definition of a CAS presented above, one can notice how the bio-ethanol system which has been briefly introduced in Chapter 1, possesses many of the mentioned elements of a CAS. Applying the CAS framework to the system gives the following:

A dynamic network of many producers, distributors and consumers acting in parallel, constantly acting and reacting (supply and demand) to what the other agents are doing. Any coherent behaviour in the system arises from the competition (within the same agent groups) and cooperation (between the agent groups) among producer, distributor and consumer agents. The overall behaviour in terms of ethanol output of the system is the result of the decisions made every moment by the many individual agents.

Another important aspect of a CAS is that its elements anticipate the future (Holland, 1992). In the bio-ethanol market this can be seen from the fact that producers will adjust (*adapt*) their production ratio of ethanol and sugar in accordance to their own specific market expectation. The same can be said of the end-users; a significant increase in ethanol prices causes the car users to switch to gasoline vehicles in anticipation of a cheaper overall fuel cost. The way in which the different elements interact within the system can be represented by “conditional rules”. The degree in which actors act following these rules varies according to the different typologies of the actors. For instance, in the case of car users there are car users that prefer the lowest price paid per distance and there are car users who find it important to be able to drive as long as possible without the need for refuelling.

As was briefly mentioned in Chapter 1, a defining aspect of a CAS is the aggregate behaviour (Holland, 1992); this is the behaviour which one usually wants to understand and modify; this is also true for this research thesis. The aggregate behaviour of the bio-ethanol market can be considered to be the change in relative output of sugar, and the different ethanol types as a function of a change in market prices.

In the scope of the implementation of biofuels for aviation, the following discussion regarding a Complex Adaptive System is given;

Emergent Behaviour

Emergence is the process by which new characteristics arise once the system is constituted (Morin, 1999; Crutchfield, 1994). Emergent behaviour is the behavioural phenomena that cannot be deconstructed solely in terms of the behaviour of individual agents (Jennings, 2000). In terms of the introduction of a new system element, biokerosene, within the existing bio-ethanol system, it is of interest to the user to understand how the biokerosene system will behave. Particularly the emergence of supply chain links connecting the existing producer units with the biokerosene consumer, the production volumes and the emerging pricing behaviour of biokerosene is of importance in the scope of this research. Following from the mentioned emergence of supply chain structure and biokerosene production behaviour, a particularly important form of emergent behaviour is most relevant to the biokerosene implementation in the system; the so-called Self-organisation.

Self-Organisation

Self-Organisation is a process by which a system develops a structure or pattern without the imposition of structure from a central or external authority or when a system displays a different output as a result of internal processes (Van Dam, Nikolic, & Lukszo, 2013). Self-organisation in itself can be seen as an adaptive response to certain changes in the environment of the system. In terms of biokerosene production, there is an element of a desire for self-organisation by the producers of bio-ethanol to organize a structure in which the biokerosene production can be implemented (when the technical capacity to produce biokerosene is introduced). Furthermore, the dynamics of biokerosene prices, considering the existing bio-ethanol pricing behaviour, is required to “self-organize” such that the biokerosene market exists in conjunction with the bio-ethanol market. The mode of behaviour and the structure in which this happens is unknown; this will be the area of interest in the simulation of such a system.

In short, the bio-ethanol system in conjunction with the implementation of a biokerosene market within this system, is considered to be a Complex Adaptive System. This is for the following main reasons;

- i. Actors within the bio-ethanol market constantly *adapt* production ratios, demand and prices in the face of a changing environment or due to interactions between each other.
- ii. The emergent behaviour caused by an implementation of a biokerosene market in the existing bio-ethanol market and the Self-Organisation which is necessary in order to facilitate such an implementation is the core area of interest within this system scope.

As has been established, the bio-ethanol market and biokerosene implementation in Brazil can be seen as a Complex Adaptive System, as has been previously established. In light of this system complexity and research interest in the behaviour of the system, there are three main simulation methods available which are considered. These are System Dynamics, Discrete Event simulation and Agent Based Modelling (Borshchev & Filippov, 2004; Brailsford, Churilov & Dangerfield, 2014; Buxton, Garnett, Macal, Pidd & Siebers, 2010; Gordon, 1961; Sterman, 2002; Van Dam, Nikolic & Lukszo, 2013). An overview of each simulation method is shown Figure 5.

	Modelling Technique	Used For
Top Down Approach	System Dynamics (SD) Feedback loops, causal relations, stocks, flows, high level of aggregation. High level system knowledge required.	Policy testing in a predefined system setting. (Total) system analysis.
	Discrete Event Simulation (DES) Entities, resources, block charts, individual unit analysis. High level and detailed system knowledge required.	Optimisation, extensive commercial use in industry.
Bottom Up Approach	Agent Based Modelling (ABM) Rule based agents, low-high level aggregation, local view, emergent behaviour. Agent level system knowledge required.	Policy testing in a less defined system setting. Emergence analysis.

Figure 5: Comparison of Simulation Methods for Complex Systems

2.3.2 Choice of Modelling Method and Software

Considering the previously mentioned simulation methods, the required analysis of the biofuel system, and the fact that one is dealing with a Complex Adaptive System (Holland, 1992), it is concluded that the preferred method is Agent Based Modelling. This modelling framework fits very well with the emergent and decentralized behaviour of the biofuel supply (Adhitya, Behdani, Lukszo & Srinivasan, 2010); in addition to this, the focus on individual agents makes the model easier to understand from a non-academic perspective; by focussing on the individual rules of the agents (such as biofuel producers and user) it is easier to understand the global system (Buxton et al, 2010; Van Dam et al, 2013). The core difference between ABM and other modelling frameworks is that one does not need to understand the total system; indeed in the case of the Brazilian bio-ethanol expansion where one is dealing with an unknown market this is precisely the case. In the SD and DES framework it is essential that the total system is defined and understood before one can start a simulation. However, the ABM level of local simplicity does raise the risk of missing out on a higher level factor heavily influencing the system; this is inherent to the ABM method and it is very important that the user realizes this (Borshchev & Filippov, 2004, Van Dam et al, 2013).

In the field of ABM there are a number of widely used modelling software tools which have a distinctive “fit-for-purpose” depending on the required use of the model (Van Dam et al, 2013; Robertson, 2005). In light of the goal of this research, the emphasis on the model is on the simplicity; the model is intended to show in an understandable manner how the ethanol system behaves with a set of user defined inputs (policies and incentives). NetLogo is a modelling tool which is universally praised for its simplicity and it is a popular software tool for ABM educational purposes (Bankes & Gilbert, 2002; Van Dam et al, 2013; Robertson, 2005; Wilensky, 2004). Another advantage of NetLogo is the community is very active and there are numerous open source models already available (Northwestern University NetLogo, 2014), this can be very useful when modelling a relatively novel system. The previously discussed aspects make that NetLogo is the software of choice for modelling in this research project.

2.4 Research Steps and Thesis Outline

This thesis can be split up into three main overall parts; the order of these parts correspond to the order in which the research is carried out;

1. The first part of the report will give an extensive overview of the Brazilian bio-ethanol market. The history of the market and particularly the rationale and motivation for the implementation of bio-ethanol in car transport will be presented. Furthermore, a discussion of the existing kerosene market is given (particularly in terms of economics) and also the latest developments of biokerosene production and economics are given. Particular attention is given to the alcohol-to-jet conversion as this pathway is obviously the most relevant in the discussion of the ethanol market in Brazil. The analysis of the Brazilian ethanol market and kerosene market will be translated into a conceptual model; the system will be decomposed into the most critical aspects such that the model can be described. A model narrative will be presented which guides the reader through the different phases of the model such that the reader has a clear understanding of what the model describes and how.
2. This part will formally describe the Agent Based Model, which includes a discussion of the most important algorithms which are present in the model. An overview is given of how the model is verified and validated and based on what information. The different types of base model verification simulations and their results are presented, such as extreme condition testing and sensitivity analyses. An important section of this part will also discuss the assumptions made within the model and how this is justified in terms of the real world situation. After the base model has been discussed the critical implementation of the biokerosene user within the ethanol system is described. Particularly the assumptions and reasoning for these assumptions are explained as, due to the fact that there is no commercial biokerosene production in place, this cannot be validated in a real world setting. A comparison of the bio-ethanol car market implantation will be made in conjunction with the critical differences of this former implementation and the aviation case.
3. Finally the model experimentation for biokerosene measures is conducted and documented. Relevant system behaviour is discussed particularly in terms of these policies and different scenarios. The results of this experimentation phase leads to a discussion of measures from both a sector and governmental point of view. The report will finish with an extended discussion, based on the results of the Agent Based Model, on how a biokerosene supply chain may arise and under which conditions.

A flow scheme of how the different parts of this thesis relate to each other is shown in Figure 6

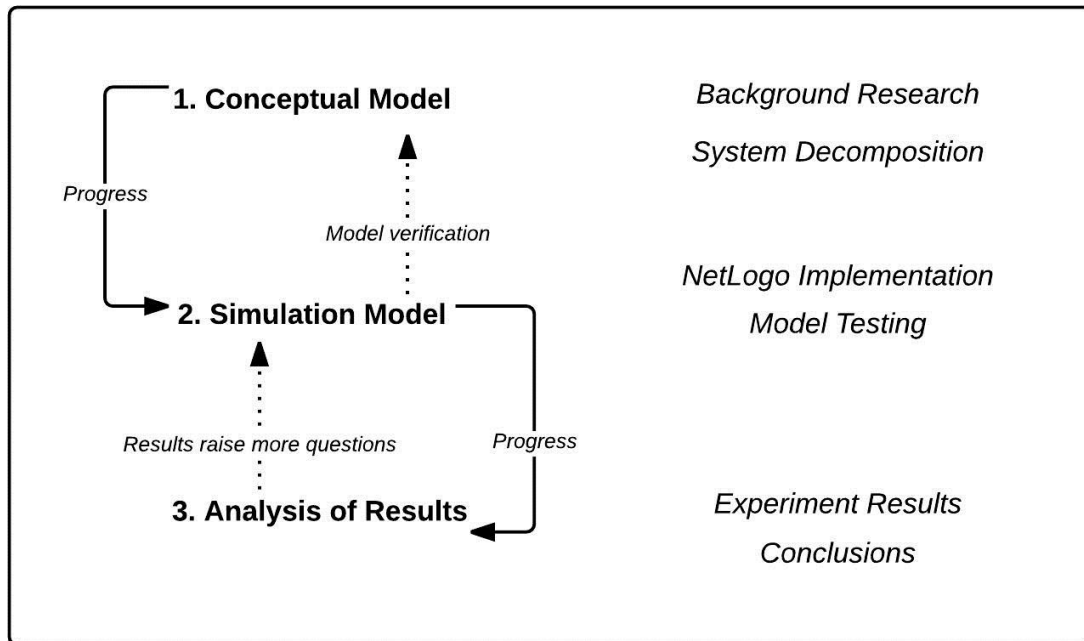
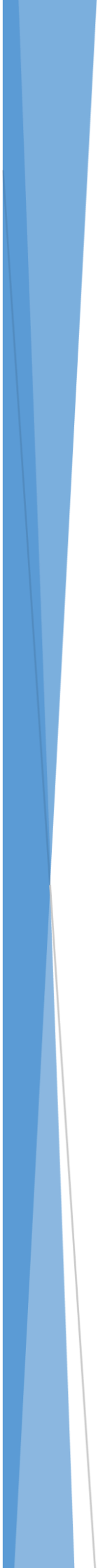


Figure 6: Flow Scheme of the Research Thesis Steps

Through this thesis and research, it is hoped that the reader gains an understanding on how the Brazilian bio-ethanol market behaves, how this can be translated to a simulation model and how the biokerosene implementation fits within this setting. More importantly, it is hoped that the reader comprehends why this specific case study is conducted and how this is relevant to the general biokerosene field which is still in the very early and vulnerable stages. The insights gained from the model should trigger an additional and different approach to biofuel policy making and to aviation biofuels in particular.

Furthermore, academically speaking, this thesis presents as a first step into aviation biofuel literature in the field of economic simulation modelling, particularly in using the Agent Based Modelling approach.



Chapter 3

The Brazilian Bio-Ethanol Market

In this chapter:

- 3.1 A Historic Overview of Brazilian Ethanol
- 3.2 Current State
- 3.3 A Socio-Technical System
- 3.4 Kerosene and Gasoline Supply Chain Comparison
- 3.5 Ethanol to Jet: BioJet
- 3.6 Conclusions

3.1 A Historic Overview of Brazilian Ethanol

The origins of the Brazilian sugar market can be traced back to the 16th century. Sugar was one of the first commodities which was exported to Europe by the colonial Portuguese settlers. As was the case with large portions of tropical Latin America the sugarcane industry thrived in this period with a substantial maturation of sugar and ethanol production (*Cortez & Rosillo-Calle, 1998*). The first use of ethanol for automobiles was between the two great wars in the 20th century; the motivation behind this implementation was the dependence of Brazil on (unstable) foreign oil supplies. The ethanol industry thrived during the second world war due to the very weak supply of foreign oil during this time which itself was caused by German submarines attacking oil tankers in the Atlantic. It was during this period that Brazil experienced a peak in ethanol production which represented 10% of the total fuel consumed in Brazil (*Charlita de Freitas & Kaneko, 2011; UNICA, 2014*).

After the Second World War, the significant increase in oil supplied and the low global prices of gasoline caused the ethanol industry to decrease in size; only in times of large sugar surpluses was ethanol produced. It was not until the global oil crisis in 1970 that the Brazilian government initiated the large-scale implementation of ethanol fuel in Brazil; this would be called the “ProAlcool” program. Starting in 1975, the government set out an aggressive set of policies to phase out the use of gasoline powered vehicles in favour of ethanol powered vehicles. The choice of feedstock for the ethanol was sugarcane.

The main reasons for the choice of feedstock were the following (*Charlita de Freitas & Kaneko, 2011; UNICA, 2014*);

1. *Global sugar prices were low.*
2. *Ethanol distillation plants across the country were idle*
3. *Brazil had a significant industry knowledge of sugarcane processing compared to other feedstock.*

The initial step in the ProAlcool program was the compulsory blending of anhydrous ethanol (which is compatible with regular cars up until a certain maximum percentage) in regular gasoline. In conjunction with this first step, the government actively pushed the automobile industry (through incentives) to develop automobiles which could run on a 100% blend of ethanol fuel. In the early 1980's the first ethanol-only vehicles (the so-called *neat vehicles*) were sold in Brazil which could run on hydrous (containing water) ethanol fuel. Until the end of the 20th century the government's policies were aimed at enforcing a relatively high blend mandate of anhydrous ethanol with gasoline (fluctuating from 10 to 25 %) and promoting the use of neat vehicles. During the early 1990's however, a combination of high sugar prices and supply shortages of ethanol caused the sale of neat vehicles to collapse; this resulted in a near gasoline-only fleet of cars running on the mandatory anhydrous ethanol and gasoline blend (*ANFAVEA, 2013*).

3.2 Current State

After the collapse of the neat ethanol automobiles in the 1990's consumer confidence in ethanol fuel use was at a low. This did not change until the introduction of the flex fuel vehicles in the year 2003. The introduction of the flex fuel vehicles is the prime cause of the renaissance of bio-ethanol fuel in Brazil (*Charlita de Freitas & Kaneko, 2011; UNICA, 2014*).



Figure 7: Gas Station Choice for Flex Users (ANFAVEA, 2013)

The flex fuel vehicle permits the user to use any combination of gasoline and hydrous ethanol, see Figure 7. This means that the user can switch the fuel consumption based on the current prices of the different fuels. This added flexibility enables the ethanol market to directly respond to supply surpluses and shortages domestically and also to global prices for oil and sugar. The popularity of the vehicles has led to the current situation in Brazil where more than 80% of the total fleet of light vehicles (small sized consumer automobiles) are composed of flex fuel vehicles (*ANFAVEA, 2013*). Also the domestic use of ethanol has increased dramatically by more than a factor two in comparison with pre-2003 levels (*UNICA, 2014*).

A particularly clear lesson which can be learned from the flex-fuel induced renaissance of the bio-ethanol market is that a strong biofuel market hinges on flexibility in terms of production volumes. Based on the assumption that biofuels will need to compete with conventional fuels on a price competitive basis, it is imperative that the biofuel market is flexible in the sense that it can react to changes in the conventional fuel prices (fossil fuels in the current case). The lack of this flexibility in the era before the introduction of flex fuels was exposed in the Brazilian case in the form of major biofuel supply shortages and corresponding falls in consumer and market confidence in the product. Per definition, biofuel supply must be considered to be unstable due to the highly sensitive nature of agricultural yields in a given season and such demand must be able to fluctuate in conjunction with these supply variations as the demand for fuel will remain relatively constant due to the inelastic nature

of the demand for fuel (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). Therefore the composition of the fuel energy mix must be able to change according to supply.

The significant increase in ethanol use and production has had the effect of further maturing the sugarcane industry as a whole. The yields from one single unit of sugarcane have doubled compared to the initial levels before the ProAlcool program was started (*BNDES & CGEE, 2008*). Furthermore, on the feedstock side the increased production of sugarcane per hectare of land and also the increase of sucrose (energy) concentration per unit of sugarcane have dramatically lowered the sugarcane production prices in Brazil; thus increasing the competitive nature of sugarcane. The Brazilian expansion of the bio-ethanol market clearly shows how demand and volume increases within any link of the supply chain can, propagate throughout the whole supply chain. It is for this reason that the focus of this thesis will be on how to initiate the *kick-starting* of this supply chain though the increase of production volumes.

The previously discussed observations are why the Brazilian sugar and ethanol market are chosen by many researchers and policy makers alike as a leading example of biofuel implementation. Particularly the economics of the ethanol market and the strong competitive ability to global oil prices has caused a significant interest in the Brazilian ethanol model (*Charlita de Freitas & Kaneko, 2011; De Gorter, Drabik, Kliauga, & Timilsina, 2013; Junginger, Faaij, Poot, Van den Wall Bake, & Walter, 2009; Chiong Meza, 2012; Banse, Kemfert, & Sorda, 2010*). It is also important to realize that the interest in the Brazilian case is also derived in part due to a lack of other large scale, long-term biofuel cases; indeed the emergence of significant biofuel supply chains in general is at the moment still a relatively scarce phenomenon (*Banse, Kemfert, & Sorda, 2010*).

3.3 The Bio-Ethanol System

The Brazilian bio-ethanol supply chain consists of four major elements (*BNDES & CGEE, 2008*). The characteristics of these elements are summarized below; an illustration of the system element flows is shown in Figure 8.

Feedstock: consisting of the growth and harvesting of sugarcane crops. Most sugarcane farmers in Brazil have contracts with a fixed refinery unit. In some instances the farm is owned by the production unit. The price for sugarcane is determined as a function of the average value of bio-ethanol during the year; this means that the price is determined after the supply of sugarcane (*BNDES & CGEE, 2008*). Therefore, sugarcane farmers do not make any significant market related decisions during the harvest season. It is for this reason that the feedstock producers are not considered in the scope of this research which is more focussed on what happens with the sugarcane after harvesting.

Production: this entails the processing of the sugarcane into bio-ethanol and/or sugar. Most modern day refineries in Brazil are specialized in either sugar and ethanol production or just ethanol production. However, when the market demands it (through sudden demand shifts), refineries are able to shift their production by up to approximately thirty percent to either product in a season. This is less likely to happen when the refinery is already specialized in producing ethanol exclusively. Decision making by refineries is based on the current market price of sugar, ethanol and gasoline. Furthermore, there is a

distinction between hydrous ethanol and anhydrous ethanol. Hydrous ethanol is ethanol which contains water and as such is incompatible with regular gasoline vehicles. Anhydrous ethanol is ethanol without (strictly speaking containing less than 0.5% water) which is compatible with regular gasoline vehicles. Anhydrous ethanol however is more expensive to produce.

Distribution: the collection and sale of bio-ethanol to the end-user; at the moment these are the domestic car users and export markets. In Brazil distributors can either choose to sell gasoline or bio-ethanol to the flex fuel market. However, gasoline needs to be blended with bio-ethanol by law; this means that distributors will always need to deal with bio-ethanol in some capacity in the fuel market. In essence the distribution phase is dominated by government policy and the supply and demand dynamics. More specifically, decision making in this regard is thus based on government blend mandates, the demand from the consumer market and the available supply from producers (BNDES & CGEE, 2008).

End Use: the use of biofuel by the consumer. This entails consumer demand dynamics such as the accepted market price of the fuel and consumption volumes. In Brazil there are two distinct groups of car users; the flex fuel user who are flexible in their use of bio-ethanol and the regular gasoline users, who consume bio-ethanol through the government induced blending mandate. Numerous studies have shown that ethanol consumers remain relatively loyal to ethanol use as long as there are no significant price and/or supply shocks; when these occur such as has happened in recent years, consumers will switch en masse to gasoline use (Charlita de Freitas & Kaneko, 2011).

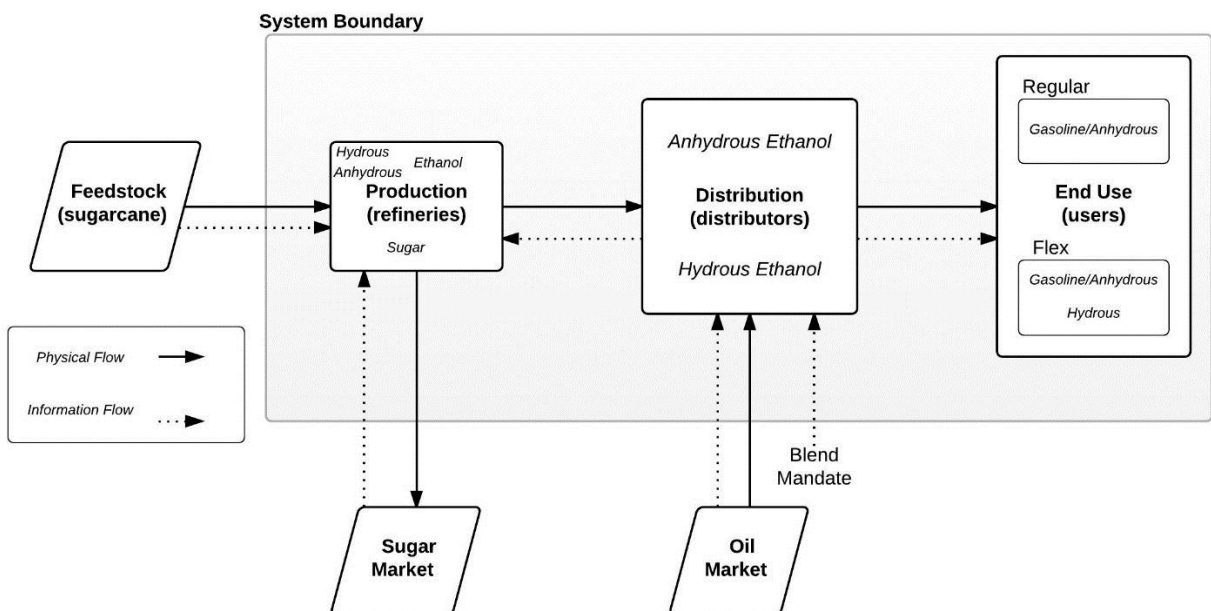


Figure 8: System Flow Chart of the Bio-Ethanol Market with corresponding Physical and Information Flows

A Socio-Technical System

The Brazilian ethanol and sugar market can be considered to be a socio-technical system. A socio-technical system is composed of the interplay within a system of humans (*social network*) and technology (*physical network*) (Van Dam, Nikolic & Lukszo, 2013). In terms of the Brazilian ethanol market, one can consider the economic aspects of ethanol and sugar prices which are determined through technicalities such as the weather, production efficiencies and overall transport technologies such as the introduction of flex fuel vehicles and consequent increase in fuel efficiency of engines (Charlita de Freitas & Kaneko, 2011). These technical aspects largely affect the social decisions in terms of demand for which product, investments in a certain technology and others factors of this kind.

Particularly in Brazil the main social dynamics are composed of the decision by car users to buy a flex fuel vehicle or a regular gasoline vehicle, the decision to tank hydrous ethanol or regular gasoline (see Figure 7) and the decisions regarding future expectations and historical events (Charlita de Freitas & Kaneko, 2011). As is characteristic of socio-technical systems, both social and technological paradigms shift continuously (Van Dam, Nikolic, & Lukszo, 2013). In the Brazilian bio-ethanol market this can best be illustrated by the change in sugarcane production efficiencies (*technical aspect*); in the past 20 years the yield of sugarcane per land area has increased by a factor two (UNICA, 2014). This has had a significant impact on the sugarcane availability and prices. In conjunction with an increase in sugarcane yields, the processing of the sugarcane has also been optimised, spurred on by the increase in ethanol demand (*social aspect*). On the consumer side, the technological development regarding flex fuel vehicles has shifted the social rules regarding the consumption of automobile fuel. As discussed in the introduction, this has had significant impacts on the ethanol market in Brazil. The Brazilian ethanol case clearly shows the characteristics of a strong interdependent relationship between technical and social system elements. The interaction between these system elements is illustrated in Figure 9.

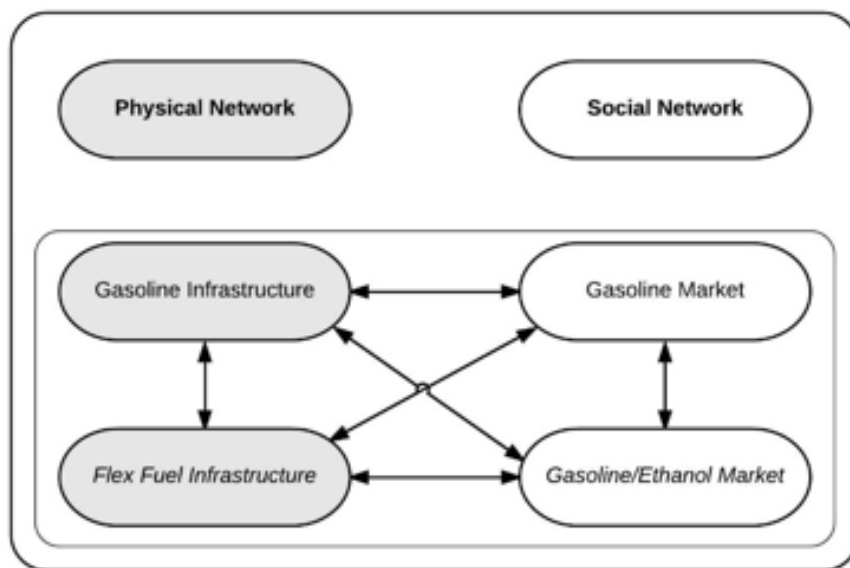


Figure 9: Interaction between physical and social networks. Adapted from (Van Dam, 2009)

3.4 Kerosene and Gasoline Supply Chain Comparison

An analysis of the kerosene market and how this relates to the Brazilian fuel market is given in the following section.

3.4.1 The Kerosene Supply Chain

Kerosene is a by-product of crude oil refining; it is a high grade fuel product with excellent combustion properties for the aviation industry (*IATA Fuel, 2014*). This has made it the premier fuel for aviation since the beginning of commercial aviation and as such the infrastructure for kerosene is extremely well-developed and mature (*Neiro & Pinto, 2004*). The kerosene supply chain consists of two major links. The first being the distribution of the fuel from the oil refineries, where the kerosene is processed from crude oil, to the main kerosene terminals at airports. The second and more complex link is the distribution of kerosene from the kerosene terminals at the airport towards each individual aircraft. A further illustration of the kerosene downstream supply chain is shown in Figure 10 where the two mentioned links in the supply chain have been identified with “Box A” and “Box B”.

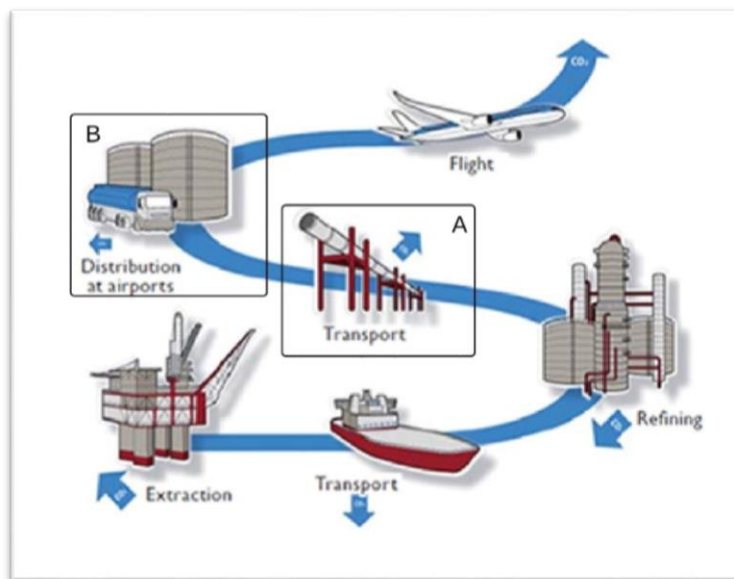


Figure 10: Kerosene Supply Chain. Adapted from (Qantas, 2013)

Link A: Refinery to Airport

Large international airports usually make use of pipeline infrastructure directly from refineries to the airports. This is motivated by the very highly centralized location of the fuel demand, the large volumes which are necessary and also to the importance of a reliable supply of the kerosene (*IATA Fuel, 2014*). This latter aspect also presents the kerosene supply chain with a significant advantage over the automobile fuel supply chain which is characterized by a much more decentralized structure.

Link B: Airport to Wing

At the airport, kerosene is usually distributed from the kerosene terminals to the aircraft via an underground pipeline system. This is especially true for the larger international airports. This system is significantly more efficient than using tank trucks to supply each individual aircraft at every individual turnaround; however the installation and maintenance of such infrastructure is very costly; therefore at smaller airports (and isolated terminals at international airports) kerosene is usually supplied via fuel trucks. The latter system however, from an individual “aircraft refill” perspective is much more costly in terms of operations. From a local cost competitive view point between conventional kerosene and biokerosene, it is imperative that biokerosene makes use of the same infrastructure as conventional kerosene (ATAG, 2009). A situation in which this is not the case, presents biokerosene with a significant economic disadvantage in logistical terms; even when production costs would be equivalent to that of regular kerosene.

Any possible advantage of biokerosene distribution over automobile bio-ethanol distribution gained through pipeline infrastructure, necessitates the technical capacity of ethanol based biokerosene to be transported in the existing pipeline infrastructure under current safety regulations. At this present time this has not been certified yet by the authorities (ATAG, 2013) and this is also a primary additional cost with which biokerosene is burdened with in relation to the conventional kerosene distribution (IATA Fuel, 2014). However, tests are currently (as of 2014) underway for providing *biodiesel* (non-alcoholic variant) based biokerosene using airport pipeline infrastructure (SkyNRG, 2014). Certification for alcohol based biofuels in pipeline infrastructure hinges on the capability for producing a drop-in fuel; meaning that biokerosene is equivalent in properties to regular kerosene. A potential risk for ethanol biofuels in pipeline infrastructure is the increased possibility, relative to conventional fuels and other non-alcohol biofuels, for corrosion. This also applies to *anhydrous* ethanol, although to a lesser degree as anhydrous ethanol still contains very small traces of water. However, ethanol transportation by pipeline in Brazil (on a limited scale) so far has not shown any negative effects in this regard (UNICA, 2014).

3.4.2 Kerosene Pricing Mechanism

The price of kerosene is almost entirely determined by the price of crude oil (Shell Aviation, 2014). This means that the price of kerosene fluctuates in line with oil price fluctuation. The price of crude oil however is notoriously difficult to predict and fully understand (Energy Charter Secretariat, 2007). It is this aspect which has significantly damaged airline profitability; the constantly changing fuel prices increase uncertainty premiums for airlines and additionally distort competition between airlines, especially when certain airlines enjoy significant fuel price advantages based on the geo-political region of their home base, see Figure 11. A further discussion of the impact of different fuel prices for airlines is given in Appendix B. In conjunction with an increase in sustainable flight operations, the opportunity for airlines to decrease their dependency on oil market fluctuations is a major reason why the aviation industry is exploring biofuel use (IATA, 2009; Lufthansa Group, 2014; ATAG, 2009). The opportunity to somewhat stabilize and, to some extent, control fuel prices in the aviation industry will be a significant focus of this research.

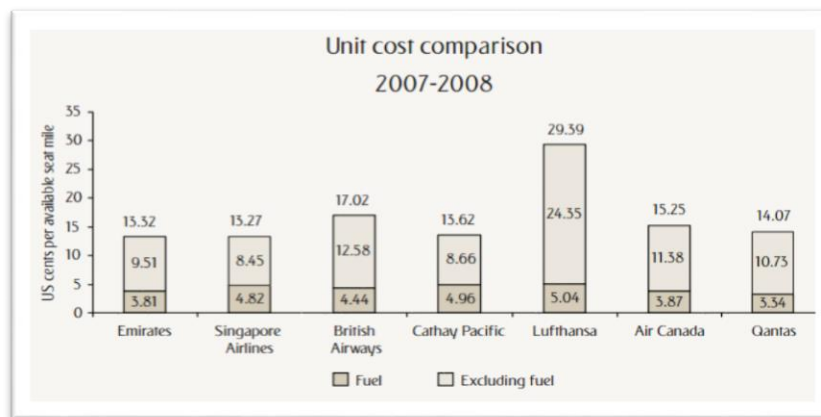


Figure 11: Comparison of the Fuel Costs between Airlines (Emirates, 2014)

3.4.3 Aviation Fuel Markets versus Automobile Fuel Markets

In comparing regular car fuel markets with that of the kerosene market it is important to take note of some of the major differences in characteristics. The primary being the fact that kerosene fuel is a much more complex fuel in terms of certification from the relevant authorities. Aircraft fuel must meet stringent requirements that fit ASTM certification (universal certification authority); this follows directly from the extremes performances range within which aircraft are found (IATA, 2013). In addition to this, the overall conservative nature of the aviation industry, which naturally follows from the strict safety regulations and capital intensive nature of its assets, prohibits rapid changes in fuel development. This is in direct contrast to automobile fuels where there are many different types of fuel (diesel, gasoline blends and the many different oil company specific fuel brands). The energy density of kerosene is a significant requirement; transportation costs in the aviation industry are exponentially related to weight and the weight of fuel makes up a significant portion of total weight of a commercial airline (Ruijgrok, 2009). This is in contrast with road transport where the weight of the fuel in relation to the empty vehicle weight is much smaller. The importance of kerosene energy density imposes any biokerosene variant with an energy density equivalence requirement with regular kerosene; this does not apply to road transport fuels and thus presents biokerosene with a significant disadvantage compared to road transport biofuels as the production costs will by definition always be lower for a lower energy density fuel (ATAG, 2009). An extensive overview of the most important kerosene certification requirements versus standard gasoline requirements is presented in Appendix C.

The profit margins of kerosene fuel made by refineries are low compared to that of other oil derived products (ATAG, 2009, Shell Aviation, 2014; IATA Fuel, 2013). This has three primary causes (Purvin & Gertz, 2008);

1. High competition globally for aviation fuel in a market where airlines continuously seek the lowest kerosene prices.
2. Overcapacity in the downstream refinery sector due to a structural over-investment in refineries and a relative abundance of kerosene from crude oil distillation.

3. *Strong competition from other sectors for crude oil; there are few resources which can be produced into the amount of different end-products as is possible with crude oil and thus the price (due to strong demand) of the raw material for kerosene is relatively very high compared to the refined product.*

As mentioned earlier, the price of kerosene is almost entirely composed of the *global* price of crude oil (ATAG, 2009). This is in contrast to the production of “crude” ethanol in Brazil as the price of ethanol is dependent on internalized, and local factors such as weather, domestic demand, export demand and more importantly global sugar prices (De Gorter, Drabik, Kliaugu, & Timilsina, 2013). The demand variance of kerosene is essentially non-existent in the aviation supply chain as there are relatively fixed amounts of kerosene necessary at kerosene supply centres. Furthermore, the demand can be predicted based on the scheduled nature of airline operations (Cheze, Gastineau & Chevallier, 2011). This last fact presents a considerable logistic advantage towards aviation fuel in that sense that the distribution of kerosene is highly centralized and that demand is highly predictable; particularly when compared to the automobile market which is highly volatile. This reduces the level of uncertainty regarding future supply and demand in the market; and as such producers of kerosene in relation to producers of automobile fuels can anticipate production volumes in a much more robust way (BNDES & CGEE, 2008). In terms of possible biokerosene production this offers producers a relative stable and predictable demand for their product; the high variance in the current ethanol demand, flex behaviour but also strong changes in overall car fuel demand, and the corresponding technical shifts which are required at the refinery level impose additional costs on producers of automobile bio-ethanol compared to the proposed biokerosene market (BNDES & CGEE, 2008).

A short overview of the key differences between the kerosene market and regular gasoline market has been given. Figure 12 illustrates the key advantages and disadvantages which may be present in the biokerosene versus automobile biofuel competition.

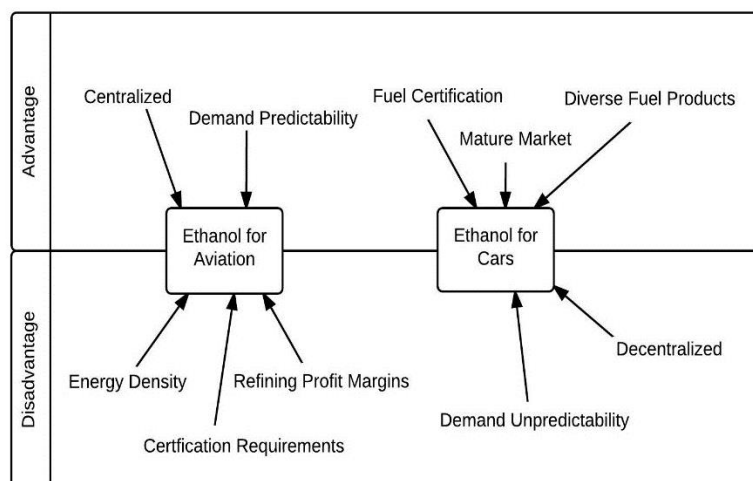


Figure 12: Potential Advantages and Disadvantages of Biokerosene Production for Aviation

3.5 Ethanol to Jet: BioJet

The aviation and biofuel industry are strongly committed towards the implementation of biokerosene (*Boeing, Embraer, FAPESP, & UNICAMP, 2013; BioPort Holland, 2013; Qantas, 2013*). However, a primary hurdle which is present at the moment is the actual cost of the feedstock (*Ziolkowska, 2013*). It is for this reason that much of the biokerosene attention has been turned towards ethanol based kerosene as ethanol can, in principle, be produced from any plant matter and the ethanol industry is already relatively mature (*BNDES & CGEE, 2008*). Also, the emerging technologies in regards to cellulosic ethanol have increased the potential of ethanol fuels (*Poet-DSM, 2014*). The most efficient biomass plant is Brazilian sugarcane; it is for this reason that a large number of international (biofuel) energy firms have established commercial pilot plants in Brazil (*BNDES & CGEE, 2008*). A comparison of photosynthetic efficiencies of biomass around the world is shown in Appendix D. Here one can clearly see the energy potential of sugarcane in relation to other plants.

Bio-ethanol is produced through the fermentation of sugars. It is for this reason that sugarcane is a primary source of bio-ethanol production due to its high sugar content; the sugar is already present in the biomass and only extraction of the sugar is necessary. It is however, also possible to obtain sugars from cellulose; this is a component which can be found in many plants and it also the most abundant organic polymer found on earth. Additionally it is possible to obtain sugars from starch, which is found in corn. Corn ethanol is the main source of bio-ethanol in the United States, however the energy efficiency of corn ethanol production is much lower than that of sugarcane ethanol and as such corn ethanol will not be considered in this section (*BNDES & CGEE, 2008*).

3.5.1 Bio-ethanol from the Direct Fermentation of Sugars

Microbial fermentation is the production of ethanol from sugars in plant material through the use of specific yeasts (as is the case in the brewing of alcoholic beverages). This method of ethanol production is also the method used in virtually all current production of biological ethanol around the world (*Ziolkowska, 2013*). The main advantage of this method is the relative simplicity; as long as there is a suitable high-sugar feedstock, and there are right conditions for the yeast to process the sugars, ethanol production requires no other significant processing, see Figure 13. However, the end-product of this form of ethanol results in a relatively high water content; hydrous ethanol. The water in hydrous ethanol presents a large problem for combustion engines as it can increase corrosion of the parts. Also in colder climates, hydrous ethanol is prone to freezing which will clog valves. Also, hydrous ethanol is much more difficult to ignite at colder temperatures. The latter is not as much of an issue in the tropical climate of Brazil, hence the possibility of hydrous ethanol as an automobile fuel in that particular country (*ANFAVEA, 2013*).

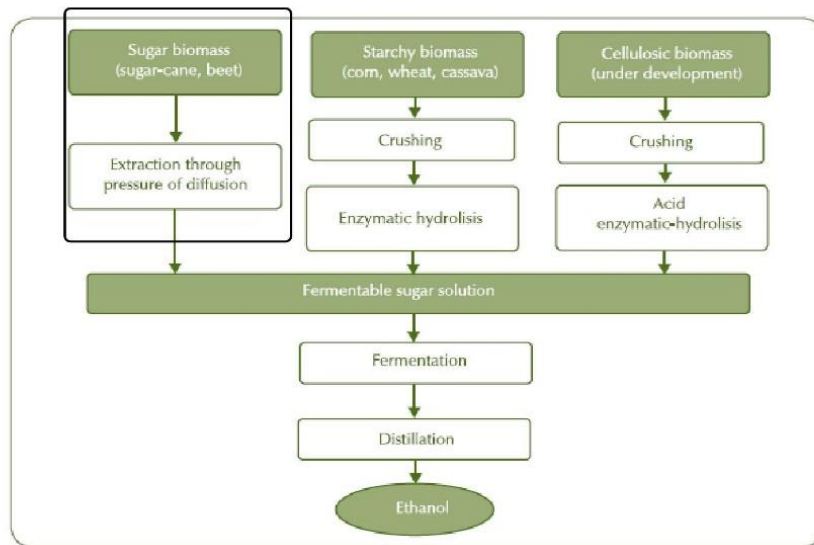


Figure 13: The Sugarcane Refining Process Pathways. Adapted from (BNDES & CGEE, 2008)

Regarding the feedstock used in conventional bio-ethanol; the overall costs are relatively very low as there is already a mature market (sugarcane ethanol market). The large availability of sugarcane and other high-sugar plants offers microbial fermentation a significant advantage as opposed to other ethanol production methods which operate in a young or non-existent market. A drawback of the previously mentioned availability of feedstock is the strong competition for this very same feedstock and the specific nature of the feedstock; sugarcane (and sugar beet) and corn feedstock are the only options for large scale bio-ethanol cultivation through this means which limits the flexibility of the feedstock sourcing. In conjunction with this is a potentially serious food versus fuel debate; the conventional bio-ethanol production from sugar biomass is a so-called first generation biofuel and does not meet the current sustainability requirements set out by the aviation industry (ATAG, 2009; SkyNRG, 2014; Ziolkowska, 2013).

3.5.2 Cellulosic Ethanol

Cellulosic ethanol production is the production of ethanol from sugars which have been obtained from the breakdown of lignocellulose; a structural material which makes up most of the mass of plants. The processing of lignocellulose into sugars can be done through a cellulolysis process which uses enzymes to break down complex cellulose. It also possible to process lignocellulose into ethanol with a gasification process ; in this process the feedstock is converted into a synthesis gas from which ethanol is then produced, however this is less energy efficient due to the extra processing (Mabee, Saddler, Sims, & Taylor, 2008). An overview of the enzymatic production pathway of cellulosic ethanol is shown in Figure 14.

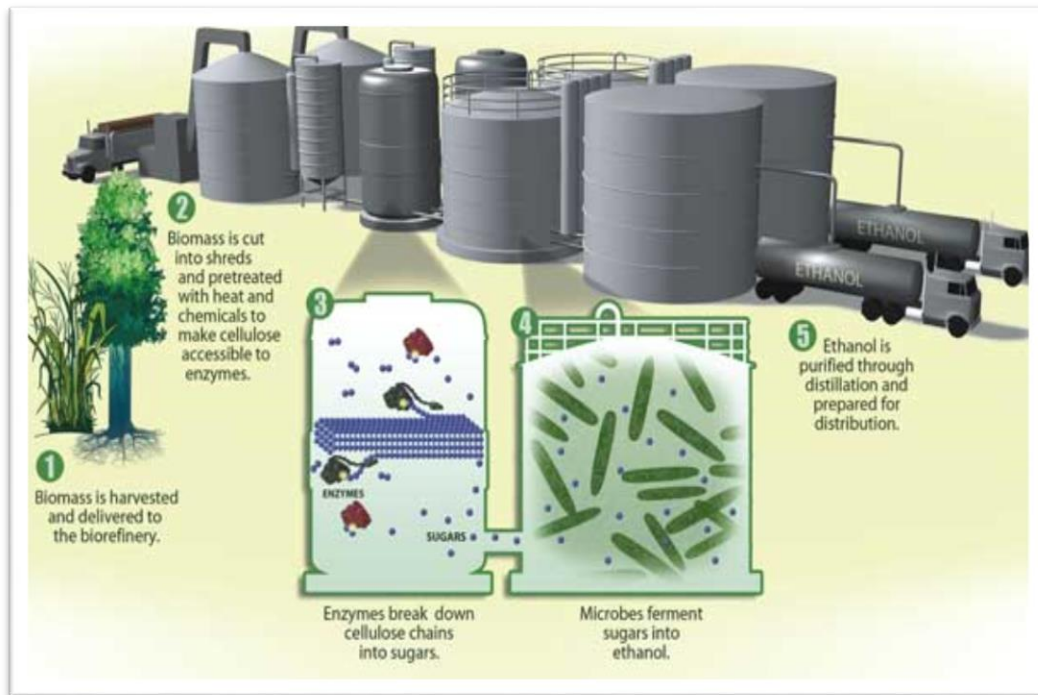


Figure 14: The Production Process of Cellulosic Ethanol (BioEnergy Consult, 2014)

The commercial production of cellulosic ethanol is in the very early stages (POET-DSM, 2014). The largest barrier in reaching commercial scale is the cost of the enzymes which are necessary for the process. There is an expectation however, that the increase in scale will be particularly effective in bringing down the unit cost of the enzymes (Carriquiry, Du, & Timilsina, 2011). However, the most promising aspect in regards to the commercial application of cellulosic ethanol, is the fact the feedstock resource is abundant. Most biomass streams contain cellulose, including wood and grass, which are the primary sources for biomass energy in the world (BioEnergy Consult, 2014). This latter aspect means that there is ample supply of feedstock and also, perhaps more importantly, the feedstock source itself can be flexible. This means that the production of cellulosic ethanol can be done using the raw material that is at hand at the specific location and time of the producer unit. From a sustainability and social viewpoint, the ability of using different feedstock also negates the possible negative impact on food prices as non-edible feedstock can be used (Carriquiry, Du, & Timilsina, 2011).

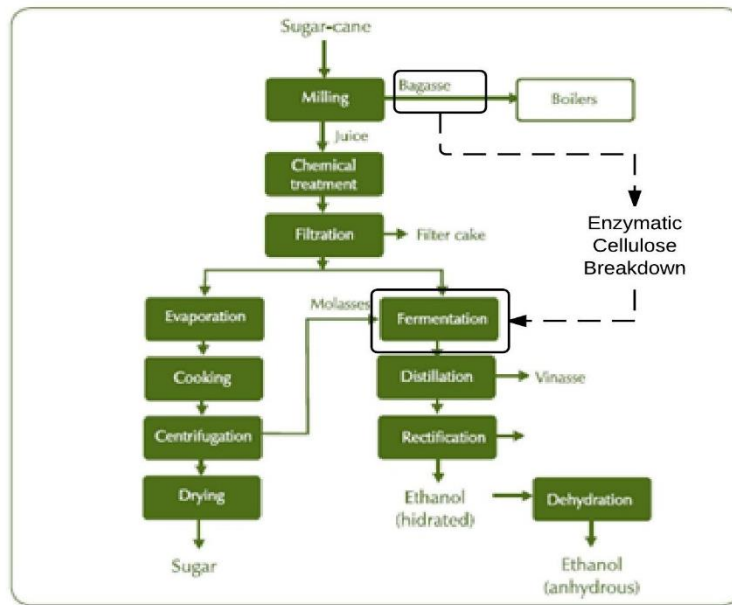


Figure 15: Cellulosic Ethanol Potential from Bagasse. Adapted from (BNDES & CGEE, 2008)

From the perspective of the Brazilian sugarcane market, a significant opportunity exists in the field of cellulosic ethanol, see Figure 15. During the conventional extraction of sugarcane juice, the leftover fibre (called bagasse, which is essentially sugarcane residue after juice extraction) is currently turned into electricity at the refineries through combustion. This process enables refineries to be fully self-sufficient in terms of energy and in most cases even refineries are net suppliers of electricity to the Brazilian electricity grid (BNDES & CGEE, 2008). However, from an energy efficiency viewpoint, the burning of the bagasse is very inefficient. The photosynthetic (solar energy conversion) efficiency from sunlight-to-biomass-to-electricity is only in the order of 0.34% (see Appendix D for further details) whereas the energy efficiency from sunlight-to-electricity of most solar panels, particularly considering the Brazilian climate, is in the order of 10-25%. From an energy (and carbon footprint) viewpoint, the possibility of producing cellulosic ethanol from bagasse presents the sugarcane market with a significant opportunity to produce additional volumes of ethanol, which technically is a second-generation, non-food competing biofuel, while also decreasing the carbon footprint of its operations and product. This latter aspect can be especially important in the field of biokerosene production where sustainability criteria are stricter than for other sectors (SkyNRG, 2014).

3.5.3 Biokerosene from Ethanol

Biokerosene production from ethanol is in the early stages of development. There are two distinct factors which are critical towards the ethanol to jet pathway (Qantas, 2013);

1. Certification by the ASTM authorities for use of ethanol based kerosene in commercial aircraft and the level of blending which is allowed (blend wall).
2. Technical and economic capacity for producing high-grade, kerosene equivalent, biokerosene.

It has been observed in recent years that the certification of the different biokerosene variants is highly correlated to the *technical readiness* of the specific biokerosene production pathway and also with the *willingness* of airlines and others users to fly with the particular biokerosene variant (IATA Fuel, 2014). In essence, it has been shown that a promising conversion pathway in combination with sufficient industrial pressure can significantly increase the speed of kerosene certification processes (Boeing, Embraer, FAPESP, & UNICAMP, 2013). It is important to note that the kerosene used in the aviation industry has not changed for a significant time and as such the introduction of new and different kerosene variants is a relatively novel phenomena in the field of kerosene certification. Therefore the most critical aspect of the bio-ethanol to jet pathway is the *technical capacity* to produce *airworthy* biokerosene. Numerous tests have been conducted in Brazil with ethanol based kerosene which suggests on the technical side that the production processes are nearing commercial capability (Boeing, Embraer, FAPESP, & UNICAMP, 2013). An overview is given in Appendix E of which conversion pathways are currently being explored, by who and using which feedstock.

In the ethanol-to-jet debate the most significant aspect is related to a sustainability and economic perspective. The aversion of many aviation actors towards flying on first generation fuels means that only ethanol variants produced from lignocellulosic ethanol can be considered (Ziolkowska, 2013). As mentioned in the previous section, this production route is in the very early stages and the commercial capability and availability is unknown. It remains to be seen when this pathway nears technical capacity and what the commercial potential of the fuel will be. This latter uncertainty will be further explored in the Agent Based Model through different yield and cost assumptions; this will follow in Chapter 6. Furthermore, the sustainability ambitions of the aviation sector have the consequence that the maturation of biokerosene production is potentially delayed; as the availability of biomass within the sustainability criteria are limited, which leads to the paradoxical situation where high sustainability requirements lead to a barrier for sustainable fuel altogether. It seems a compromise is necessary between the speed of implementation, cost of biokerosene and the perceived sustainability of the production and use of this biokerosene, see Figure 16.

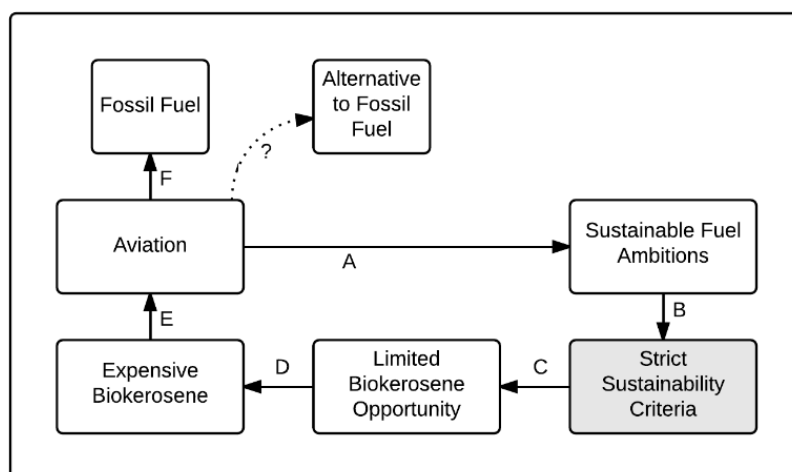


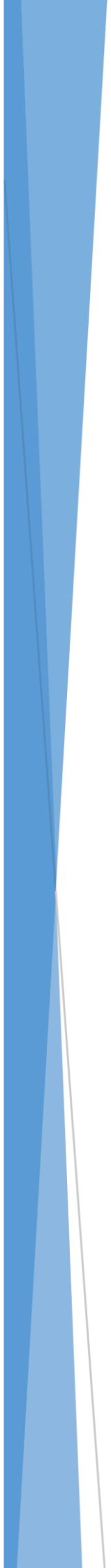
Figure 16: The Sustainability Paradox: Strict Criteria Can Lead to a Status Quo

To further illustrate this aspect, in a comparison with the (German) electricity market, it has been shown that first a maturation of the electricity market as a whole was required, based on (cheap and abundant) fossil fuels. Once the downstream side of the electricity markets was matured, a sharp shift towards a more sustainable *source* of electricity was possible (“die *Energiewende*”); spurred on by the large, established downstream electricity market which may not have arisen in the first place without the use of fossil fuels (*Jacobsson & Lauber, 2004*). In the latter case, the establishment of the fuel *form* was first necessary after which the fuel *source* was adapted towards renewable energy. This may compare to the technological establishment of the *biofuel form* for aviation *after* which the *biomass source* of the biofuel can be adapted according to sustainability criteria. At the current time this process is the other way round in light of the sensitivity of biofuels in the public perception.

3.6 Conclusions

In short, the following aspects can be concluded about the background of Brazilian bio-ethanol and the ethanol-to-jet pathway;

Brazil’s bio-ethanol market has been driven through *strong governmental support*. The kerosene market and (car) bio-ethanol market show significant differences. The main one being the technical requirements for the fuels and the logistics. Biokerosene production from ethanol is still in the early technical stages, however the upscaling and sustainability potential is relatively large due to the emergence of cellulosic ethanol production which in theory means all biomass can to some point be seen as a feedstock source for ethanol. Furthermore, ethanol production itself is already very mature.



Chapter 4

Towards an Agent Based Model

In this chapter:

- 4.1 System Decomposition
- 4.2 Concept Formalisation
- 4.3 Model Formalisation
- 4.4 Conclusions

4.1 System Decomposition

In order to conceptualize a model of any system it is imperative that the system is broken down into smaller chunks for it to be successfully analysed (*Van Dam, Nikolic, & Lukszo, 2013*). This goes further than assembling the relevant actors and their interactions within that arena; it is also necessary to take into account the dynamics within the actors themselves and the manner in which the interactions take place. The initial steps in the system decomposition are therefore the identification of the system elements and the interaction patterns within and between these elements (*Bankes & Gilbert, 2002; Holland, 1992; Sterman, 2002*).

4.1.1 System Elements: The Agents

In an Agent Based Model the most important elements are the agents themselves. There is no strict definition of what an Agent Based Model is or what constitutes an “agent” (*Van Dam, Nikolic, & Lukszo, 2013*). In this report agents are referred to as entities in a system to be studied, which are capable of making decisions which influence other agents’ decisions and the environment in which they are present. Following from the literature regarding the bio-ethanol market and consequent aviation biokerosene supply chain the following agents are identified and defined.

Users

In Brazil there are three distinct different types of car users, the extent to which users can transfer between these types is dependent on the user type.

Type 1: Users of type 1 are car users who drive regular gasoline vehicles. In Brazil this entails that they drive on a blend of gasoline with anhydrous ethanol (market regulated by the government, referred to as *gasohol* from now on). Regular car users cannot switch between fuel products freely; this can only be done once these users buy a new car; this is assumed to happen once every few (*this is not uniform for all users but randomly distributed*) years (*ANFAVEA, 2013*).

Type 2: Users of type 2 are car users who own the so-called Flex-Fuel-Vehicle (FFV). This means that these users can freely switch between hydrous ethanol fuel consumption and gasohol consumption. Users of type 2 however are Flex users who at the current moment have chosen to drive on regular gasoline over hydrous fuel. This is plausible given a certain current price level of hydrous fuel versus gasohol, where a lower gasohol price increases the likelihood of this occurrence; the higher the regular gasoline price relative to hydrous ethanol, the less users there are of type 2.

Type 3: Users of type 3, like users of type 2, are car users who own a FFV, but at the moment choose to drive on hydrous ethanol over gasohol fuel. This is plausible given a certain current price level of hydrous fuel versus gasohol, where a lower hydrous price increases the likelihood of this occurrence; the higher the hydrous ethanol price relative to gasohol, the less users there are of type 3.

All car users are assumed to have a certain *inclination* (this is personal, and randomly distributed in the model) towards either gasohol fuel consumption or hydrous consumption. This inclination is related to for instance the fact that users may prefer the available car models in the regular car market as opposed to the FFV market which has a limited amount of car models, as it is particularly focussed on the smaller car segment where users are more likely to be sensitive to cost (*Pacina & Silveira, 2011*). In addition to the fuel inclination, all car users also have a personal inclination towards the *frequency* of evaluating the cost of the current fuel consumption. This is related to the inclination for hydrous and gasohol consumption; hydrous inclined users are assumed more sensitive towards cost and as such will have a higher inclination towards checking the price of fuel in order to optimize fuel costs. It is most important to realize the overall importance of the *concept* of switching between fuels and product inclinations than the actual level and value of the inclinations itself. This issue, and also other subsequent issues relating to quantitative relations will be further explained in the validation and experimentation part of this thesis.

Distributors

Car users buy their fuel from *petrol stations* which in turn receive the respective fuel volumes (gasoline, hydrous and anhydrous ethanol) from regional distributors (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). The demand of car users directly affects the demand of the different fuels for the individual petrol stations. Therefore, individual car users and petrol stations are considered equal; that is petrol stations represent a higher level of aggregation of individual car users and are thus considered to consist of the same agent group (Users). Distributors on the other hand, are the so-called *price setters* in the ethanol and gasoline market (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). They are the agents who are most sensitive to economic pricing mechanisms, demand and supply dynamics and technological developments. Distributors are limited in the number of direct choices that they have in the physical world; the decisions distributors can make are based entirely on an *information* basis; that is to say that the price levels that a distributor sets in turn affect the *physical* flows of ethanol products towards the distributor (*upstream*) and away from the distributor (*downstream*). In turn, the premise on which distributors set their product prices is assumed to be dependent on the amount of product in stock and the rate at which these stocks change, this is in line with a general view on oil supply chain management (*Neiro & Pinto, 2004*).

Refineries

Distributors receive their ethanol products from refineries. Refineries in turn process sugarcane into either sugar, hydrous ethanol or anhydrous ethanol, where anhydrous ethanol is a further processed form of ethanol and as such is per definition more expensive to produce than hydrous ethanol (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). The production ratios, *which are composed of the amount of sugarcane used for the specific product divided by the total sugarcane supply*, of the three products can shift throughout each harvest. The maximum degree of the ratio changes is generally in the order of 30% production shift of the original product ratios at the start of season. In the model this translates

to a maximum change of 10% per quarter as the sugarcane production itself is beyond the scope of the model (external) and as such harvest seasonality is not taken into account. It is important to note that hydrous ethanol and anhydrous ethanol are closely related in that sense that refineries with a large portion of hydrous ethanol production will also have a corresponding high portion of anhydrous ethanol production relative to sugar production, these refineries are focussed on ethanol production (BNDES & CGEE, 2008).

It is possible for refineries to choose not to produce a certain product; this results in a zero production ratio for that particular product, in this case the refinery is a specialist in either ethanol (distillery) or sugar production. The decision by refineries to alter their production ratios is dependent on the prices that the refineries receive for the product, the technical efficiency and thus production cost that each individual refinery has in relation to the production of sugar and ethanol and also on the inertial willingness of refineries to change product ratios (UNICA, 2014). A formalisation of the decision making on product ratio setting is given in the model formalisation part of this chapter. A representation of the sugarcane processing at the refinery is shown in Figure 17.

In the flowchart one can see the different pathways towards the three sugarcane end-products: sugar, hydrous ethanol and anhydrous ethanol within a sugarcane refinery.

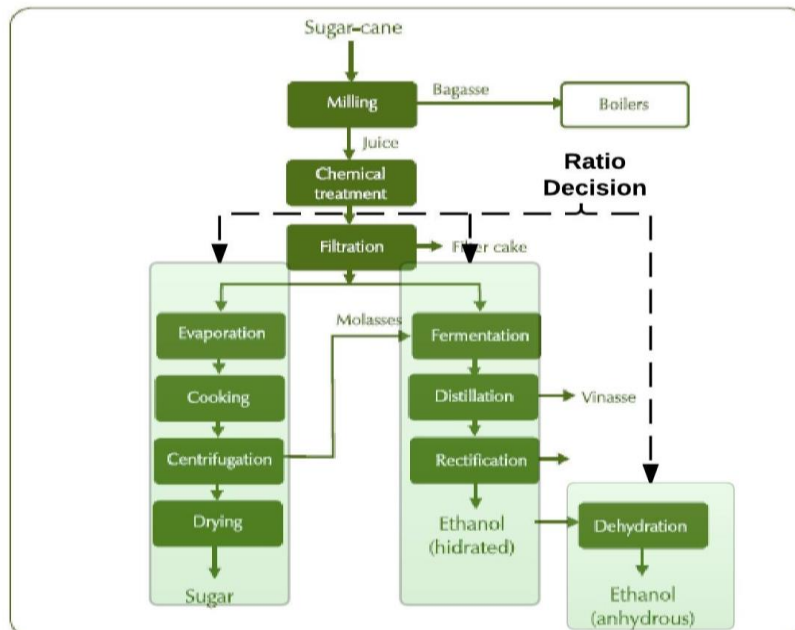


Figure 17: Sugar, Hydrous and Anhydrous Ethanol Production Ratio Decision Pathway. Adapted from (BNDES & CGEE, 2008)

4.1.2 System Elements: Agent Decisions, Behaviours and their States

Agents make decisions which affect the states and subsequent decisions of other agents (Van Dam, Nikolic, & Lukszo, 2013). Also the environment in which this interaction occurs is affected by agent's decision making. An identification of agent decision making, interaction and the states of agents is given below.

Users

Car user agents make decisions regarding the type of fuel that they consume. As discussed in the identification of the user agents; the decision making is dependent on the user type and the pricing of different fuel products. Within the decision making of user agents the following concepts are present.

Fuel Preference:

Individual car users are social agents; this inherently means that users possess to an extent *bounded rationality*; this means that there is a limit to the information that the users have with regards to the fuel market. Users are only aware of the current and historical prices for fuel at their local distributor. The *fuel preference* by an individual, is the preference by a car user for a certain fuel product; even when considering the fuel products as equivalent (in pricing terms) to each other. For instance, some car users may feel more inclined towards biofuel use on sustainability grounds. Others may be more inclined towards gasoline use based on the premise that they can travel further without having to re-tank than if they were using hydrous ethanol (hydrous ethanol has a lower energy density). The fuel preference is a primary reason why the distribution of fuel products within the automobile energy market is non-homogenous and varies over time (Charlita de Freitas & Kaneko, 2011).

Switch Inclination:

In addition to the preference of users for a certain fuel product, users possess an intrinsic level of inclination for making the switch between fuel products. Some users may want to stick to the same product longer in spite of price changes due to for instance a level of resistance towards change. Vice versa this also holds; some users may be much more willing to switch fuel products to reduce their overall fuel costs. The concept of users with a switch inclination is a primary reason why the fuel market shows non-linearity in respect to changes in fuel prices. De Gorter, Drabik, Kliaugas, & Timilsina (2013) show that the switch inclination of car users in the Brazilian ethanol market can be modelled with a logistic function.

Figure 18 shows this function (based on different sensitivities) which were observed in the year 2011, where the positive y-axis represents a shift (in volume) towards hydrous consumption and a negative y-axis represents a shift towards gasohol. A positive x-axis represents a price difference increase between gasohol prices and hydrous prices, where a positive difference refers to gasohol prices being higher than hydrous prices. The rate at which these shifts occurred is unknown and has been approximated using different scenarios.

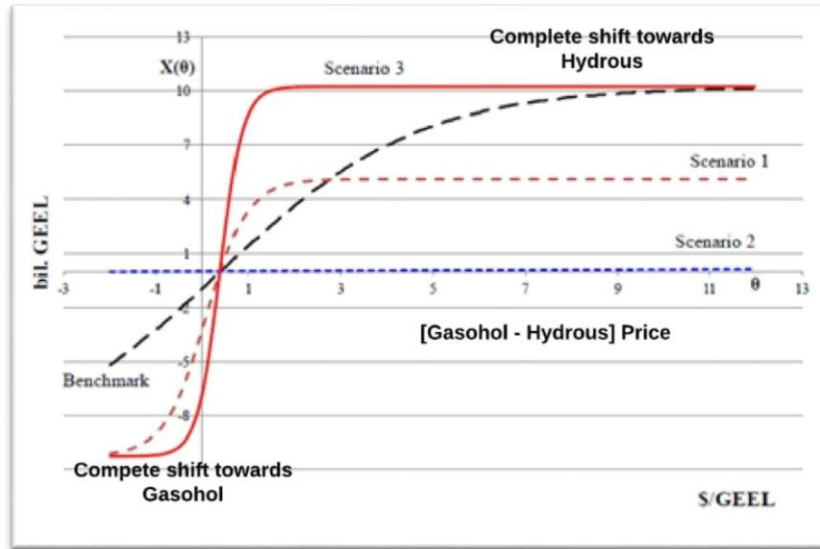


Figure 18: Logistic Function for Modelling the Switch in Fuel Demand by Brazilian Car Users. Adapted from (De Gorter, Drabik, Kliauga, & Timilsina, 2013)

Relative Price Difference:

The most important concept within user decision making is the relative difference in prices between hydrous ethanol and gasohol prices. (De Gorter, Drabik, Kliauga, & Timilsina, 2013). The price of the fuel products is determined on the basis of the following aspects.

$$P_H = I_{Haverage} + T_H + M_H \quad (1)$$

$$P_{E\alpha} = \alpha \times (I_{Aaverage} + T_A) + (1 - \alpha) \times (P_G + T_G) + M_A \quad (2)$$

Where P_H , $P_{E\alpha}$ and P_G (measured in \$ / Liter) are the user prices for hydrous ethanol, gasohol and gasoline, $I_{Haverage}$ and $I_{Aaverage}$ (measured in \$ / Liter) are the internal hydrous and ethanol prices which are taken as the average production prices for both products of all refineries, T_H , T_A and T_G (measured in \$ / Liter) are the tax on hydrous, anhydrous and gasoline and M_H and M_A (measured in \$ / Liter) are the marketing margins for hydrous and gasohol fuel. Furthermore the blending mandate is represented by α (ratio).

The base prices of both ethanol products are dependent on producer prices (technical yields), the taxes depend on external government inputs, and the market margins are set by distribution centres (*De Gorter, Drabik, Kliaugas, & Timilsina, 2013*). The relative price difference between gasohol and hydrous relates to the difference in price between the energy equivalent hydrous price and energy equivalent gasohol. The energy equivalent price of both products is determined on the basis of the distance one can travel per unit volume of each product. This is an important factor considering that hydrous ethanol users can travel only a smaller fraction ($2/3^{\text{rds}}$) of the distance that pure gasoline (100% gasoline) users can on the same amount of fuel. As such, the absolute price of hydrous ethanol must always be lower (by roughly one-third) to that of gasoline in order to remain price competitive. Users will base their switching behaviour on the relative price difference as opposed to the absolute price difference (*Charlita de Freitas & Kaneko, 2011*). When the different energy densities of the fuels are incorporated, the relative price difference of gasohol and hydrous fuel is defined as the following.

$$P_{\delta} = (P_{E\alpha} \times \frac{E_{E\alpha}}{E_G}) - (\frac{E_H}{E_G} \times P_H) \quad (3)$$

Where P_{δ} is the energy equivalent price difference between gasohol and hydrous users price (measured in \$ / Liter), $E_{E\alpha}$ is the energy density of gasohol (measured in Joules / Liter), E_G is the energy density of gasoline (measured in Joules / Liter) and E_H is the energy density of hydrous ethanol (measured in Joules / Liter).

Demand Switch:

Users will decide to switch to a different user type, or decide not to switch at all depending on the *relative price difference, fuel preference and switch inclination*. The switch (or none switch) will affect the demand of the individual for hydrous ethanol or gasohol accordingly. The frequency of the switch is dependent on the switch inclination of the users. The higher the inclination to switch, the more frequent the users evaluate their preference for fuel and the more frequent users can switch if they choose to do so.

Distributors

The distributor agents are responsible for maintaining a balance in the supply and demand of the bio-ethanol fuel market. In terms of their decision making, the main concept which is present is the decision regarding the price setting of both ethanol products in the *downstream* market (distributor to user) and *upstream* market (refinery to distributor). By manipulating the prices continuously in both markets, distributors can influence the production ratios of hydrous and anhydrous ethanol and also the demand ratios (*BNDES & CGEE, 2008*).

Hydrous and Gasohol Margins:

The means through which distributors can set hydrous and gasohol prices is through the setting of the market margins for these products which are equal on both the user side and refinery side. An increase in the margin for a product will increase the production ratio setting in the producer side of the market, as the product becomes more profitable. In conjunction with this it will decrease the demand on the user side for the product (due to it being more expensive). It is important to note that gasohol and hydrous ethanol are in direct competition with each other and as such only the *relative difference* between the margins will alter production and demand ratios for this product (BNDES & CGEE, 2008). However an increase in the margins for both products will have the effect of lowering production ratios for sugar as sugar production will be less profitable than ethanol production to producers. The same is true for a decrease in margins; sugar production will increase at the cost of ethanol production. This has been observed numerous times in Brazil through different global sugar price spikes (UNICA, 2014). The manner in which distributors determine the market margins is discussed in the model formalisation and sensitivity analyses section of this thesis.

Stock Levels:

The distribution of hydrous and anhydrous ethanol entails the collection and selling of both products. As with any supply chain, this inherently entails the concept of having to store the goods. In the bio-ethanol market, the storage of fuels is done in large storage terminals. Through government regulation, distributors must blend anhydrous ethanol with gasoline at these terminals before the gasohol blend can be passed on to the user market (BNDES & CGEE, 2008).

The precise workings of the Brazilian distribution market are publicly unknown (confidential), therefore the following assumptions are made in regards to the storage of fuels at the distribution level.

1. Most distribution centres in the Brazilian market are owned by Brazilian state company Petrobras, which distorts any market competition within this sector (BNDES & CGEE, 2008). Together with the fact that distribution centres each serve their own geographical market, the assumption is made that intra distribution competition does not exist; therefore the size of all storage terminals is uniform for every distributor agent. Additionally, the system under study is related to the price setting by distributors in terms of *demand and supply*. The distributors are therefore not purely profit seeking agents, but are agents with the main goal of stabilizing the supply and demand of the fuel market. This is in line with the governmental goals of guaranteeing a stable fuel supply for the country (Charlita de Freitas & Kaneko, 2011).
2. In light of the responsibility by distributors to maintain a stable supply of fuel products, it is assumed that a decrease in the stock of a certain product, which may occur when demand is larger than supply, necessitates the distributor to increase the prices (through margins) for that product; this incentivizes refineries to produce more and disincentives users to demand that particular product. The opposite is true for an increase in the stock of a certain product, in this case distributors will set a margin which disincentives the production of that product and

incentivize the demand for that product by the users. The measurement of what constitutes a decrease in stock is assumed to be the *stock level*. The stock level is the percentage that the storage capacity for either ethanol product is full relative to the maximum capacity of the storage facility.

$$S_L = \frac{S_i}{Max_S} \times 100\% \quad (4)$$

Where S_L is the stock level (measured in %), S_i is the amount of product, i , in stock (measured in Liters) and Max_S is the maximum amount of storage capacity (measured in Liters).

The degree of uncertainty regarding the distribution storage system elements is an area of particular focus during the sensitivity analyses and validation parts of this thesis. A schematic representation of the stock level concept and how this translates to the setting of prices by distributors is shown in Figure 19.

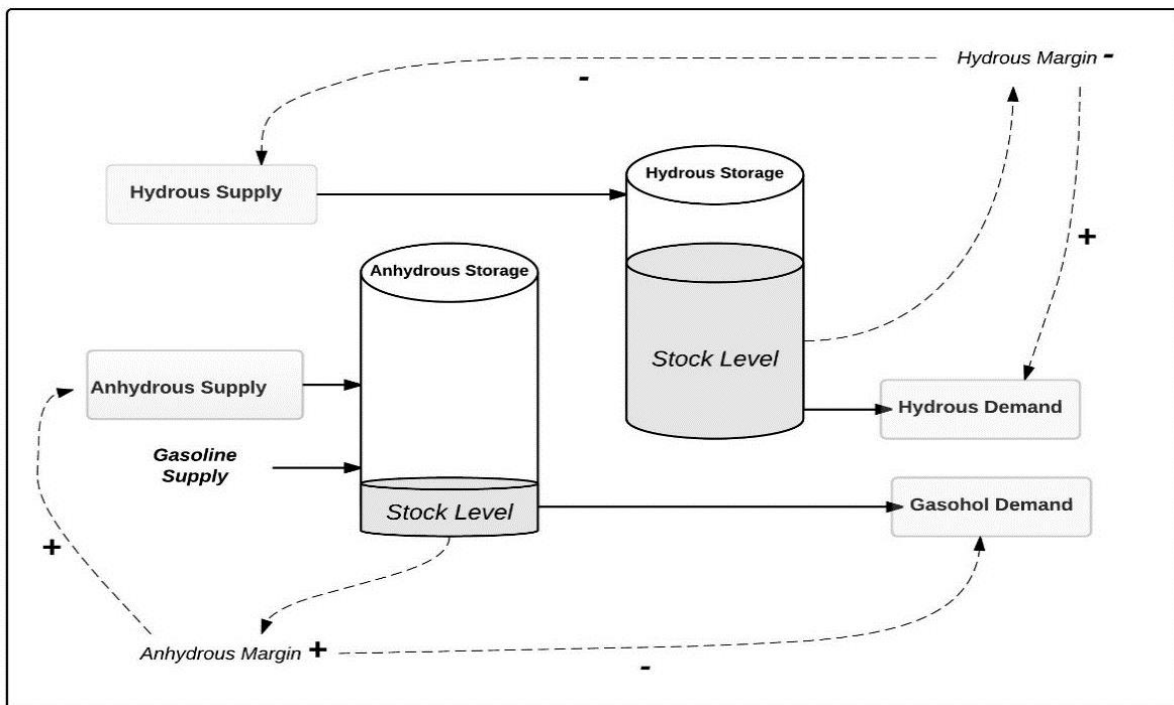


Figure 19: Schematic Overview of the Distributor Storage Concepts and their Relationships

Refineries

The refineries, being the producer agents in the system, are a critical element in terms of decision making; the overall production volumes of bio-ethanol depend on these decisions which in turn affects the decisions made by the user market. This dynamic is the desired system behaviour under study in the scope of biofuel implementation.

Internal Prices:

The internal prices of refineries refers to the price of each product (hydrous ethanol, anhydrous ethanol and sugar) at each individual refinery in order for the refinery to make zero profits (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). Thus the internal price is the price at which a refinery will make nor profit, nor loss for that product. It can be regarded to be the production price of each product at any individual refinery plus the economic margin to maintain the business. The internal price of each product is determined based on the *technical production efficiencies and yields* of each individual refinery.

$$I_H = \frac{P_{SC} + C_H}{Y_H} \quad I_A = \frac{P_{SC} + C_A}{Y_A} \quad I_S = \frac{P_{SC} + C_S}{Y_S} \quad (5)$$

Where P_{SC} is the price of sugarcane (measured in \$ / Tonne), C_H , C_A and C_S are the processing costs of hydrous, anhydrous ethanol and sugar (measured in \$ / Tonne of sugarcane). Furthermore, the processing costs are the costs of processing a unit of sugarcane into the particular product, incorporating the net reduction on costs due to the burning of bagasse for electricity. In addition to this, the sugar processing cost incorporates the reduction in overall cost due to the added production of ethanol products from molasses, which is a sugar by-product. Y_H , Y_A and Y_S are the yields of hydrous, anhydrous ethanol and sugar; this is the amount of product which can be produced from a unit of sugarcane (measured in Liters, Kg / Tonne of sugarcane).

Revenue:

The revenue of each individual refinery is determined through the *average* market price, consisting of the *average* internal prices for all refineries and the average margins which are set by the distributors. As the study of interest is in the profitability of each product, for comparing reasons, the volume sold for each product should be equal. Therefore in the scope of this research, the revenue is defined as the revenue *per unit* of product. The sugar market in Brazil is part of the global market and as such the global prices of sugar are taken as an external price; they are not directly influenced by the system (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). This latter assumption is not entirely valid when one considers *significantly large* shifts in sugar production; as Brazil is one of the largest sugar producers indirectly the prices of sugar will be indirectly affected. Therefore, in the face of large and sudden production shifts one must take caution in formulating conclusions based on the simulations; this is further elaborated in Chapter 5.

The revenue of each sugarcane product is defined as;

$$R_H = I_{Haverage} + M_{Haverage} \quad (6)$$

$$R_A = I_{Aaverage} + M_{Aaverage} \quad (7)$$

$$R_S = P_S \quad (8)$$

Where R_H , R_A and R_S are the revenues of hydrous, anhydrous ethanol and sugar for refineries per unit of product (measured in \$ / Liter,Kg), and P_S is the global price for sugar (measured in \$ / Kg).

In the Brazilian bio-ethanol setting, producers of sugarcane and ethanol receive the same base price for their products based on the quality of the sugarcane and ethanol provided (sugar and energy concentration) and the downstream market prices of sugarcane derived products. This is a result of the unique *CONSECUNA* (BNDES & CGEE, 2008) payment system; where producer prices paid to sugarcane farmers are based on the end consumer prices at the demand side of the value chain and the portion that the sugarcane production cost has in the overall costs throughout the value chain. The *CONSECUNA* system assures a maximum supply of sugarcane during the season as sugarcane farmers are not influenced by current prices; they are production maximizing and at the end of a harvest they will evaluate their financial performance. The payment system is very similar to the *Netback* pricing system which was employed by OPEC in the 1980's and 1990's to determine crude oil prices (Energy Charter Secretariat, 2007). The *CONSECUNA* system also ensures the ethanol market with a supply push drive as opposed to a demand pull instrument, see Figure 20.

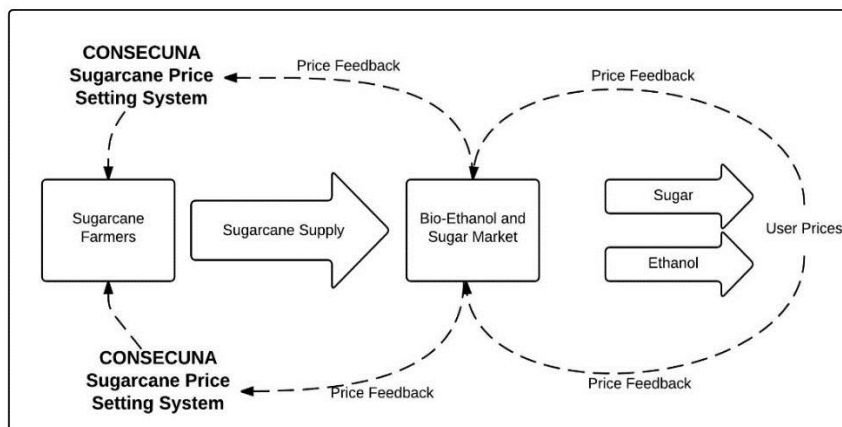


Figure 20: Sugarcane Market Push through the CONSECUNA System

Profit:

The profit of each individual refinery is defined as the market revenue of the product minus the internal price of the individual refinery. In essence, the profit (or loss), is the gap between the average market price of the product and the internal (zero profit) price of the product. The defining aspect in this respect is that refineries have different yields and production efficiencies; this again depends on the sugarcane quality of the area in which the refinery finds itself, the modern technical facilities available at the refinery and the specialisation of the refinery for either sugar or ethanol production (*BNDES & CGEE, 2008*). To simulate the heterogeneity in the refinery sector, the technical parameters (yields, processing costs) are randomly distributed across the refinery market.

$$Profit_H = R_H - I_H \quad (9)$$

$$Profit_A = R_A - I_A \quad (10)$$

$$Profit_S = R_S - I_S \quad (11)$$

Where $Profit_H$, $Profit_A$ and $Profit_S$ are the profits made by refineries for hydrous, anhydrous ethanol and sugar per unit of product (measured in \$ / Liter,Kg).

Expected Profit:

Refineries ultimately base their decisions in regards to production ratios on the expected future potential profit of each product. The concept of expected profit, or forecasting, is largely determined by historical data. As such, the expected optimal profits are determined on the basis of previous profits where the most recent data weighs heavier than older datasets; this may ultimately be observed in the Brazilian bio-ethanol cycle of overexpansion in either ethanol or sugar which leads to supply shocks in times of significant demand (and external price) changes (*De Gorter, Drabik, Kliaugas, & Timilsina, 2013*). The forecasting by refineries of the future profits is modelled with a simple exponential smoothing method. This is an often used and accepted method to model forecasting behaviour by commercial entities (*Gardner, 1985*).

$$Profit_{HE} = \beta \times Profit_H + (1 - \beta) \times Profit_{HE-1} \quad (12)$$

$$Profit_{AE} = \beta \times Profit_A + (1 - \beta) \times Profit_{AE-1} \quad (13)$$

$$Profit_{SE} = \beta \times Profit_S + (1 - \beta) \times Profit_{SE-1} \quad (14)$$

Where $Profit_{HE}$, $Profit_{AE}$ and $Profit_{SE}$ are the expected profit for hydrous, anhydrous ethanol and sugar (measured in \$ / Liter, Kg), $Profit_{HE-1}$, $Profit_{AE-1}$ and $Profit_{SE-1}$ are the previous expected profit and β is the smoothness factor. This parameter determines the degree of smoothing of the function. It is important to realize that in the case of a trend, the simple exponential smoothing method may not be adequate as it is intended to be used on random data series. In the case of the bio-ethanol model regarding profits, a true trend is not expected due to the frequent (and relatively sudden) changes of the market. In the verification section of the model this latter aspect shall be further discussed.

Production Ratios:

Considering the scope of this research, the shift by refineries of the production ratios, *Hydrous Ratio*, *Anhydrous Ratio*, *Ethanol Ratio* and *Sugar Ratio*, is the single most important element of the studied system. Based on the expected profit, a refinery will alter the ratio of product output according to the most valuable outcome. There is a technical limit however to the extent and frequency of this *Ratio Shift* as the shift itself directly affects current production capabilities at the refineries. In the scope of the model this limit is set at a maximum of 10% shift per quarter (*BNDES & CGEE, 2008*). Also the frequency in which refineries can alter ratios is related to the sugarcane harvest cycle, which varies in between regions in Brazil and also across the different seasons. Nevertheless, considering the sheer volume of the Brazilian sugarcane processing and the scope of the model, the actual decision making in regards to ratio shifts and expected market dynamics, is considered uniform (season cycle independent) across the refinery sector which is justified by large scale variation of the sugarcane season within Brazil (*UNICA, 2014*).

$$Prod_S = Y_S \times Ratio_S \times SC \quad (15)$$

$$Prod_H = Y_H \times Ratio_H \times Ratio_E \times SC \quad (16)$$

$$Prod_A = Y_A \times Ratio_A \times Ratio_E \times SC \quad (17)$$

Where $Prod_S$, $Prod_H$ and $Prod_A$ are the total production of respectively sugar and hydrous, anhydrous ethanol (measured in Kg, Liters), $Ratio_S$ and $Ratio_E$ are the respective ratios of sugar and ethanol, $Ratio_H$ and $Ratio_A$ are the respective ratios of hydrous and anhydrous ethanol and SC is the total supply of sugarcane at the refineries (measured in Tonnes).

4.1.4 System Elements: the Environment

In Agent Based Modelling the environment is considered to be composed of system elements which affect agents but are not directly affected by agents themselves (Van Dam, Nikolic, & Lukszo, 2013). The main elements for which this is true in the bio-ethanol system are presented next.

Global Sugar Price:

The price of sugar, directly affects the decisions of refinery agents. However, the price of sugar is not directly affected by refinery production as the global price of sugar is dependent on many other external factors, such as weather conditions and growth markets. However, due to the fact that Brazil is one of the largest producers of sugar in the world, the price of sugar may be affected by Brazilian refineries when there are *significant* shifts in sugar production. Therefore, when shifts in sugar production remain relatively small, the external sugar market assumption holds, while for larger sugar production shifts the assumption will be less valid (the quantitative nature of this is unknown) (De Gorter, Drabik, Kliauga, & Timilsina, 2013). In light of the scope of the studied system (bio-ethanol market), the sugar market dynamics are considered *entirely* external; sugar price shocks remain important environmental elements as recent gluts in sugar prices have shown (De Gorter, Drabik, Kliauga, & Timilsina, 2013). Significant sugar shocks will be explored in the model; through the simulation of a stepwise increase/decrease in demand and shift in prices.

Gasoline Price:

As is the case with the sugar price, the gasoline price directly affects the agents in the system. Particularly distributors and users are affected as the gasoline price is a direct determinant for the price competitiveness of hydrous ethanol. The Brazilian government in recent years has pursued a policy of artificially fixing the domestic prices of gasoline to fight inflation; this has proven to negatively impact the ethanol market (ANFAVEA, 2013). The market distortion of gasoline pricing makes it a critical component of the system environment. As the gasoline price is a critical component of the bio-ethanol fuel market model; significant shocks in gasoline prices are explored in the model.

Blend Mandate

The Brazilian government has imposed the Brazilian fuel market with an ethanol blend mandate since the start of the ProAlcool program; gasoline fuel can only be sold in conjunction with an anhydrous ethanol mix which historically has varied between 5 and 25 % of fuel volume (UNICA, 2014). The blend mandate is another critical component of the ethanol system; it guarantees the system of a demand for ethanol. This guarantee is crucial as the bio-ethanol market is ill-equipped for sudden demand shifts, as was the case in the pre-flex era where a supply shortage of ethanol destroyed the ethanol market (Cortez & Rosillo-Calle, 1998). The blend mandate itself is reviewed by the government (*yearly, but only changed in times of a clear need to change*) based on different factors such as the availability of ethanol,

the price of gasoline and the state of the overall ethanol and sugar market. The mandate directly affects distributor agents. The degree to which the blend mandate guarantees the existence of the bio-ethanol market altogether is explored in the experimentation section of this report.

Taxes:

In close relation to the blend mandate is the tax imposed by the government on all fuel products. As is the case with the blend mandate, the height of the tax is dependent on the state of the market and government strategies. The tax directly affects distributor agents. It is important to note that all fuel products, including ethanol, are taxed to some degree by the government (*UNICA, 2014*). The Brazilian government can use the tax system to manipulate the cost competitiveness of ethanol in relation to regular gasoline. Also the overall price level of fuel can be manipulated through taxes; this latter element is particularly relevant in the scope of inflation fighting measures; this can distort the domestic fuel market significantly (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*).

Sugarcane Price:

The price of sugarcane is considered to be part of the environment in the scope of the research; the subject under study is the decision making on the product composition of the *end-user demand* of sugarcane processing. Due to the previously mentioned *CONSECUNA* incentive program in Brazil, the price of sugarcane is determined retrospectively based on end user prices. Therefore, the price of sugarcane will increase or decrease as a function of the price competition within the external sugar, gasoline and ethanol prices. Supply shocks due to weather aspects however, can significantly impact the market dynamics which has been observed in recent times in Brazil (*BNDES & CGEE, 2008*). In the modelled system, sudden changes in sugarcane price (induced externally by the user or environment) can simulate these supply shocks.

4.1.5 System Elements Summary

Figure 21 gives a schematic representation of the discussed agent behaviour concepts in the Brazilian bio-ethanol market. It can be seen how the refinery, distributor and user markets are connected directly in a physical sense; through the flow of hydrous and anhydrous ethanol. Also the environment concepts are shown where it can be observed that the information flow is a one-way indicating the external nature of the concepts. Furthermore, the different concepts (indicated in the grey boxes) which belong to each agent group are presented, where it can be seen how they affect and are themselves affected by the agents of which they belong. It can be clearly seen how the distribution agents and their concepts, are the link in the value chain which connects the supply and demand in the bio-ethanol market.

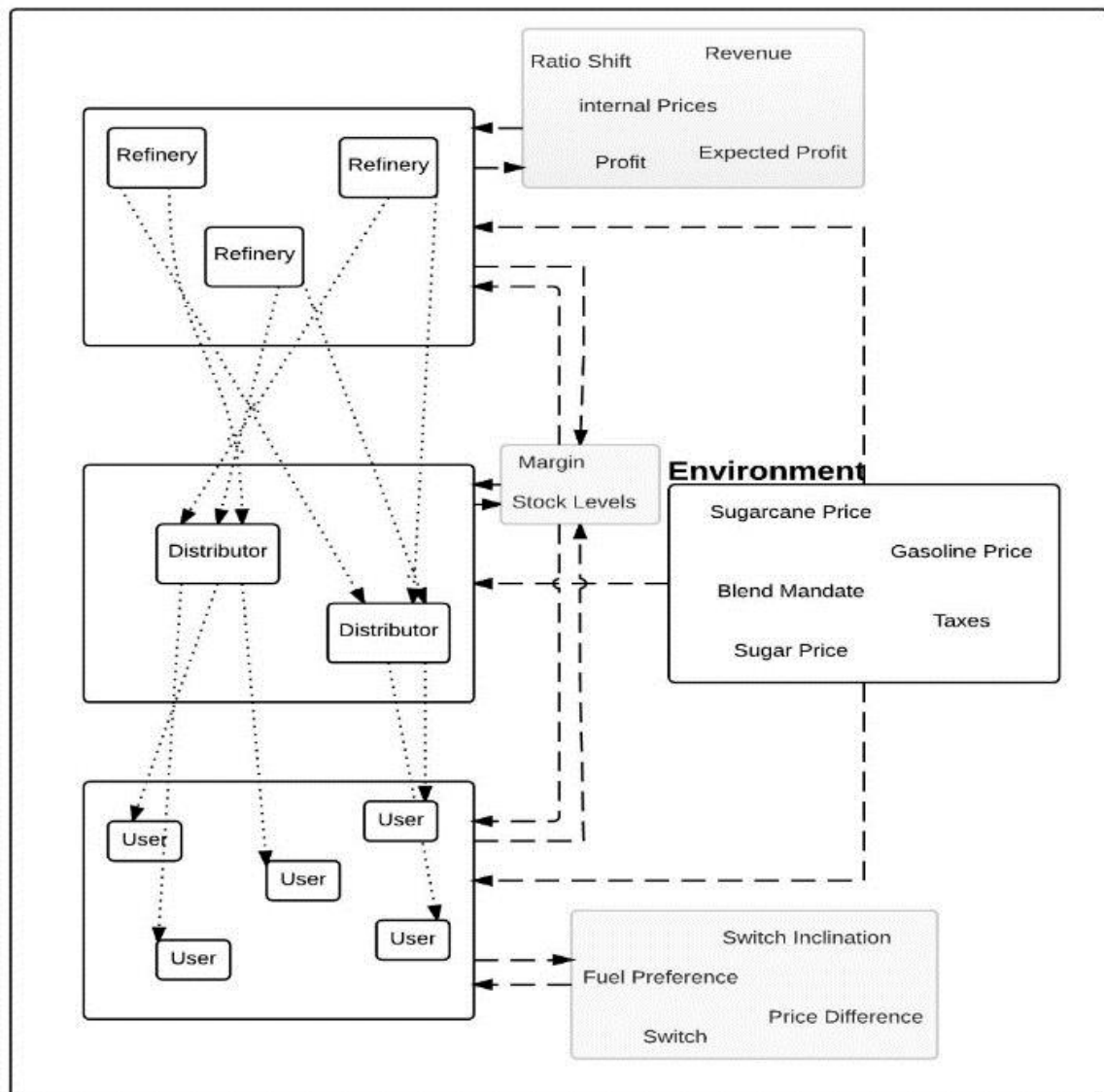


Figure 21: Representation of the System Elements and their Relationships in the Bio-Ethanol Market Model

4.2 Concept Formalisation

The main concepts of the system have been identified; however in order to be able to model the system in a manner in which no ambiguity exists in the interpretation of the concepts, a formalisation of the concepts is strictly necessary (Van Dam, Nikolic, & Lukszo, 2013).

4.2.1 Data Structure

The concepts which have previously been defined are not useful yet in the sense that they are not computer understandable. In order to convert the main concepts of the system into concepts which computers can understand it is necessary to describe the concepts in terms of the so-called primitive types. An overview of the concepts used with their corresponding primitive types is given in Table 1. A full description of all variables used, their values and their units is shown in Appendix F.

Table 1: Main Concept Variables, their Data Type and their Unit

Concept Variable	Data Type	Unit
User_type	integer	[-]
Fuel_preference	random-float	[-]
Switch_inclination	random-float	[-]
Price_difference	double	[\$ / L]
Switch	double	[-]
Hydrous/Anhydrous_margin	double	[\$/L]
Stock_level	double	[-]
Internal_price	double	[\$ / L] and [\$ / Kg]
Revenue	double	[\$ / Tonne]
Profit	double	[\$ / Tonne]
Expected_profit	double	[\$ / Tonne]
Ratio_shift	double	[-]
Production_Ratio	double	[-]
Global_sugar_price	double	[\$ / Kg]
Gasoline_price	double	[\$ / L]
Blend_mandate	double	[%]
Tax	double	[\$ / L]
Sugarcane_price	double	[\$ / Tonne]

4.2.2 The Ontology

The ontology of the system formally encodes the “*what*” is in the model including objects, concepts and other entities which are assumed to exist within the system boundaries and the relationships that exist between them (Van Dam, Nikolic, & Lukszo, 2013). Figure 22 shows a simple schematic overview of the ontology of the model where a distinction is made in *what* a concept *is* and *does*.

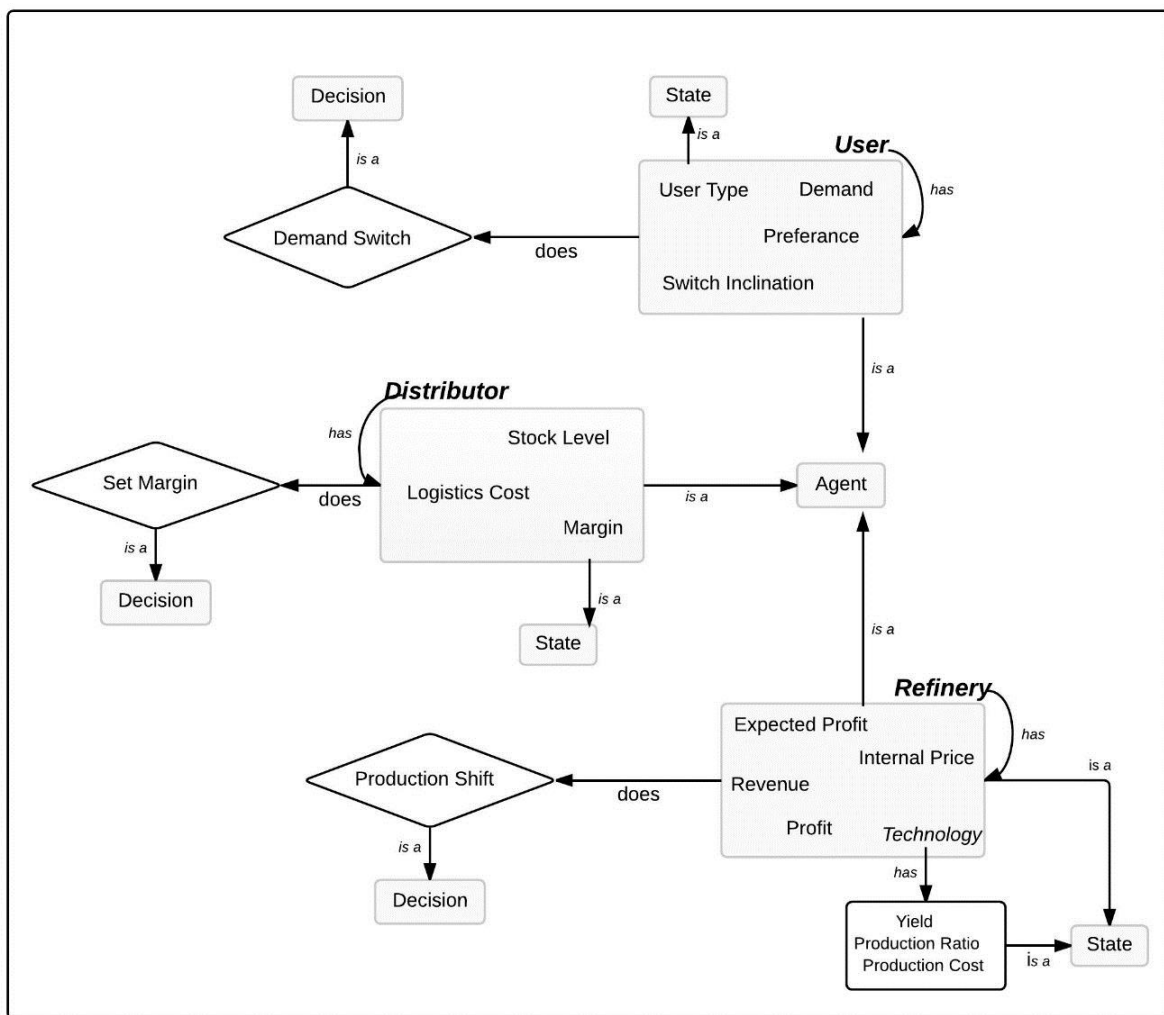


Figure 22: Schematic Overview of the Ontology of the Bio-Ethanol System

4.3 Model Formalisation

After the concepts have been formalised, it is known “*who*” and “*what*” is in the model. The next step is to determine “*who*” does “*what*” and “*when*” (Van Dam, Nikolic, & Lukszo, 2013).

4.3.1 The Model Narrative

When the building blocks of the bio-ethanol model have been defined, one can start to build the model narrative; that is the description of the system that is being studied in terms of model processes and outcomes. In more concrete terms, the model narrative specifies when agent interaction occurs and by which agents (Van Dam, Nikolic, & Lukszo, 2013). From the narrative, it should be possible for a human being to understand the model while also being able to understand the language that a machine (or simulator) uses. In line with the system concepts the narrative of the bio-ethanol market model is determined. A simplistic overview of the model narrative, where the sequence of the steps in the model is made clear, is shown in Figure 23.

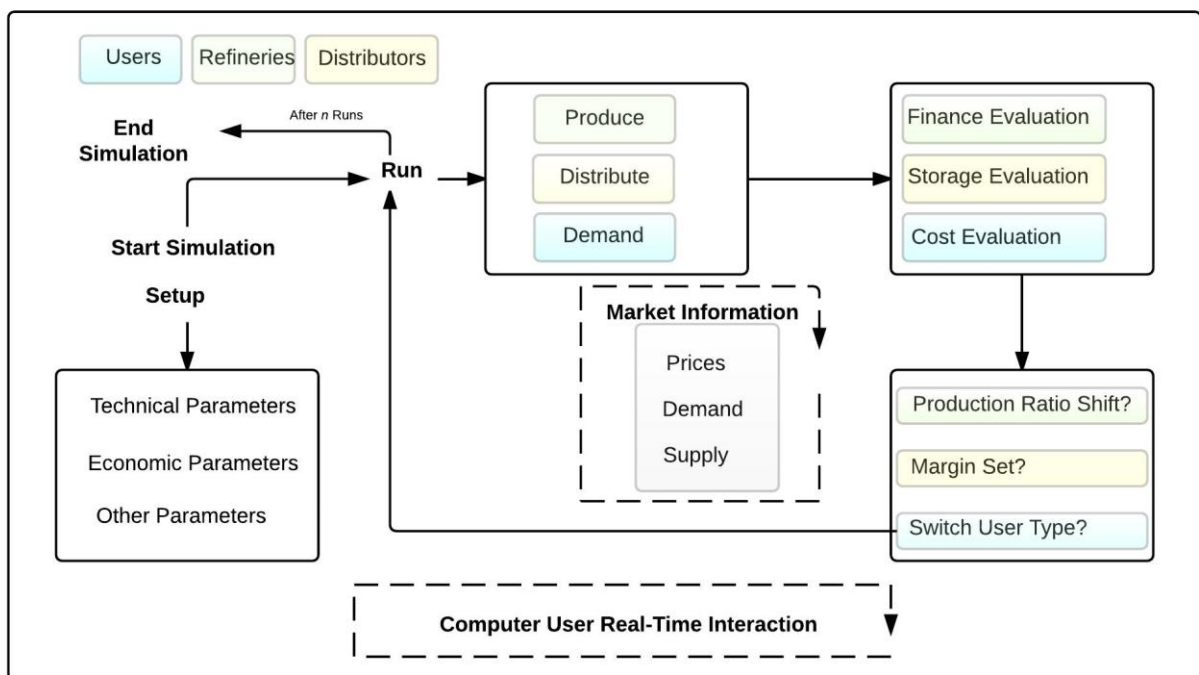


Figure 23: Model Narrative in Flow Chart Form of the Bio-Ethanol Model

4.3.2 Pseudo Code

A defining aspect of Agent Based Modelling is the modelling of decisions which are made by agents, the implementation of the concepts of the objects, and the overall determination of the system (behaviour) output (Borshchev & Filippov, 2004). The decision making in the model is simulated by the use of algorithms; these algorithms are a rule based set of assignments which a machine (or simulator) runs in order to simulate the system.

Pseudo-code is a description of algorithms written in a human-readable form, which also provides an insight into the structure of these algorithms while omitting computer specific details. Pseudo-code bridges the gap between an informal model narrative and the specific computer code. (Van Dam, Nikolic, & Lukszo, 2013). As the defining aspects of the model narrative make use of algorithms, a description of these model elements is given in pseudo-code in order to understand the implementation in a simulation programming setting. This pseudo-code description of the algorithms is shown in Figure 24.

For a further in-depth overview of the algorithms and coding which is used in the model, one is referred to Appendix K. This gives the entire source code of the model. The NetLogo code is a very accessible coding environment which can easily be interpreted by novel modellers (Wilensky, 2004). Furthermore, for an extensive overview of all the variables used, their values and their meaning one is referred to Appendix F

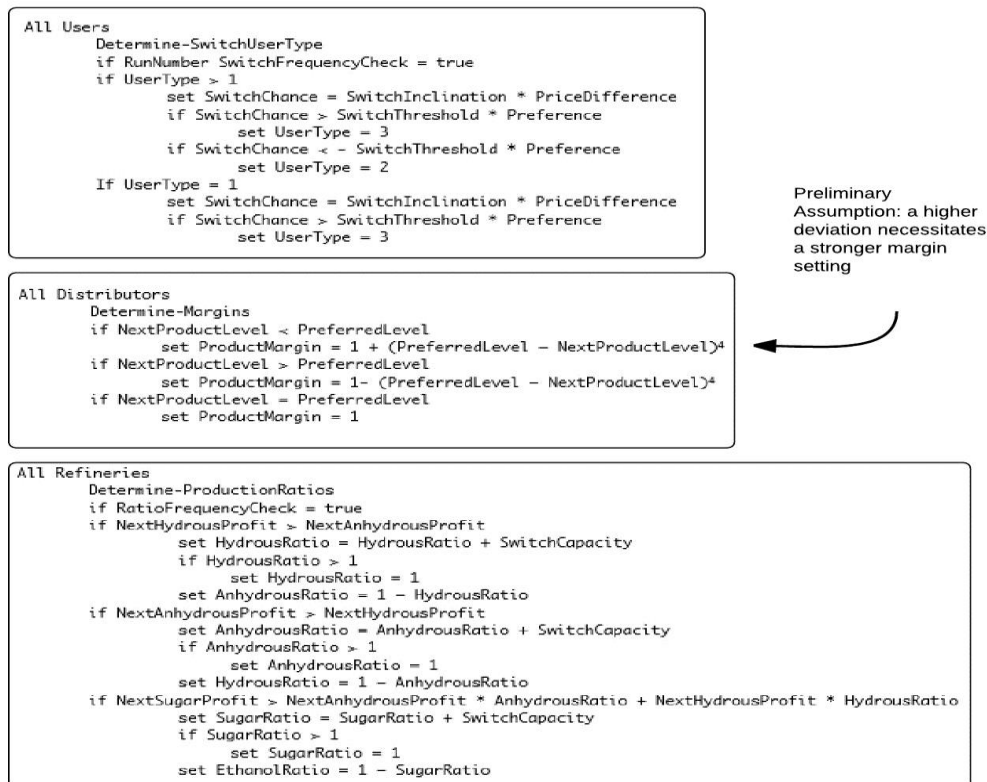


Figure 24: Pseudo Code Simplified Representation of the Main Model Algorithms in the Proposed Model


4.4 Conclusions

The first research sub-question can be answered on the basis of this chapter.

“What typology of actors are present within the bio-ethanol market in Brazil and what conditional rules typify the interaction between these actors?”

The bio-ethanol market is composed of the refinery, distributor and user actors. Refineries are the producer actors of the system who supply fuels to the distributors which are the “stabilizers” of the market. The user actors can be typified by dividing them into three groups; regular gasohol users, flex gasohol users and flex hydrous users. Furthermore within these groups there exists a distribution in actor properties; this creates a highly dynamic market.

Refineries shift their production ratios on the basis of the highest expected profit (profit seeking). Users shift demand on the basis of lowest cost (cost minimizing). Distributors set market prices on the basis of product inventory (stabilizing). All actions affect the price setting decisions and vice versa creating a highly volatile pricing pattern which in turn causes large changes in the demand and supply of bio-ethanol. The actors react to these changes on a purely economic basis.



Chapter 5

Implementing the Base Model

In this chapter:

- 5.1. NetLogo
- 5.2 The Base Model: The Brazilian Ethanol Model
- 5.3 Base Model Verification
- 5.4 Base Model Validation and Exploration
- 5.5 Conclusions

5.1 NetLogo

NetLogo is a modelling language specifically meant for ABM. It was designed to be “low threshold, no ceiling” (Wilensky, 2004). It is because of this that NetLogo is one of the more popular ABM tools used for educational and communicational purposes. The core elements of the NetLogo paradigm are the following (Wilensky, 2004);

1. *Turtles*; are the equivalent of agents in the NetLogo environment. Turtles can own different properties which only the specific turtle itself can access. A distinction between different groups of agents is made using *breeds*. This enables the user to subdivide agents into different classes.
2. *Links*; connect turtles with one another. They can have physical and social properties and the user can define whether the flows over links are *one-way* or *two-way flows*.
3. *Observer*; the observer is the NetLogo defined *computer user* (human being) environment. It represents the computer user of the model as an external *agent* or object which makes it possible to influence the system, or to follow in more detail sub-system information. It is a critical part of the NetLogo paradigm as it enables computer users to experiment and explore the model in an interactive way. For instance the observer can call information on different parts of the system over time and can also change system parameters before and during each simulation.

One final distinct element of NetLogo is that it is specifically designed so that actors within the system operate in parallel with each other. NetLogo achieves this through the random order of running procedures within the model. One whole round of iteration sequences can be defined in *ticks*. Ticks may be the real-world equivalent of time, but can also represent in a more discrete manner process iterations (continuous system independent of events versus a step like system which depends on specific events).

5.2 The Base Model: The Brazilian Ethanol Model

The implementation of the previously described formal model elements of the Base Model in NetLogo is described in the following sections.

5.2.1 NetLogo Model Elements

The code implementation of the Brazilian bio-ethanol model in the NetLogo is shown in the Appendix K. However, the most important qualitative aspects of the model are described below.

Agents

The distribution, refinery and user agents are represented in the model through the use of different *breeds*. All breeds have their own characteristic properties. Breeds are a sub-group of *turtles*. As such the model consists of the breed Refineries with singular term Refinery, the breed Distributors with

singular term Distributor and the breed Users with singular term User. Each breed “owns” characteristic variables; these variables are derived from the model conceptualisation. For instance the breed Refineries owns the variable *Sugar_Production_Ratio* which is unique to that breed and is part of the technology concept defined in the conceptualisation.

Variables which do not belong uniquely to any breed and are accessible by any part of the model are represented as *Globals*. For instance the variable *Gasoline_Price* is accessible by any element in the model as it is not unique to any one concept.

Setup Procedure

The setup procedure assigns agents with the characteristic values used in the model. An overview of these parameters can be seen in Appendix K. The setup procedure assigns each single agent with the properties defined by the system architect. Technology and economic properties can be assigned according to a probability density function; this can simulate the variation in the real world of individual users and refineries. For instance the production yields of refineries vary due to different technological efficiencies (modern versus old facilities) and geographic location. Particularly in the user agent the individual preferences of users varies; some users are more price sensitive than others for instance.

Go Procedure

The Go Procedure makes the model iterate over all procedures which are required to run during an iteration. In essence the Go Procedure is what makes the model *tick* in a literal sense as each iteration of the Go Procedure results in the addition of a tick. The amount of ticks represents the amount of iterations (and Go Procedures) which have been run; in this sense ticks can represent the concept of time. In the Brazilian bio-ethanol model the chosen tick equivalence with the real world concept of time is one day; that is to say that one tick represents the passing of a single day in the real world. This assumption is derived from the fact that users, refineries and distributors are assumed not to make any more than one decision in a day; this is also reflected from the overall sugarcane system information which is available from (UNICA, 2014). Also the order of time in which users need to demand fuel is assumed to be in the order of days and not smaller than a single day, meaning that agents cannot make any decision more than once in a day.

The most important procedures which are run through an iteration of the model (called on by the Go Procedure) are described below.

Produce (Refineries):

Based on the initial technology settings which have been assigned in the Setup Procedure, the output of each refinery turtle is determined in terms of sugar, hydrous and anhydrous ethanol. The output of each product is in terms of the total unit of sugarcane input. The sugarcane input is constant for every refinery and is directly in proportion to the total available sugarcane supply in the Brazilian market (assumed constant as the order of time is days). The underlying assumption is that the scope of the

research is to study the decision making *within* the refineries system and as such interactions with other agents and differences in sizes of the refinery turtles would introduce an additional level of intra-agent interaction (and adds competition *between* refineries). The competition between refineries is not of interest as particularly in Brazil the prices are determined retrospectively due to the *CONSECUNA* system (*BNDES & CGEE, 2008*). The limitation imposed on the availability of market information to the refineries by the latter system means that the refinery agents are strictly focussed on themselves and not on what other refineries are doing. This aspect will be experimented with later with the introduction of a biorefinery agents in Chapter 7.

Demand (Users):

Depending on the state in which the User finds itself (*type 1, 2 or 3*) and based on the blending mandate that is currently in place, the User demands an amount of either gasohol or hydrous fuel. All users demand the same amount of energy equivalent fuel; therefore the demand only relates to the form of this fuel demand (hydrous form or gasohol form).

Distribute (Distributors):

Distributor turtles draw up an inventory of the total demand of fuel by the users which are connected to the distributor (which is based on the spatial location of the users) and the total fuel supply by the refineries. This leads to an output of hydrous/anhydrous oversupply, shortage or supply equilibrium; the formal model output of this will be the variable *Hydrous_Gap* and *Anhydrous_Gap*.

Store (Distributors):

Following from the fuel supply gaps, the stock level of each distributor turtle is changed and determined through the Store procedure. Each distributor turtle has the same storage capacity and starting inventory (assumed as half of capacity) for each ethanol product. Based on the value of these gaps for each product, the stocks are then lowered or added up until the maximum capacity is reached or the stock level is zero. When the stock would otherwise exceed these limits (meaning that the gaps are larger than the available storage parameters), this leads to an in or outflow of the product of the system. The system is modelled in such a way that distributors will avoid this situation as this is their main objective in the model; *stabilize the supply and demand of the ethanol market*. However, when it does occur and distributors are unable to maintain this stability it can be translated in the real world by the necessity of having to import (external) ethanol and the potential to export (external) ethanol in times of supply shortages and surpluses. The output of the *Store* procedure is the stock level of each product at each distributor.

RefineryFinance (Refineries):

Refineries turtles determine the production costs (internal prices) for each product. These costs follow from each refineries' technological setting in terms of production yields and processing costs. In addition to these refinery unique parameters, a significant portion of the production costs follows from the global *Sugarcane_Price*. Based on the global "*MarketHydrous_Price*", "*MarketAnhydrous_Price*" and "*MarketSugar_Price*", refineries determine the potential profit made for each product. With potential, it is meant that refineries will determine the full maximum achievable profits based on a maximum production ratio for each product; that is to say the profit the refinery could have made if the production ratio was maximized towards the specific product. Finally, refineries make a forecast for the next terms profit for each product (the *expected profit*). The output for this procedure is the determination of the profit and *expected profit* for each product and the *internal price* for each product.

MarketReaction (Refineries):

On the basis of the profit forecast (*expected profit*) for each individual product, each refinery turtle will make a decision on the production ratio. This decision is purely based on a profit maximizing basis. The first profit comparison is made between ethanol production and sugar production (as hydrous and anhydrous production are related to one another). The production ratio of the highest profit yielding product group (ethanol and sugar) will be increased by a certain percentage (which follows from a user input variable *Switch-Capacity but is limited to a maximum of 10%*) and subsequently the lower profit yielding production group ratio will be decreased. Furthermore the anhydrous and hydrous profits are compared and the product with the higher profit will also have a ratio increase (and the other ratio will be decreased). Total Production Ratio values are limited by a maximum and minimum of 100% and 0% respectively; once these limits are reached, ratio optimisation has reached its absolute boundary and thus cannot further increase or decrease beyond that point. The output of this procedure is the new or unchanged *production ratio* for each product.

Negotiate (Distributors):

Each distributor turtle, makes a forecast for the next hydrous and anhydrous product storage levels. Based on these forecasts, distributors determine a *Hydrous_Margin* and *Anhydrous_Margin* for the products. A higher storage level leads to a lower margin (meaning that there is ample supply and the product is valued less) and a lower storage level leads to a higher margin (meaning that the product is scarce and thus more valuable). An exact determination of the margin setting is explained in the experimentation of the model; this has to do with the high level of uncertainty regarding the economic market dynamics in the supply chain. The generic method in which the margin is determined is based on an exponential increase in the margin when the storage level moves below a *Preferred_Level* and an exponential decrease in the margin when the storage level moves above the *Preferred_Level*. In turn these margins affect the *MarketHydrous_Price* and *MarketAnhydrous_Price* global variables. The output of this procedure are the *margins* for each ethanol and sugar product.

Switch (Users):

A critical aspect of the bio-ethanol model is the switch procedure of the user turtles. Based on the current user type setting of the users (*1=regular gasohol, 2=flex gasohol and 3= flex hydrous*), the individual economic parameters which are assigned in the setup procedure and the *Relative_PriceGap*, users turtles will remain within the same user type or change the user type. A detailed description of the switch algorithm was explained in Chapter 4. The output of this procedure is a new or unchanged user type for the individual turtle.

The Sugar Market

Following from the model conceptualisation, the sugar market is considered to be a semi-external object within the bio-ethanol system. The implementation of the sugar market in the model is conducted as follows.

To represent the sugar market (and corresponding demand), an additional breed of turtles is added, *Externals*. This breed is not formally an agent as it has no changing states (unless incurred through the user) and no direct decisions are made. The externals breed does however own a *TotalSugar_Demand*; which follows from the domestic and international sugar demand. Depending on user defined settings; the sugar market can be considered to be entirely external in that sense that the externals breed is not affected by the iterations in the model or the sugar market can be considered to be within the system boundary. When the latter is the case, the external breed, just as with the distributor *Negotiate* procedure, can influence the market price of sugar based on total sugar output by the refineries. However, the determination of these economic market dynamics is highly uncertain; this will be further explained in the experimentation section. In the base model, and in conjunction with the model conceptualisation, the sugar market is assumed to be external which means that the sugar demand volumes are constant and the only change in the market is the global price of sugar (which is a computer user input parameter).

Note on the NetLogo Procedures

The purpose of the previous explanation regarding some of the important NetLogo model procedures is to give an insight into main operations which are run throughout the model iterations. It is stressed that for a full description (coding) of the NetLogo implementation one refers to Appendix K.

5.2.2 NetLogo Model Variables and Input

After the implementation of the coding structure of the NetLogo Model, it is important to determine the input values for the different parameters. A distinction must be made between actual values taken from the real-world bio-ethanol market, the parameters of which the absolute values are uncertain and the parameters which are inherently variable. The variance between the different market properties is taken as a randomly distributed variance; meaning that it is assumed that the total Brazilian bio-ethanol market, in a technical sense shows a random distribution of the technical parameters within a certain range. This is a deviation from the real-world as there a particular high concentration (localized) centres for the market specifically in the Sao Paolo state (*BNDES & CGEE, 2008*). However, the view of the model is to simulate the bio-ethanol market dynamics and not to explore geographic competition between regions in Brazil. This latter point is in line with other research which has been conducted on the bio-ethanol market. (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*).

Real-World Brazilian Parameters

An overview of the system parameters taken from the Brazilian market is shown in Table 2. It must be stressed that the values themselves are variable between certain ranges as every sugarcane refinery in Brazil is different to some extent. Also, the random variation which is introduced in these parameters is done to add an element of system heterogeneity. This latter aspect can strongly enhance the robustness of the model results, if there is no significant behavioural change between runs (*Sterman, 2002*).

As there are always variations between seasons in the sugarcane market, the baseline for the values is taken as the year 2011 (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). Table 2 only shows the most critical parameters, for a full overview of all parameters one is referred to the Appendix F.

Table 2: Critical Real-World Parameter Values of the Brazilian Bio-Ethanol System

Parameter	Value	Unit	Source
Energy Content Anhydrous Ethanol Relative to Gasoline	0.67	[-]	(UNICA, 2014)
Energy Content Anhydrous Ethanol Relative to Gasoline	0.67	[-]	(UNICA, 2014)
Sugar Yield per Tonne of Sugarcane	133 ± random(10)	[Kg / Tonne]	(UNICA, 2014)
Hydrous Ethanol Yield per Tonne of Sugarcane	75.03 ± random(5)	[L / Tonne]	(UNICA, 2014)
Anhydrous Ethanol Yield per Tonne of Sugarcane	71.74 ± random(5)	[L / Tonne]	(UNICA, 2014)
Share of Hydrous Ethanol of Total Ethanol Production	0.71 ± random(10)	[-]	(UNICA, 2014)
Share of Sugar of Total Sugarcane Processing	0.4 + random(0.2)	[-]	(UNICA, 2014)
Net Processing Cost of Sugar per Tonne of Sugarcane	46.56 ± random(20)	[\$ / Tonne]	(UNICA, 2014)
Net Processing Cost of Hydrous Ethanol per Tonne of Sugarcane	16.01 ± random(10)	[\$ / Tonne]	(UNICA, 2014)
Net Processing Cost of Anhydrous Ethanol per Tonne Sugarcane	28.54 ± random(5)	[\$ / Tonne]	(UNICA, 2014)
Tax on Gasoline	1.28	[\$ / Litre]	(SINDICOM, 2014)
Tax on Hydrous Ethanol Fuel	0.26	[\$ / Litre]	(SINDICOM, 2014)
Tax on Anhydrous Ethanol	0.05	[\$ / Litre]	(SINDICOM, 2014)
Blend Mandate	25	[%]	(SINDICOM, 2014)
Total Fuel Demand (Gasoline equivalent)	38.26 E 9	[Liters / Year]	(UNICA, 2014)
Total Sugarcane Production	1.69 E 6	[Tonnes]	(UNICA, 2014)

Assumed System Parameters

An overview of system parameters which are inherently uncertain is given in Table 3. This uncertainty can come from the fact that some of the system concepts are based on an *assumption* of how the real-world operates. For instance the user preferences and switch inclinations are an intrinsic system assumption. However, the overall system behaviour which arises should show the same pattern as real-world data. This aspect will be dealt with in the verification and validation parts of this report.

Another reason for the uncertainty in parameters, is the fact that many industrial information and data is confidential. Particularly in the distribution sector, in the pricing mechanism, no real-world data is available as this is business proprietary information (BNDES & CGEE, 2008; De Gorter, Drabik, Kliaugas, & Timilsina, 2013). Again, the validity of the chosen variables will be dealt with in the verification section.

Table 3: Uncertain Assumption Based System Parameters: Distributors and Refineries

Parameter	Value	Unit	Description
Preferred Stock Level of Distribution Terminals	0.5	[-]	Stock / Maximum Capacity
Maximum Capacity of Distribution Terminals	1.05 E 9	[Liters]	Equivalent to 10 days of total User Fuel Demand
Production Switch Capacity by Refineries	0.1	[-]	Ratio change that is possible at each review moment
Ratio Check Frequency	28	[days]	Interval between which refineries do a ratio check

As was stated in the model formalisation section of this report, all refineries and distributors are assumed to be equal in size and capacity (the impact that this may impose is discussed in Chapter 7) in order to fairly focus on the market behaviour in terms of changes in the environment (sugarcane price, sugar price, oil price). As such, market competition based on the different sizes of the agents is not incorporated in the model. Furthermore, the only variation between distributors is that each distributor is connected to a different portion of the user market. The variation between refineries is based on a random set of technical parameters to simulate heterogeneity between refineries in terms of technical efficiency and technical specialism for a certain sugarcane product; these variations should not affect the global pattern of the behaviour of the system. However the latter aspect does not hold for the parameters in the user market; due to the different typologies in the user market with the corresponding structurally different system properties it is necessary to further make the assumptions for the user agents explicit. This is shown in Figure 25. It is important to note that the distribution in the initial user types (*flex hydrous*, *flex gasohol* and *regular gasohol*) is uniformly randomized. That is to say that on average there is an equal share of each user type in the market (one-third per user type). A discussion of how the assumptions made in the user market relate to real-world behavioural patterns is presented in the verification and validation section of this report.

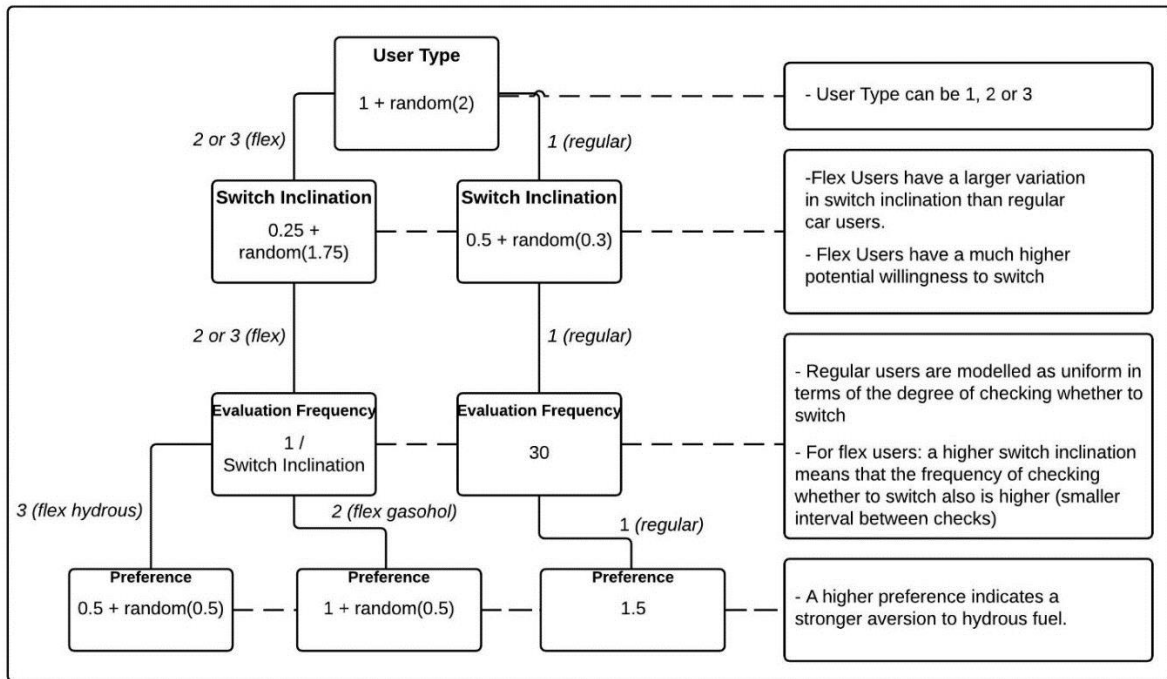


Figure 25: Schematic Overview of the Assumed System Parameter Values: Users

Variable System Parameters

The purpose of the model is to help the (*human*) user to be able to identify emergent behavioural patterns in the bio-ethanol system. However, the behaviour in the system is induced by the varying external commodity prices of sugarcane, sugar and oil (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). Therefore it is assumed that these parameters are variable. However, in order to be able to test the different sets of parameter value combinations, it is important to identify the baseline values for the parameters. An overview of the values which are taken for the baseline is given in Table 4. These values, in line with the real-world parameters, are taken from the real-world data in the year 2011.

Table 4: Variable Parameter Baseline Values

Parameter	Baseline Value	Unit	Source
Sugarcane Price	56.11	[\$ / Tonne]	(UNICA, 2014)
Sugar Price	0.7	[\$ /Kg]	(UNICA, 2014)
Gasoline Price	1.05	[\$ / Liter]	(ANP, 2014)

5.2.3 The Model Interface and Output

The interface of the model is the environment in which the (*human*) user can observe system output, manipulate system parameters, and start/setup model procedures. It is effectively the link between the user of the model and the model itself. A full visual description of the total Interface can be seen in the Appendix G. An important feature of the interface however is the *World* feature. This represents the system model in a visual manner and it can serve as a determinant of spatial distribution aspects. In the Brazilian bio-ethanol model, the variations in distance between the turtles itself do represent a higher or lower logistic cost. This is particularly relevant in the implementation of the *BioJet* model where under some scenarios it is possible to test the effects of the implementation of biokerosene transport using the existing kerosene infrastructure. Furthermore, the visualisation features help the (*human*) user to identify how the different locations in the user market affect the demand dynamics within these markets. This corresponds to real-world behaviour in that sense that the markets which are closest to the refineries in Brazil, are also the markets with lower prices for ethanol (BNDES & CGEE, 2008). This latter aspect is discussed in more detail later in the report (validation).

“World” NetLogo Visualisation of the Model Output

The model is designed to simulate the behaviour of the bio-ethanol market throughout the supply chain. From a visual point of view, it is interesting to be able to see during a simulation run how the system behaves. This aspect has been accomplished through the use of different colours to show which sugarcane product dominates each “chain” in the supply chain. Furthermore, the different user types in the system each have a specific colour which enables the user to follow the switching behaviour of this system element. The visualisation aspects of the model are intended for single runs where the user studying the system can alter system parameters during the runs themselves. An illustration of how the “World” NetLogo tool looks like is given in Figure 26. For demonstration purposes the supply chain is set in the Sao Paulo state which is by far the largest sugarcane market in Brazil (BNDES & CGEE, 2008).



Figure 26: Visualisation of the NetLogo “World”

Data Output of the Model

The most important element of the model is the data output it generates. As most simulation tests make use of multiple runs, it is essential to have a clear output data structure for the model. In NetLogo itself, the user can observe real-time information that the system generates. However, this is only useful when one wants to interactively explore the model. For proper analyses of the system output it is necessary to generate data files of the system information which can be processed by a third party software tool. In this case, the data analysis tool used is R (R, 2014). R makes it possible to accurately process data into many different forms of charts and diagrams. It can read the file output of the NetLogo model (.csv file) and easily manipulate the data once it has been read. A further documentation of the script which is used in the analysis of the model data files is shown in Appendix J.

In terms of the most critical system output parameters which are of interest in the scope of this research and model, the following parameters are summarized in Table 5.

Table 5: Overview of the System Output Parameters in the Base Model

Parameter (system indicator)	Unit	Description
Sugar Production Ratio	[-]	Sugar Production / (Sugar + Hydrous + Anhydrous) Production
Hydrous Production Ratio	[-]	Hydrous Ethanol Production / (Sugar + Hydrous + Anhydrous) Production
Anhydrous Production Ratio	[-]	Anhydrous Production / (Sugar + Hydrous + Anhydrous) Production
Hydrous User Price	[\$ / L]	Average Hydrous User Price
Gasohol User Price	[\$ / L]	Average Gasohol User Price
Anhydrous Price	[\$ / L]	Average Anhydrous Distributor Price
Flex Hydrous Users Ratio [3]	[-]	Number of User Type = 3 / (total number users)
Flex Gasohol Users Ratio [2]	[-]	Number of User Type = 2 / (total number users)
Regular Gasohol Users Ratio [1]	[-]	Number of User Type = 1 / (total number users)

Software Implementation Summary

It has been described how the bio-ethanol market can be translated, in terms of a proposed understanding of real market behaviour, into a NetLogo model. Depending on how a specific user intends to use the model, it has been described in general how the model works, under what conditions and what the output that the model generates can be. Once the base model has been verified, once can begin to add the biokerosene market element into the model.

5.3 Base Model Verification

After the software implementation of the model, the next step in modelling is the verification of the model. The verification of the model is the process of checking whether the software implementation of the model conceptualisation and formulisation has been correctly done; that is, to check whether the model correctly represents the intended model features (*Van Dam, Nikolic, & Lukszo, 2013*).

5.3.1 Model Testing

To gain confidence that the model has been constructed in such a way that the output that is generated is correct to the intended design of the model, a number of different tests are to be conducted. First of all, it is important to explore, on a very small scale if all concepts behave as they should. This can be done by running the model with a single agent or (in the case of the supply chain) with a single set (refinery, distributor and user) of agents. After the model performs as expected under the single set condition, it is necessary to test the model using a large number of agents; this test tells the user whether the model can handle the many different interactions between the agents and if the large scale system has been well incorporated within the model. The conclusion of the verification test are shown below.

Extreme Condition and Boundary Testing:

In terms of actual verification steps, the first step which is conducted is to test how the model behaves under extreme conditions. That is to say, how does the model react to parameter values which are close to the boundaries of what the actually intended model is designed to simulate.

Result

- i. As can be expected, the model gives a run-time error when there is not at least 1 agent available of each agent breed (refinery, distributor and user). This makes complete sense as otherwise there is no supply chain in existence.
- ii. For a very large number of agents (500+), the model becomes unresponsive. This indicates that the computation of all model steps for this large amount of agents is beyond that of the practical scope of the model. It is important to remember that the model has been designed to simulate the Brazilian ethanol-market on an aggregate level; that is to say 1 agent in the model represents a much larger group of actual actors in the system. Therefore, this high number of agents is not necessary and impractical. The base line number of agents is; 50 Refineries, 5 distributors and 100 users. This follows from the real-world relative portions in Brazil.
- iii. The run time of 1000 ticks is adequate for all system patterns to emerge. Therefore as a baseline value, the run time of the model is taken as 1000 ticks which translate to 1000 days.
- iv. Further extreme model inputs are dealt with by the model adequately indicating that the boundaries in the model interface are correct.

Sanity Tests:

In sanity testing one determines whether a model behaves, in terms of the system patterns, as expected under given plausible inputs (*Van Dam, Nikolic, & Lukszo, 2013*). For the bio-ethanol model this is particularly important as the output of the model is to show how different sets of external prices, in combination with other user defined inputs, the different groups of agents will behave. This aspect will have significant importance when one wants to conduct experiments on the BioJet model, as for this model no real-world data will be available.

Result

- i. A lower blend mandate and a decrease in gasohol taxes, decreases the price of gasohol accordingly and thus increases the portion of gasohol users. This makes complete sense considering that anhydrous ethanol is more expensive than gasoline and users are sensitive to lower gasohol prices. The opposite is true when mandates and taxes are increased; this is to be expected.
- ii. An increase in global sugar prices, increases the portion of sugar production. This is in line with the profit maximizing assumptions of refinery agents.
- iii. High stock levels lead to lower prices of the product. Vice versa, low stock levels lead to higher prices of the product. This indeed indicates the concept of scarcity at the distribution agents leading to higher product prices vice versa.
- iv. At low numbers of agents the system behaviour shows a step-wise change in behaviour; this corresponds to the discrete methodology in the model in which an agent can change production/demand ratios. For larger number of agents, this is less apparent as the many different properties of the agents (including switch frequency and inclination) cause the aggregate system behaviour to behave more uniformly. This aspect makes sense and is entirely within the expected scope of the model as this follows from a formal (user defined) assumption.
- v. Initially, one can observe that system behaviour is very dynamic. It can be seen how the refinery production ratio system clearly is in search of an equilibrium. This aspect can be explained by the fact that the model is set up under random parameters. This is illustrated in Figure 27. This behaviour makes sense and although this initial equilibrium seeking behaviour is not strictly part of the real-world pattern under study, it is an important element as it shows that the model does actively seek a demand and supply match; which is precisely what the overall system has been designed to do; based on real-world assumptions (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). It is very important however that the user of the model realizes this aspect, before drawing conclusions from other system behaviour.

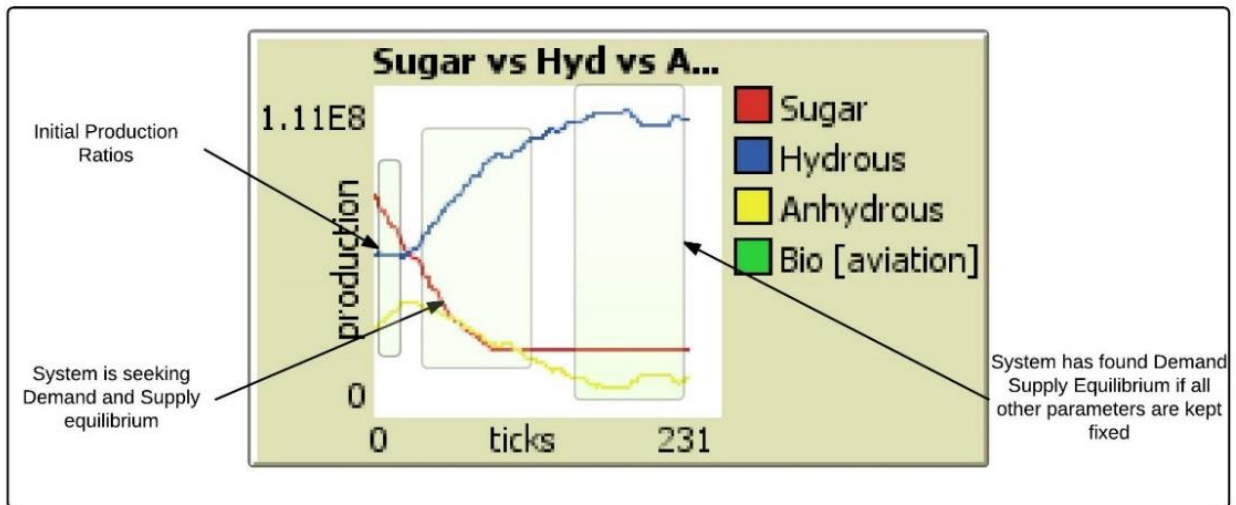


Figure 27: System Equilibrium Seeking Behaviour in the Base Model

5.3.2 Baseline Determination of Model Parameters and Model Sensitivity

The base model has initially shown that it can correctly simulate the bio-ethanol system which has been defined in the scope of this research. The final steps in the base model implementation before one can compare the results of the model with actual real-world behaviour (validation), is the determination of the parameter values of the concepts which have been introduced by the user and are thus based on an assumption of the real-world as opposed to an actual real-world concept. Particularly the price setting mechanism of the distributor agents needs to be examined. Also, it is important to do a sensitivity test to explore whether the many different runs show the same behaviour indicating a true system pattern, as opposed to a single random simulation run which by chance shows a change in behaviour (outlier) (Sterman, 2002).

Exponential Smoothing

The smoothing of the profits and stock levels by the producers and distributors respectively did not show any significant impact on the behaviour of these agents. As a matter of fact, when the smoothing factor is taken as one (implying no smoothing), the behaviour of both producers and distributors were less volatile. This indicates that the smoothing is not able to be used as a forecasting method by the agents. A possible reason for this, is the fact that the market is set up to be very "reaction" based; this is also made clear when dealing with the distributor price setting mechanism. That is to say, the agents are assumed to adapt to the changing market conditions which are given as an external input (through the simulation test). In light of this, it is concluded that in the model the agents react to the actual data in the system and do not try to forecast the changing market in this particular case.

Distributors Price Setting Mechanism

In the model formalisation, the assumption was made that distributor agents will increase product prices when their stocks of that particular product are low and vice versa, the price of the product decreases when stocks are high. This assumption is made with the view that distributors are responsible for maintaining a stable supply and demand in the bio-ethanol market. It is assumed that distributors have a certain maximum capacity for storing the products and a certain “market power” which indicates the degree to which the price setting margins affect the overall consumer and producers prices. A higher margin thus indicates high value for the producer (profit) and higher cost for the consumer. As explained earlier, these prices directly affect the decisions of users (lower demand with higher price) and producers (higher supply with higher price) which both enable the stock levels of the distributor to increase (it works the other way round when the margin is lowered). In the conceptualisation of the price setting mechanism, it is assumed that the stock level near 100% and 0% must be avoided at all cost. Therefore, at these stock level ranges, the market margins are significantly increased/decreased which further causes a volatile market situation. At some point the volatility (frequent change in price) becomes so large, that it does not make sense when comparing to price setting aspects in the real-world; it is important that the user realizes this and that this does not necessary need to affect the usefulness of the model results; it merely means that the supply and demand have reached the boundaries of the system.

An important aspect of both concepts, being capacity size and market margin power, is to find a compromise between maintaining sufficient supplies in the supply chain, without overly affecting the price levels of the products (stable prices); this is an inherent feature of many supply chain models particularly in terms of fuel supply (*Energy Charter Secretariat, 2007*). These two concepts have been tested, with a variable set of combinations in order to identify which set of market power and storage capacity are most preferable in view of this compromise. The results of these tests are shown in Figure 28.

A conclusion which can be drawn from the tests is that the maximum capacity of the storage terminals at the distributor level is not a determining factor in this system element. This may be explained by the fact that a larger capacity delays the “speed” at which the distributor is forced to act in terms of margin setting; the delay itself is not significant in terms of the stabilizing nature of the supply and demand. Furthermore, based on the tests, the degree of market power that the distributors require to maintain supply and demand is in the order of (*market margin times market constant*) 25% of total product prices. This margin is in line with the market margins which are observed in the Brazilian real-world system where a typical margin is in the range of 10-30% for all fuel types (*De Gorter, Drabik, Kliauga, & Timilsina, 2013; UNICA, 2014*). Also, it can be seen that for higher market margins, the price levels of the fuels become much more volatile, indicating a constant and frequent overreaction by the system to the price levels. Therefore, as a baseline parameter value, the marketing constant variable in the model is fixed at no less but also no more than 0.5. The maximal storage capacity is kept fixed at 10 times the daily demand for fuel by the user market, which means the market can supply the fuel product for a maximum 10 days without any supplies from refineries.

In Figure 28 (below), the stock levels at the distributors are shown as function of time. Also, the margin levels as a function of time are shown (bottom). In both graphs, the x-axis corresponds to the distributor capacity of respectively 10, 30 and 50 days. The y-axis corresponds to the market margin power (from 0 to 1) with which the distributors are “empowered”; that is to say the higher the market power, the more impact the margin setting has on the prices of both ethanol products. With this in mind, it makes sense that a compromise is needed between having enough “power” to effectively manage the supply and demand, and maintaining relatively stable prices for the ethanol products.

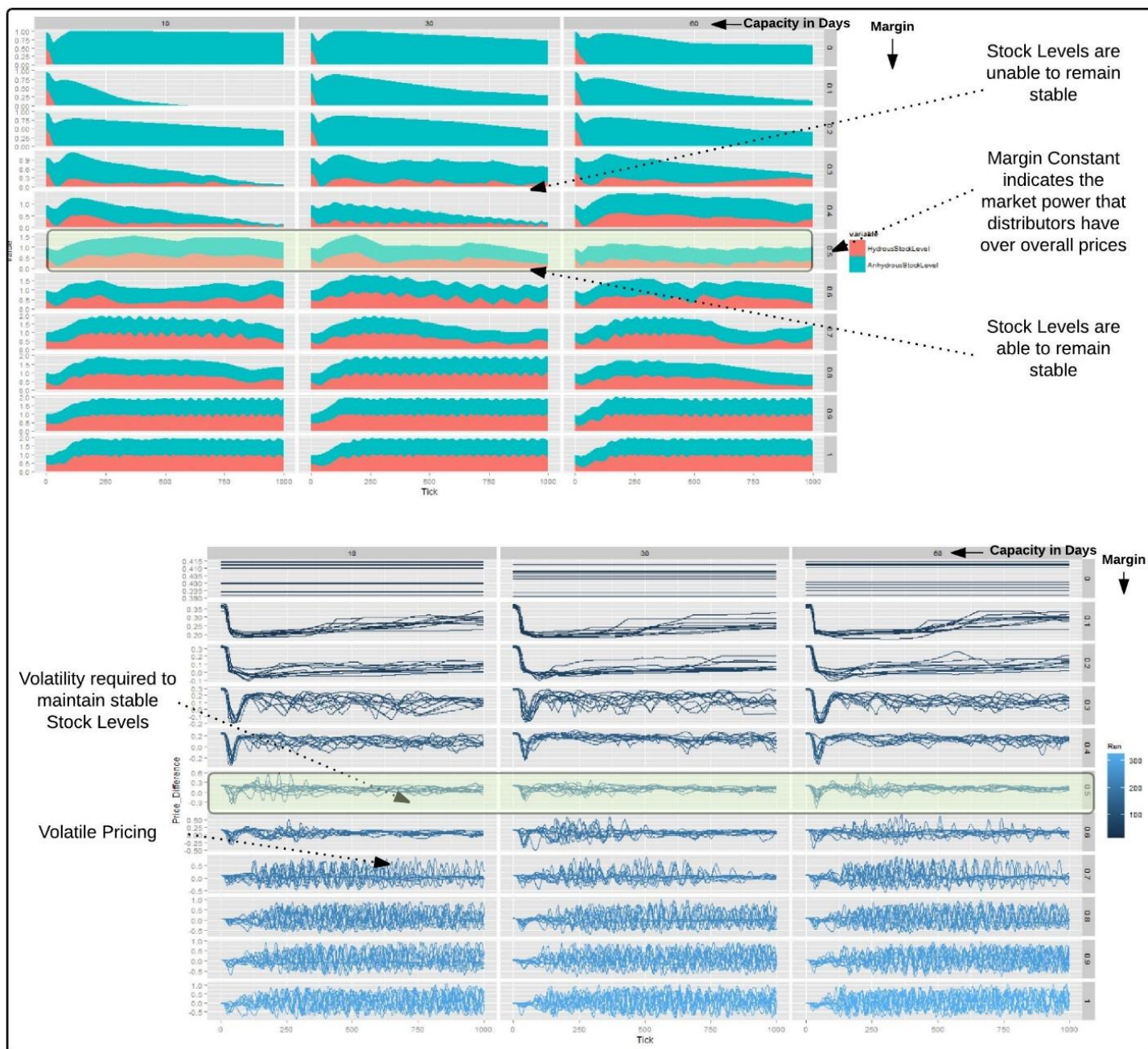


Figure 28: Distributor Price Setting Compromise between Volatility and Supply Stability

Base Model Sensitivity Analysis

To test the sensitivity of the model to the random initialisation of the parameter values a number of tests are run with a large amount of multiple runs in order to identify if indeed the system behaviour acts uniformly or that different runs with corresponding different start-values have a large impact on the outcome of the model output. The base model has been run according to the baseline values which are described earlier in this chapter. The results of the multiple run testing for the hydrous production ratio, and the price difference between gasohol and hydrous over time are presented in Figure 29. The main conclusion one can draw out of the sensitivity test is that the random initialisation of the system parameters does impact the quantitative output of the model, but it does not affect the qualitative output. This latter aspect is reaffirmed by the fact that clearly it is visible how the system moves to a certain equilibrium with the same mode of behaviour.

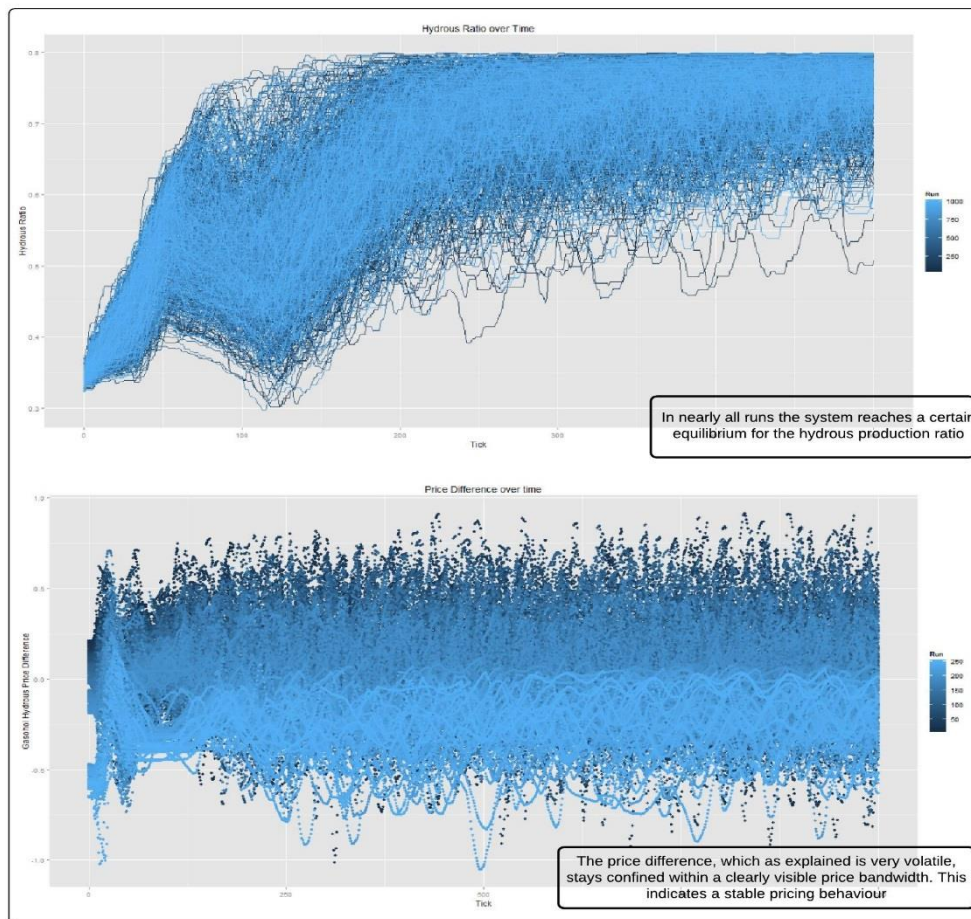


Figure 29: Sensitivity Runs for Hydrous Production and Fuel Price Difference

5.4 Base Model Validation and Exploration

The validation steps of the base model and additional analysis of the base model behaviour and output is described in the following sections.

5.4.1 Validation Background

Methods

With the verification of the base model, where the answer is given on whether the model has been implemented as was intended by the user, the validation of the model is concerned with the question whether the *right system* has been modelled. Does the model indeed give insights into the original system under study and does this give the user an answer to the questions of the problem owner (*Van Dam, Nikolic, & Lukszo, 2013*)? A traditional view on validating a model is to compare the data directly to real-world data to see if the produced system output shows the same result (Sargent, 1998). However, in view of a research problem into the exploration of emerging behaviour with a significant “lack” of real-world data, this way of thinking in regards to validating is not useful (*Louie & Carley, 2008*). This latter aspect is the case in the BioJet model. However, in the case of the base model which models the market aspects of the bio-ethanol market in Brazil, there *is* significant real-world data. As such, the validation of the base model will be done through the validation methods “*historic replay*” and “*literature validation*” (*Van Dam, Nikolic, & Lukszo, 2013*).

Base Model Testing

There is no single definition on what constitutes the correct validation of a model using historic replay (*Van Dam, Nikolic, & Lukszo, 2013*). It depends very much on what the user of the model intends to do with the results. Is the aim to replicate quantitative system behaviour and as such use the model as a forecasting tool? In the latter case the model should be able to replicate historic data in quantitative terms. Or is the user more interested in replicating qualitative patterns which have historically (and currently) been observed in the real-world? From the research problem and methodology it is clear that the latter view on historic/current validation is what is required in the scope of this model. Therefore, a comparison of the qualitative system patterns is made through the experimentation of the model. In order to use the model to gain an insight into emergent system behaviour it is necessary to pre-determine a series of appropriate experiments.

Experiment Background

The experimentation in this section will be focussed on the replication of real-world regularities of the Brazilian ethanol market; specifically regarding the allocation of demand and supply in terms of ethanol products and sugar. Considering the generative nature of Agent Based Modelling, the following type of hypothesis testing can be formed (*Van Dam, Nikolic, & Lukszo, 2013*).

“Under the specified conditions, a macroscopic regularity of interest (*to the user*) emerges from the designed Agent Based Model.”

This type of hypothesis relates to the modelling of a real-world regularity. That is to say, there exists a phenomenon that one observes in the real-world which cannot be directly explained, which one tries to replicate according to how one believes this phenomenon might work. In the case of the Brazilian bio-ethanol model, there are two important phenomena which are under study. These are the changing *production ratios* of the supply and demand of sugarcane products and the changing *price levels* of these products.

Changing Production Ratios and Demand

As it has been made clear throughout the report, the Brazilian ethanol market is typified by an ever shifting allotment of sugarcane use for different sugarcane derived products. Historically, the sugarcane system has undergone the shift from sugarcane into only sugar, to the addition of alcohol (beverage) production and eventually to the addition of industrial alcohol production for fuel usage. These shifts have usually been in leaps and bounds, driven by technological, societal and political developments (*Cortez & Rosillo-Calle, 1998*). More recently, the significant increase in ethanol production for fuel usage has caused the sugarcane market to be highly volatile. The nature of sugarcane processing, where sugar and ethanol production are highly related to one another, means that processers (refineries) of sugarcane can relatively easily shift their production ratios. The Brazilian ethanol market in recent years has shown to be constantly changing; due to weather conditions, government policy and external global price changes of fuel and sugar (*BNDES & CGEE, 2008*). The first set of experiments will need to determine if the constructed Agent Based Model can replicate the shifting behaviour of the refineries (*production*) and users (*demand*). The parameter values under which these experiments are conducted will be based on real-world values, a detailed overview of these values is shown in Appendix F.

Behaviour under Study

The Brazilian ethanol market shows a clear tendency to increase the relative production of sugar, in the face of a significant increase in global sugar prices. Furthermore, a glut in the sugar market causes the production of ethanol to significantly increase and sugar production to decrease. The shift in demand and supply of sugar also causes the price of ethanol (both hydrous and anhydrous) to shift which in turn affects the demand for these products. This also holds for shifts in external gasoline prices, the availability of sugarcane and the overall demand (and corresponding price shift) for sugarcane.

The Parameter Sweep

The method in which the experiments are carried out is through the use of a *parameter sweep*. The parameter sweep is the exploration of the model at different parameter settings. The different parameter settings can simulate different real-world scenarios. A distinction can be made between exploring different scenarios and the exploring of a scenario space (*Van Dam, Nikolic, & Lukszo, 2013*).

A scenario is a particular set of parameter combinations which can replicate a real-world situation in the system. A scenario space is the total set of parameter combinations (likely or unlikely in the real-world) within which the model can be explored. This latter aspect gives the user an insight into what possible behaviour may emerge, and under which kind of parameter setting, without taking into account any particular real-world probability of these parameter combinations occurring. The exploring of the scenarios space is ideal for investigating *possible* behaviour as opposed to the exploring of a scenario which explores what behaviour may emerge given a *certain* parameter setting (Van Dam et al, 2013).

The experiments in this research will make use of both a scenario setting and a scenario space setting; with the former being particularly useful for exploring the emergence of a biokerosene supply chain, this is done in the BioJet exploration section. NetLogo has a built-in tool, *BehaviorSpace* (Northwestern University Netlogo, 2014), which enables the user to carry out parameter sweeps; both through the specifying of certain parameter combinations or through the iteration of many possible sets of parameter combinations. The latter method however may require a significant number of computer runs and as such may require a lot of time to run which is not always practical, therefore it is important to define the boundaries of the scenario space as accurately as possible. The choice of the boundaries is based on the baseline values, historic outliers of these values and future expected ranges for these values. Furthermore, the sensitivity to small changes in the parameters is relatively small due to the strong influence of the market setting power of the distributors within the market as has been shown in the sensitivity analyses. This means that the incremental steps in parameter values in the experiments can be taken in relatively large steps (Van Dam et al, 2013).

5.4.2 Base Model Experiment Design

Experiment A: Sugar Price versus Gasoline Price

The first experiment explores the effect of a different set of price combinations between sugar prices and external gasoline prices. From the literature (De Gorter et al, 2013; Pacina & Silveira, 2011) it is expected that an increase in sugar prices will shift the production ratio towards sugar production at the expense of ethanol production. In conjunction with this, an increase in gasoline prices will shift production ratios from anhydrous ethanol to hydrous ethanol as the relative price of the gasohol blend will entice flex users to switch towards hydrous fuel use which decreases demand for anhydrous ethanol.

The parameter sweep is done using the following minimum and maximum values for the sugar price and the gasoline price with a uniform step increase, see Table 6. The area of interest in regards to this experiment is the *Production Ratio* of hydrous ethanol, anhydrous ethanol and sugar for the total refinery system. In addition to this, the effects on the difference in price (*Price Difference*) between gasohol fuel and hydrous fuel is measured; it is expected that an increase in sugar prices will increase overall ethanol prices and thus make gasohol more attractive relative to hydrous fuel (gasohol consists of only 25% ethanol as opposed to 100% ethanol in hydrous fuel). Closely related to the price difference is the shift in ratio (*Users Ratio*) between hydrous and gasohol flex users and regular gasoline users. An

increase in the price difference is expected to increase the number of hydrous users at the expense of gasohol users.

Table 6: Parameter Sweep Ranges for Sugar Price vs Gasoline Price

	Sugar Price [\$/Kg]	Gasoline Price [\$/L]
Minimum	0.6	0.6
Maximum	1.8	1.3
Increment	0.2	0.2
Baseline Value	1.0 (UNICA, 2014)	1.050 (UNICA, 2014)

Experiment B: Sugarcane Price versus Gasoline Price

The second experiment is closely related to the first experiment except that now the impact on the system by a change in sugarcane price is explored, see Table 7. As stated in the literature, the sugarcane price is determined retrospectively by the market through the *CONSECUNA* system (BNDES & CGEE, 2008), and as such an increase in sugarcane price is usually the direct consequence of an increase in downstream prices for sugarcane products; these in turn are determined on the basis of supply and demand. A significant determinant on the availability of sugarcane is the weather condition in a particular year. Sugarcane output can vary by as much as 40% between seasons due to bad/good weather conditions (BNDES & CGEE, 2008) The general unpredictability of weather conditions also dictates the unpredictability of sugarcane prices. Therefore the parameter sweep for sugarcane prices is done within a broad range.

Table 7: Parameter Sweep Ranges for Sugarcane Price vs Gasoline Price

	Sugarcane Price [\$/Tonne]	Gasoline Price [\$/L]
Minimum	30	0.6
Maximum	110	1.3
Increment	20	0.2
Baseline Value	56.11 (UNICA, 2014)	1.050 (UNICA, 2014)

The area of interest is the same as with Experiment A; total *Production Ratio*, *Price Difference* and demand *Users Ratio*.

Experiment C: Market Flexibility

The dominant feature of the Brazilian bio-ethanol market is the fact that throughout all stages of the supply chain there exists a certain level of flexibility. This ensures that the market can adjust to external shocks to the system (external price changes, domestic developments and sugarcane availability). Before the introduction of the flex fuel vehicle, this degree of flexibility was non-existent which led to severe supply crises (*Cortez & Rosillo-Calle, 1998*). This experiment will explore the impact of the flexibility of the system in regards to the price difference of hydrous and gasohol fuel, and the level of profits which are made by refineries. The experiment will test the following baseline scenarios:

1. *Refineries can shift production ratios and users can switch between fuels.*
2. *Refineries can shift production ratios and users cannot switch between fuels.*
3. *Refineries cannot shift production ratios and users can switch between fuels.*
4. *Refineries cannot shift production ratios and users cannot switch between fuels.*

The area of interest in this experiment is the total amount of profit that refineries make (hydrous, anhydrous ethanol and sugar combined) and the *Price Difference* between gasohol and hydrous fuel.

Model Settings

The model experiments are run under the baseline value settings, unless the parameter sweep dictates otherwise. The complete set of baseline values themselves can be seen in Appendix F. Furthermore, unless specifically stated, all scenarios refer to a change of parameter value at the beginning (*initial value*) of a run.

Repetitions:

Agent Based Models are chaotic in nature (*Van Dam, Nikolic, & Lukszo, 2013*). This has also been shown in the sensitivity analyses of the base model. Therefore it is of importance to make multiple runs of any experiment in order to make sure the outcome of an experiment is not part of a system outlier (*Holland, 1992*). In practical terms this means that the experiments that are run are repeated a number of times; the exact number however is dependent on the experiment itself and the behaviour one is looking for. Based on the sensitivity analysis the number of runs in the experiments is determined; these indicate that the number of runs required needs not be too high as the behaviour is not sensitive to the different runs. For the base model experiments the number of runs per experiment is 10.

5.4.3 Base Model Results and Data Analysis

Experiment A: Sugar Price versus Gasoline Price

The ratio of the different production elements (hydrous = green, anhydrous = blue, sugar = red) as a function of time is shown in Figure 30. There are 35 different plots which correspond to the 35 combinations of sugar price and gasoline price. A ratio value of 1 indicates a 100% sugarcane dedication to that product; the plots are stacked.

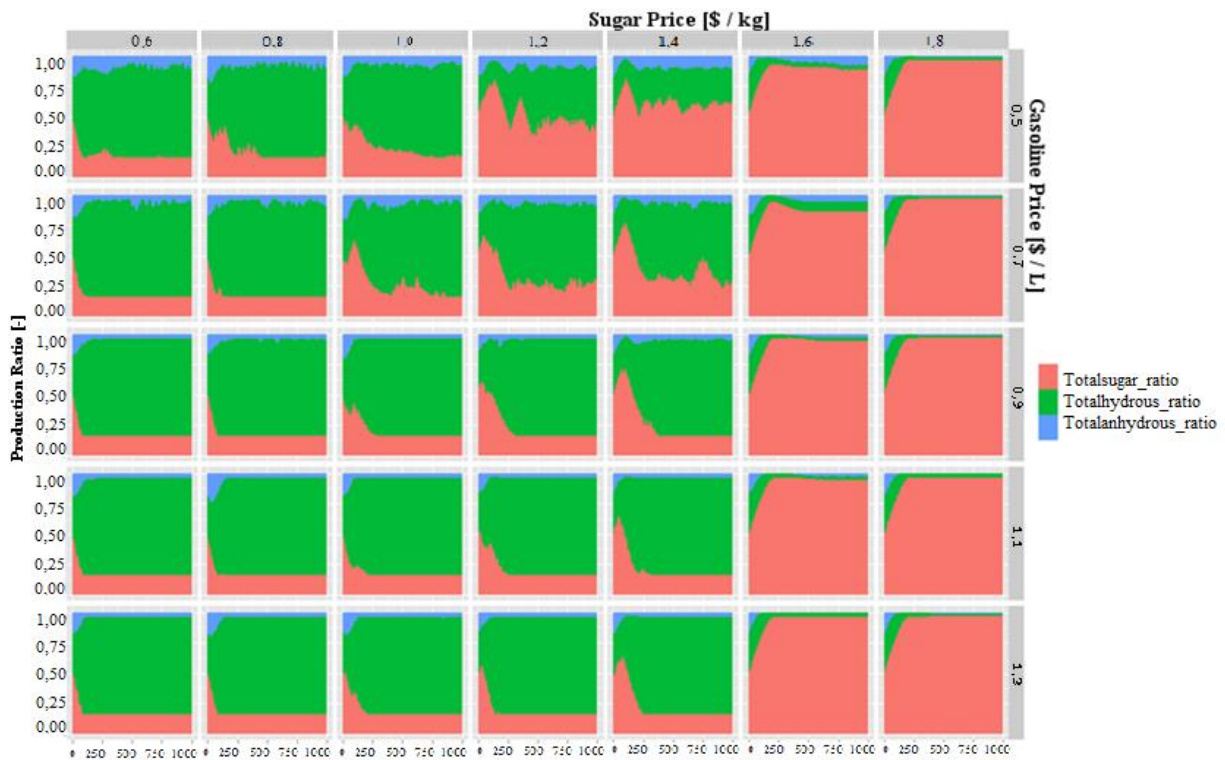


Figure 30: Production Ratio as a function of Sugar Price and Gasoline Price

Pattern Visualisation, Identification and Discussion: Production Ratios

- i. It can be clearly seen that an increase in the price of sugar steadily stimulates the refineries to switch towards a larger share of sugar production. In the phase between the lowest sugar price and highest sugar price, the unstable (noisy) pattern of the sugar ratio and hydrous ratio can be observed. This means that in these ranges of prices, the decision by the refineries to shift ratios is ambiguous; it is not clear for each refinery which product is most profitable. Also the decision making in this phase is much more sensitive to smaller price changes in hydrous fuel prices.
- ii. Additionally, it can be clearly seen that an increase in gasoline prices shifts the production ratio from sugar production towards hydrous ethanol production. It is interesting to note that the ratio of anhydrous ethanol does not change significantly at any price combination; this may be due to the relative small size of the anhydrous market compared to sugar and hydrous ethanol or it may mean that hydrous production is relatively more profitable. This element will be further examined in Figure 31.

- iii. A leading conclusion is that the sugar price dominates the decision by refineries to determine production ratios. At lower commodity prices, the market is clearly more *volatile*; indicating a relatively frequent change in the market output levels caused by a much more “fluid” user market where users are switching more frequently and producers are shifting their production ratios more often than in a non-volatile market situation.

The Price Difference (Gasohol Price – Hydrous Price) is shown in Figure 31. There are 35 different plots which correspond to the 35 combinations of sugar price and gasoline price.

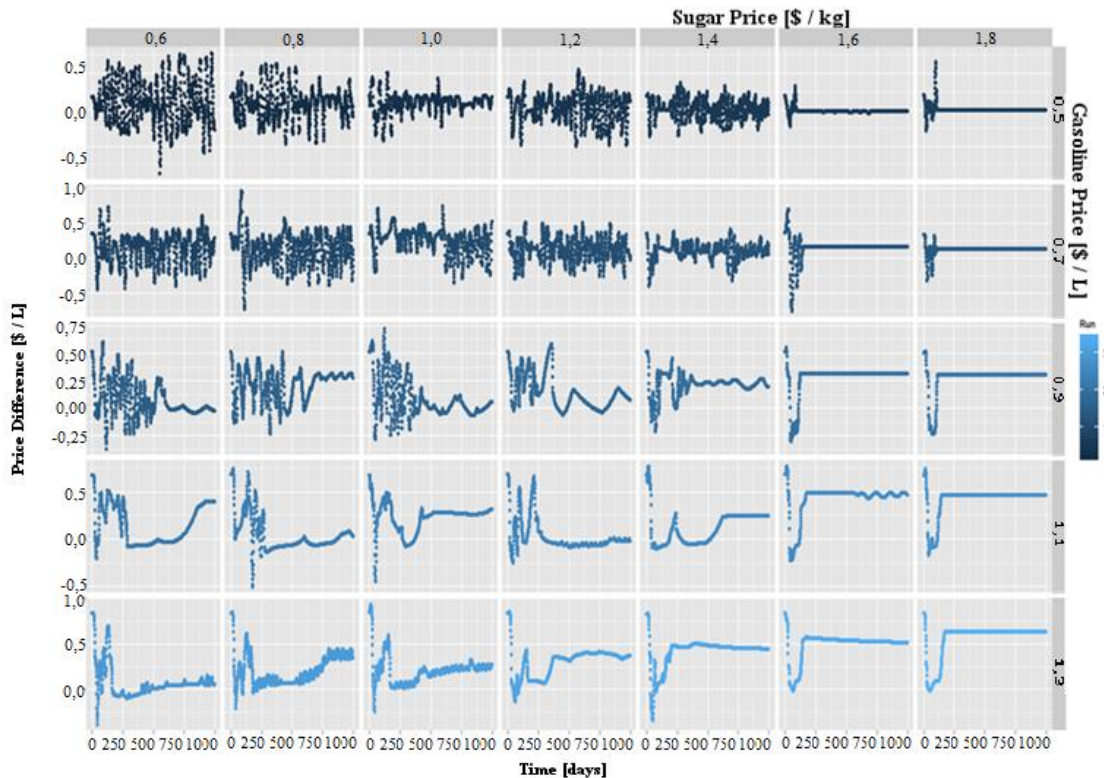


Figure 31: Price Difference Gasohol - Hydrous Fuel as a function of Sugar Price and Gasoline Price

Pattern Visualisation, Identification and Discussion: Price Difference

- i. The Price Difference between gasohol and hydrous fuel shows very chaotic behaviour. As was discussed in the sensitivity analyses section of this report it makes sense as to why this is the case. The chaos implies a constant shift in production prices, stock levels and user demand which can be expected of a dynamic market such as the Brazilian bio-ethanol market. Furthermore, Figure 32 clearly shows how a lower price of both sugar and gasoline increases the volatility of the price difference.
- ii. The price of sugar affects the Price Difference variable by making the decision of refineries more ambiguous as the price of sugar is lower. At the lower price ranges, refineries have no clear cut profitable product which means the refineries are heterogeneous in the level of sugar output.

As was seen Figure 31, a higher sugar price makes the decisions on sugar output by refineries much more clear cut which results in a stable price difference.

- iii. It is interesting to note how an increase in gasoline prices increases the overall price difference between gasohol and hydrous. This make sense due to the fact that gasohol is composed of 75 % gasoline. It can be expected that flex users will switch en masse as the gasoline prices increase.
- iv. A leading conclusion is that the price of gasoline dominates the difference in price between the different fuels and as such will dominate the decision making in the fuel market relative to the sugar price.

The distribution of user types within the user market (user ratios) for type 1 = regular gasohol, red, type 2 = flex gasohol, green, type 3 = flex hydrous, blue are shown in Figure 32. There are 35 different plots which correspond to the 35 combinations of sugar price and gasoline price. The plots are stacked.

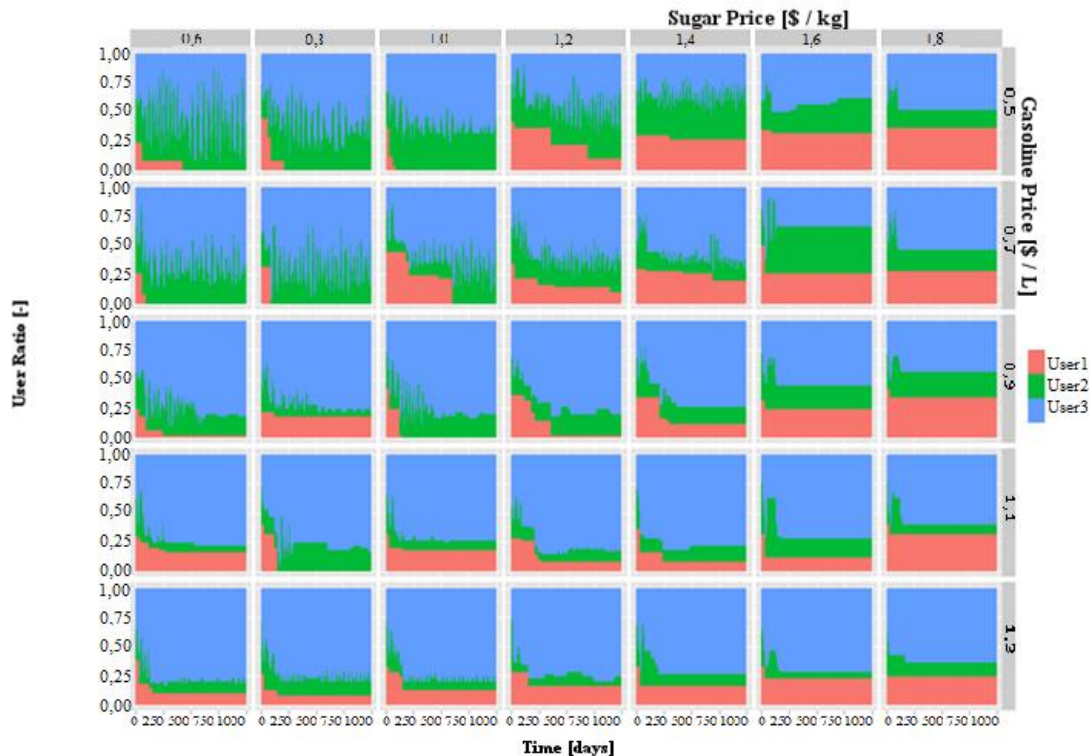


Figure 32: User Ratios as a function of Sugar Price and Gasoline Price

Pattern Visualisation, Identification and Discussion: Users Ratios

- i. As was stated in the previous section, indeed one can observe the larger portion of users being of user state 3 (= Hydrous User), as the price of gasoline increases. Concurrently, the noise which was observed at lower gasoline prices levels also translates into an ambiguous flex fuel user market which can be seen the through frequent “spikes” in the plots.

- ii. An increase in sugar prices, surprisingly seems to affect the users market. It can be observed that an increase in sugar prices, decreases the amount of flex users; that is to say that there are relatively more regular gasohol users in the market. This may be explained by the decrease in supply of ethanol, due to a shift of refinery production towards sugar, which translates into an increase of hydrous fuel prices. Also, there is less incentive for regular gasoline car users to switch towards flex fuel vehicles.
- iii. The frequent amount of spikes between Users2 (*flex gasohol*) and Users3 (*flex hydrous*) is a typical feature of the Brazilian flexible fuel market. It shows that lower commodity prices for sugar and gasoline, increases the demand dynamics aspect of the system where agents are able to choose between products.

Experiment Conclusion

The main purpose of this experiment is to see how external commodity price changes affect the bio-ethanol base line model and if this behaviour corresponds to what one would expect. It can be concluded that this is the case as it has been shown how lower commodity and more ambiguous prices for sugar and gasoline cause the system to become heterogeneous. The system in itself becomes more volatile which one would expect as there is no clear cut most profitable product.

In terms of the impact of a different level of sugar price and gasoline the price on the production ratios, user demand ratios and price difference between the fuels the following can be said;

1. Sugar Production increases as a function of an increase in sugar price
2. Hydrous Production increases as a function of an increase in gasoline price
3. Anhydrous Production is not significantly impacted by changes in sugar and gasoline price
4. Low commodity prices for fuel and sugar increase the volatility of fuel prices
5. At low sugar prices, an increase in gasoline prices increases hydrous demand
6. At low commodity prices, the fuel demand market is very volatile (follows from 4).

A comparison of the above statements with real-world data is given later in this section.

Experiment B: Sugarcane Price versus Gasoline Price

The ratio of the different production elements (hydrous = green, anhydrous = blue, sugar = red) as a function of time is shown in Figure 33. There are 25 different plots which correspond to the 25 combinations of sugarcane price and gasoline price.

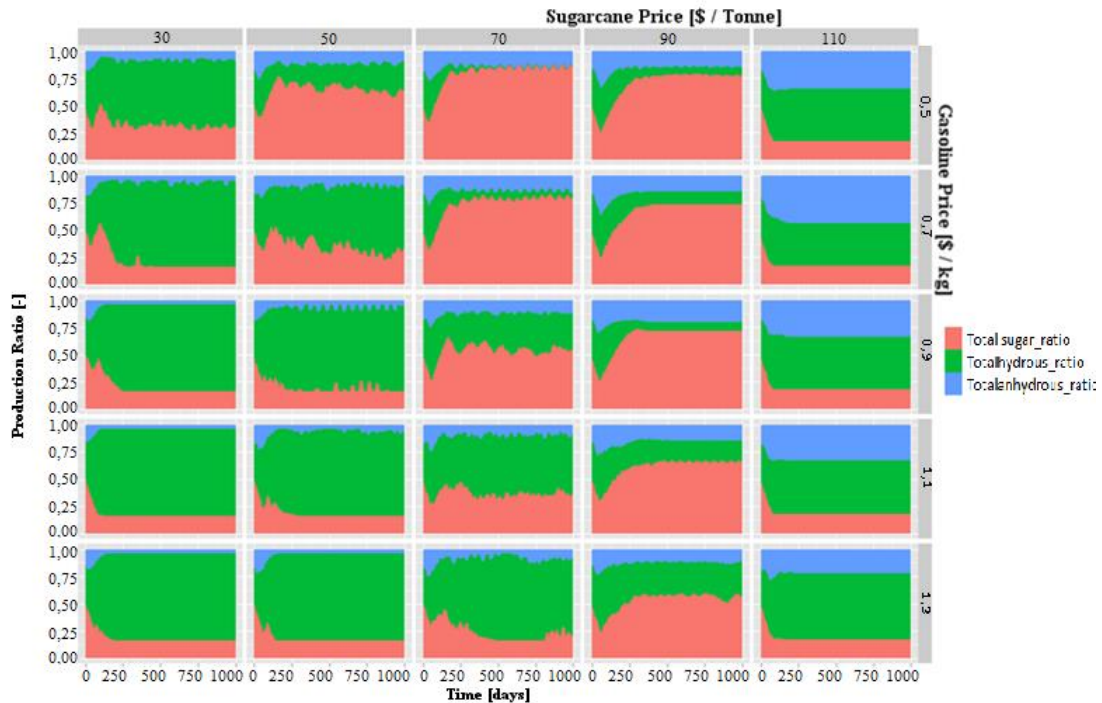


Figure 33: Production Ratio as a function of Sugarcane Price and Gasoline Price

Pattern Visualisation, Identification and Discussion: Production Ratios

- i. As was the case with experiment A, it can be seen that the increase in gasoline prices increases the relative ratio of hydrous production at the expense of sugar and anhydrous production. However, the effect is much less clear than with experiment A.
- ii. It seems that the increase in sugarcane price has a much stronger impact on the production ratio. The ratio of sugar increases at the expense of hydrous ethanol. This can be explained by the switching of car users towards non-hydrous fuel. However, in the scenario of a sugarcane price of $110 \text{ \$ / Tonne}$, the ratio of sugar production has suddenly decreased and anhydrous production has substantially increased. This indicates a tipping point in the system.
- iii. As is the case in experiment A, the lower price levels of the commodities create a more volatile market behaviour than at the higher price levels, indicating more decision ambiguity for refineries.

The Price Difference (Gasohol Price – Hydrous Price) is shown in Figure 34. There are 25 different plots which correspond to the 25 combinations of sugarcane price and gasoline price.

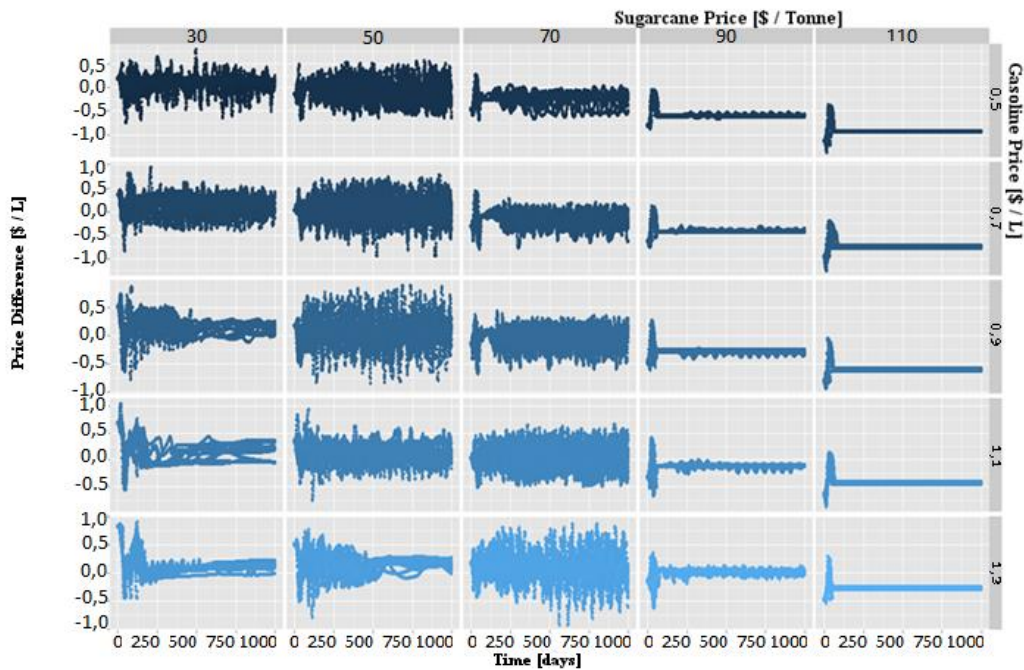


Figure 34: Price Difference between Gasohol and Hydrous Fuels as a function of Sugarcane Price and Gasoline Price

Pattern Visualisation, Identification and Discussion: Price Difference

- i. The same noise is present as with experiment A. However, the noise is more prominent and exists for most gasoline price levels. The dominant feature is the stabilization of the Price Difference at higher sugarcane prices. Furthermore, it can be clearly seen how higher sugarcane prices cause the Price Difference to become negative, indicating that hydrous fuel is more expensive than gasohol fuel. This is particularly the case at a sugarcane price level of $110 \text{ \$ / Tonne}$. The significantly lower price level of gasohol relative to hydrous fuel may explain the sudden shift in Figure 33, in which the sugar output is suddenly reduced. It may imply a higher price for hydrous ethanol which in turn means that refineries can increase their profits by increasing hydrous ethanol output at the expense of sugar.
- ii. The range of the Price Difference outliers (maximum and minimum) is fixed within a constant bandwidth; this is due to the market influence powers of the distributors and can be expected. Furthermore, an increase in sugarcane prices clearly converges the Price Difference variable towards a constant value which indicates that the maximum acceptable Price Difference for most flex users has been reached.
- iii. A leading conclusion is the fact that the sugarcane price determines the actual *level* of difference between the fuels, but it does not affect how the price difference *behaves* (*mode of price development in qualitative terms*) over time.

The distribution of user types within the user market (user ratios) for type 1 = regular gasohol, red, type 2 = flex gasohol, green, type 3 = flex hydrous, blue are shown in Figure 35. There are 25 different plots which correspond to the 25 combinations of sugarcane price and gasoline price. The plots are stacked.

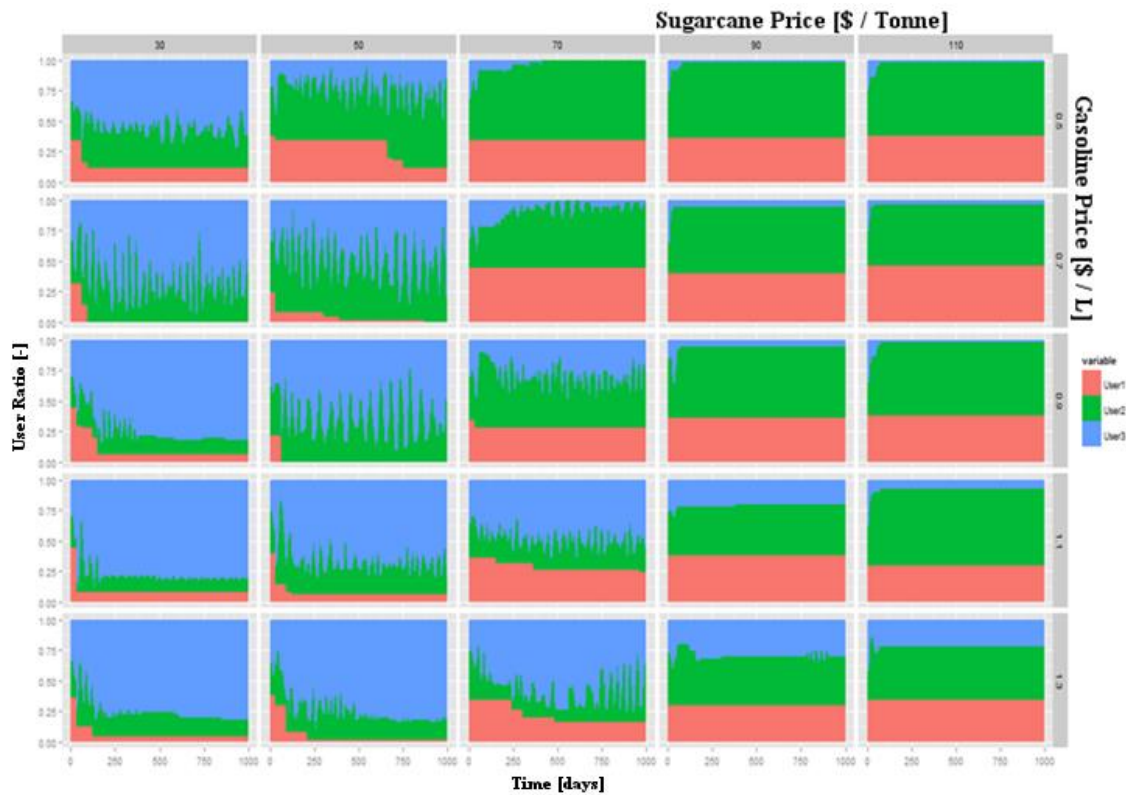


Figure 35: User Ratios as a function of Sugarcane Price and Gasoline Price

Pattern Visualisation, Identification and Discussion: Production Ratios

- i. Figure 35 shows that the increase in sugarcane price significantly affects the ethanol fuel market; hydrous users switch en masse towards gasohol use. At prices around the baseline level for sugarcane ($56.11 \text{ \$ / Tonne}$) and lower, the system displays the typical flex fuel characteristics of ambiguous ratios of hydrous flex users versus gasohol flex users.
- ii. The change in gasoline prices does not affect the system as much as the change in sugarcane prices does. This demonstrates how influential the sugarcane (and also sugar) price is within the bio-ethanol market.
- iii. A leading conclusion is that the cost of feedstock is what dictates market behaviour over the actual behaviour of gasoline prices.
- iv. The relative constant level of regular gasohol users (user type 1) indicates that the price changes are not large enough to tip these users over into buying a flex fuel vehicle (threshold has not been reached). The tipping point for the above situation is very abrupt, indicating that the model of the regular car users is relatively uniform in terms of switching preference towards flex vehicles.

Experiment Conclusion

Experiment B follows the conclusions of experiment A closely. The main difference being that the sugarcane price dominates the system behaviour especially in comparison to the influence of the sugar price. The fact that the price of sugarcane is also a highly volatile, implies that the Brazilian bio-ethanol market and fuel market are heavily determined by the availability of sugarcane. This is in line with expectation; crude resources determine most of the prices of derived products (*IATA Fuel, 2013*). An important element however, is that the price setting of sugarcane in the real-world (Brazilian system) occurs after the determination of sugarcane derived products. As such, it can be expected that price dynamics regarding the sugarcane market will be delayed compared to the fuel and sugar market.

In terms of the impact of a different level of sugarcane price and gasoline the price on the production ratios, user demand ratios and price difference between the fuels the following can be said;

1. A high sugarcane price correlates to an increase in sugar production, with low gasoline prices.
2. High gasoline prices increases the production of ethanol (hydrous).
3. A tipping point exists for sugarcane price, indicating a large influence on fuel market (see 4).
4. A sufficient increase in sugarcane price tips the fuel market towards anhydrous demand.
5. Low sugarcane prices leads to high market volatility in both fuel price terms and demand terms.

A comparison of the above statements with real-world data is given later in this section.

Experiment C: Market Flexibility

Figure 36 shows the Price Difference between Gasohol and Hydrous fuel as a function of time for four different scenarios. The top left plot being the non-flexible refinery and non-flex user scenario. The top right plot being the flexible refinery and non-flex user scenario. The bottom left being the non-flexible refinery and flex-user scenario and the bottom right plot being the flexible refinery and flex user scenario.

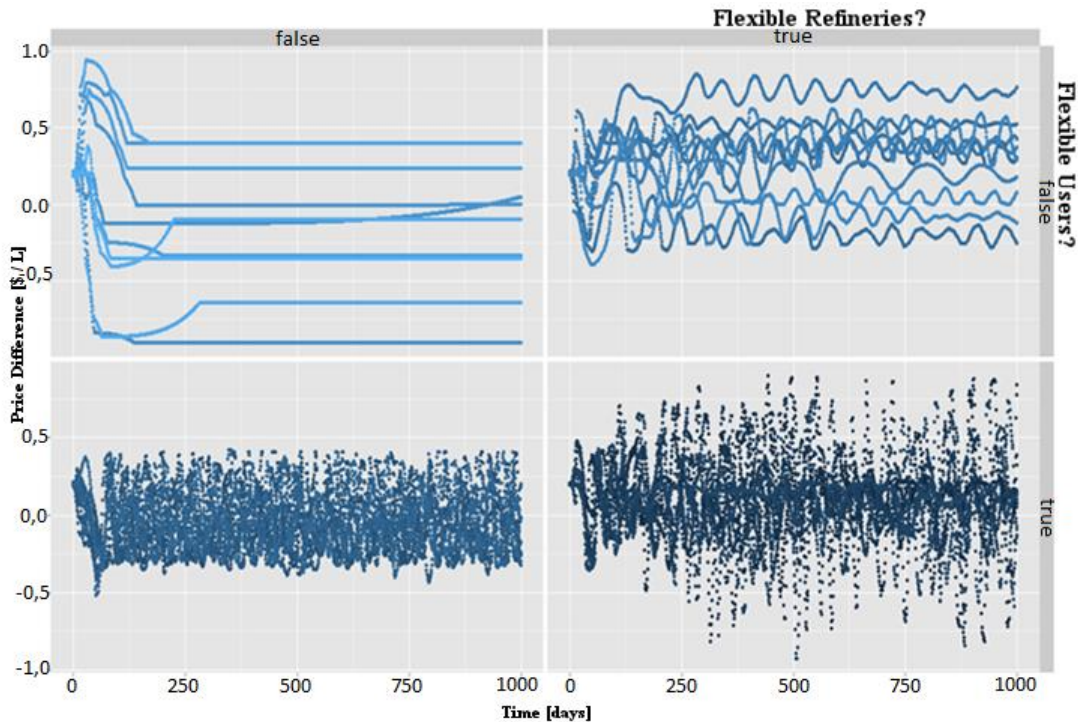


Figure 36: Price Difference of Gasohol and hydrous fuel as a function of Flexibility in the Market

Pattern Visualisation, Identification and Discussion: Price Difference

- i. A clear illustration is given of the effects that the flexibility of the system has on the system behaviour. The ability by refineries to be able to switch production ratios means that the price of hydrous fuel relative to gasohol, on average, is lower than when the refineries are not able to switch. This behaviour is evident through the observation of the top left and top right plots.
- ii. The ability by car users to switch fuel demand has less of an impact on the price levels; it primarily adds a level of price volatility to the market.
- iii. As previously discussed, the flexibility of the system is typified by the noise in the plots indicating “non-sticky” prices. Together with the distributor pricing mechanism this is the driver of the volatile prices.

Figure 37 shows the Total Profits made by the refineries as a function of time for four different scenarios. The top left plot being the non-flexible refinery and non-flex user scenario. The top right plot being the flexible refinery and non-flex user scenario. The bottom left being the non-flexible refinery and flex-user scenario and the bottom right plot being the flexible refinery and flex user scenario.

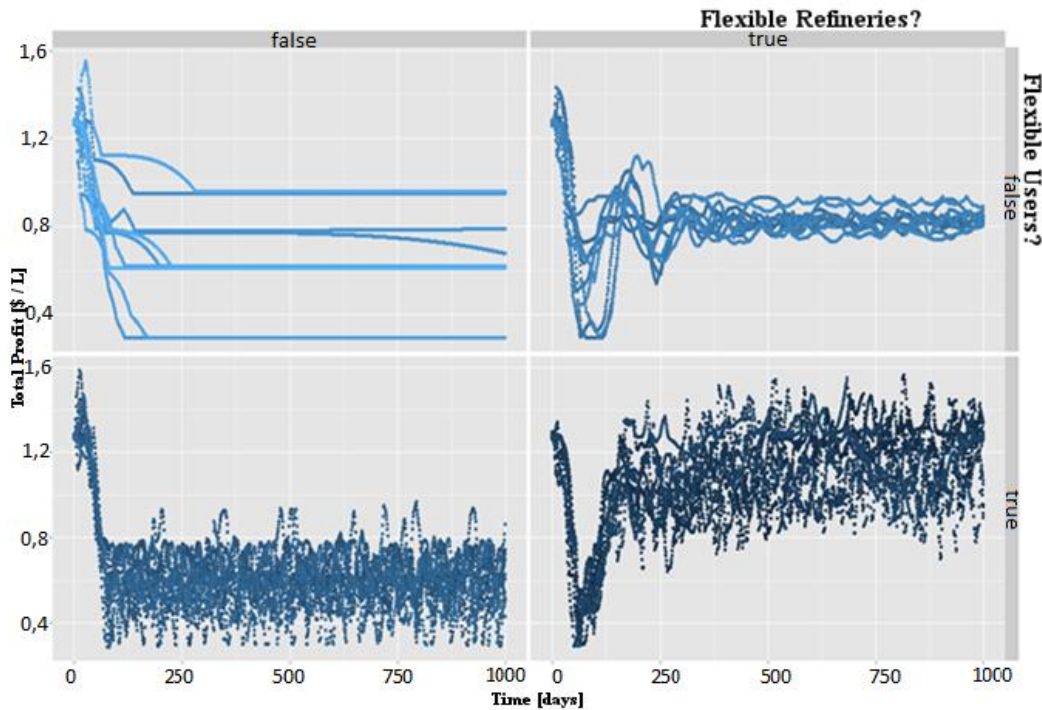


Figure 37: Total Profits by Refineries as a function of Flexibility in the Market

Pattern Visualisation, Identification and Discussion: Total Profits

- i. In addition to the Price Difference plots, the plots of the total profits made by refineries indicates that the flexibility of the system on average, benefits the refineries as well; the flexibility ensures that the profit range between refineries is relatively small which may be interpreted as a healthy market situation from external point of view. The non-flexible scenario implies that there is a possibility of the entire refinery sector making very low profits and thus increasing the likelihood of refineries having to close down. This in turn will impact the availability of ethanol and affect the user side of the system as well.
- ii. The initial dip made in the plots is related to the equilibrium mismatch of the initial demand and supply conditions which were previously discussed. An interesting feature in this region (*time 0 – 100*) of the plots is the small bandwidth within which the profits vary. This implies that the *change* in system states dominates the volatile tendency (which means that the behavioural shifts are indeed significant). Furthermore, an equilibrium state of the system causes the system noise to increase implying that the system moves towards a volatile state once equilibrium has been reached. In short, the equilibrium phase facilitates the volatile (internal) behaviour, while significant price level changes (external) cause the behaviour to be much more uniform with lower variations over time and between different simulation runs.

Experiment Conclusion

Experiment C clearly shows how the flexibility of the Brazilian bio-ethanol market creates a net benefit to the demand and supply side of the system. This justifies the government policy in Brazil of maintaining variable mandates, taxes and supporting the use of flex fuel vehicles. The results also indicate the importance of market flexibility in any biofuel market (or agricultural market for that matter) as the nature of the production of the base product (sugarcane) is inherently unpredictable due to sensitivity of the product to weather and technology developments. Also, even when either only the demand side or the supply side of the market can be flexible, a significant benefit is still shown for the total system.

It appears that the increase of competition between users for the cheapest fuel product, leads to higher profits for refineries. This may be explained by the fact that users demand more hydrous ethanol and as such demand more volumes from refineries than if they were to use a gasohol blend (which means a lower demand for ethanol).

In terms of the impact of a different level of flexibility in the bio-ethanol market on the price difference between gasohol and hydrous fuel and the total profits made by refineries following can be said;

1. Flexible refineries makes hydrous fuel more price competitive in relation to gasohol
2. Flexible users adds a volatility aspect to the price dynamics
3. Flexible refineries in combination with flexible users leads to the highest level of profit for refineries
4. Non-flexibility likely raises the risk of losses by refineries in the face of changing markets

5.4.4 Real World Data Comparison

A final aspect of the validation of the base model is to compare the results of the model output with actual real-world data; a “historic replay” (*Van Dam, Nikolic, & Lukszo, 2013*). This is not a straight forward matter as often it is difficult, and in some cases impossible, to determine whether real-world patterns are directly related to certain elements (*De Gorter, Drabik, Kliauga, & Timilsina, 2013*). For instance, the oil price clearly affects many other commodity prices but the actual degree to which this happens is unclear due to the many different factors which also are assumed to play a role. It is clear in the sugar and oil market that these two prices are in practice linked to each other, considering the large scale of oil demand and supply one may assume that sugar is affected by oil prices and not the other way around. However, in cases of weather disruptions and other external factors the sugar price may still behave independent of oil. Therefore in the comparison of the real-world data and the generated output by the base model it is assumed for simplicity’s sake that oil and sugar prices are at least to a certain degree independent of each other.

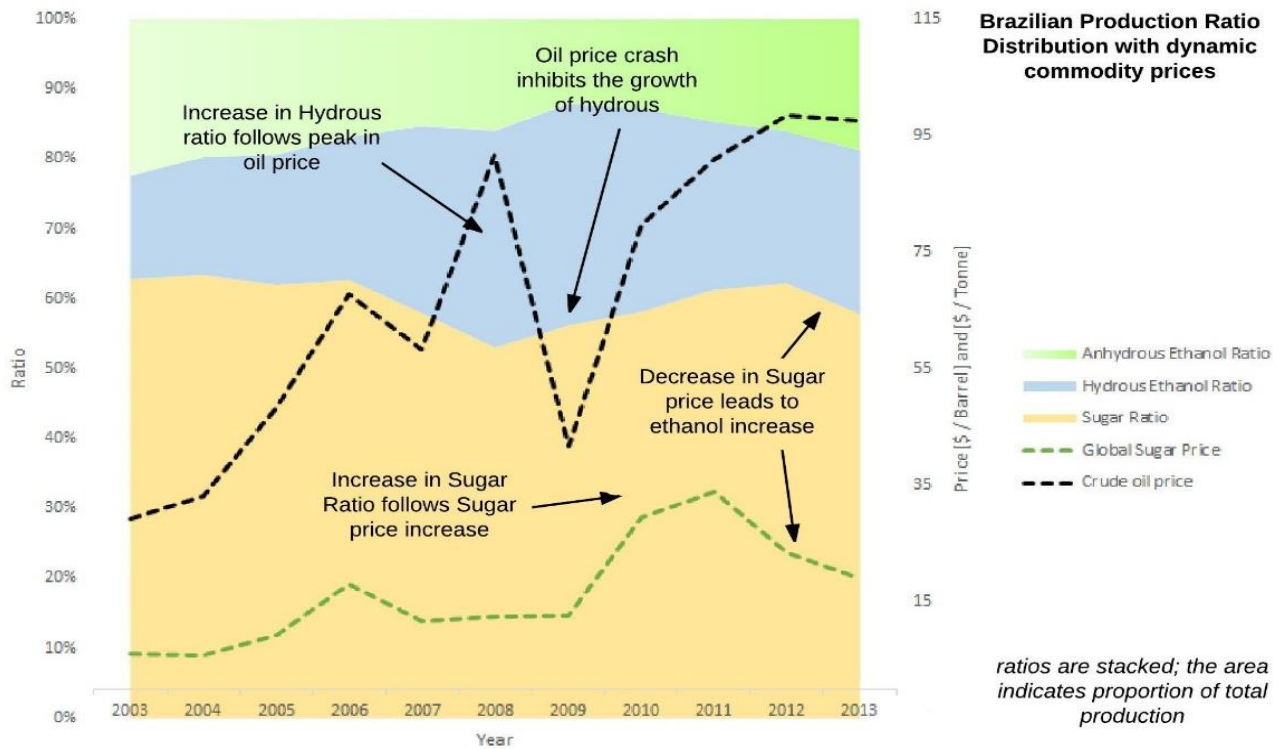


Figure 38: Historical Sugar Prices, Oil Prices and Production Ratios of Hydrous, Anhydrous Ethanol and Sugar from the Year 2003 – 2013 (UNICA, 2014).

Production Ratio Response to Commodity Prices

Figure 38 shows the historical price development of sugar and crude oil. As mentioned earlier, it is not possible to draw any definitive one-on-one conclusions regarding the interdependence of the prices and product ratio. However, it is interesting to note how the increase of sugar prices is followed by an increase in the production ratio of sugar. Furthermore, when the sugar price remains constant, it is seen how a sharp increase of oil price seems to be followed by an increase in hydrous ethanol production.

As was concluded in the exploration of the base model, it seems that sharp changes in prices of the commodities is leading in terms of production changes, this is also observed in the real-world data. The financial crisis of 2009, and the corresponding crash in oil price presents as an interesting opportunity to explore the bio-ethanol market reaction to extreme shocks in the system; the gradual decrease of ethanol following this event seems to indicate that indeed low gasoline prices leads to less demand and production of hydrous ethanol. All production ratio changes seem to occur after changes in commodity prices which indicates that producers react to these prices. This may justify the external assumption of these prices from the bio-ethanol system.

It is important to take note that Figure 38 and the observations which are made with regards to price and production development should be seen as indicative only; definitive conclusions cannot be made as the commodity prices are notoriously complex. This is also true for Figure 39 and the corresponding discussion which follows on the next page.

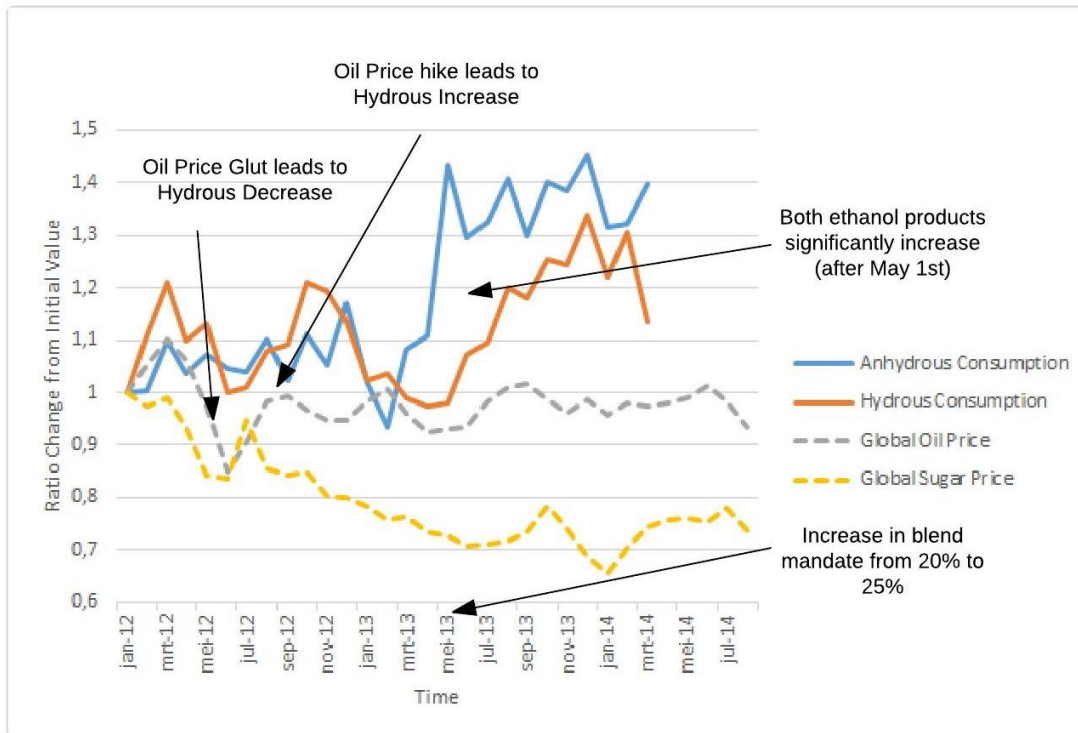


Figure 39: Historical Prices for Oil and Sugar and the Consumption of Hydrous and Anhydrous Ethanol. All plots show the deviation of the values as a ratio of the initial price/consumption level at January 2012 (UNICA, 2014).

Demand Ratio Response to Commodity Prices

From Figure 39 it is evident how the gradual decrease in global sugar price, is offset by an increase in consumption of ethanol. This is in line with the base model results; the low competition for sugarcane has made ethanol much more attractive for fuel users. The oil price, in the period under study was relatively stable as such, conclusions based on the oil price are difficult to draw from this set of data. However, at the beginning of the plots, the sharp decrease in oil price is followed by a sharp decrease in hydrous consumption. Again this may indicate that hydrous fuel is less attractive in relation to gasohol for flex users and this corresponds to the results of the base model.

At around the halfway mark of the plots, the demand for ethanol (both) is significantly increased. This is a direct consequence to a the change in governmental blending mandate for anhydrous ethanol with gasoline, as from 1st May 2013, the blend mandate was increased to 25% up from 20% (UNICA, 2014). Together with the low levels of sugar price, this explains the sudden increase in specifically the consumption of anhydrous ethanol which is obvious to the sudden shift in policy. The gradual increase in hydrous consumption further illustrates the increase and popularity of flex fuel vehicles in the face of relatively cheap sugar with respect to oil. This was observed in the base model results where a large portion of user *type 1* (regular gasohol) switched towards flex fuel vehicles.

5.5 Conclusions

The second research sub-question can be answered on the basis of this chapter.

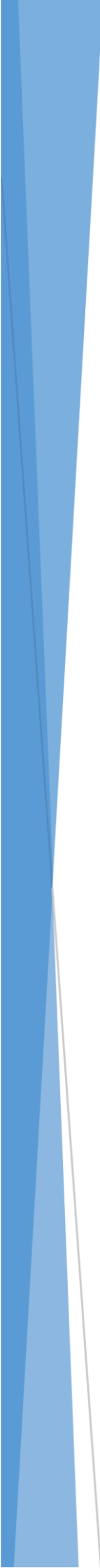
“How does the interaction between actors in the bio-ethanol market affect the aggregate behaviour of the market?”

A switch in demand by user actors, affects the price setting actions of distributor actors which in turn affects the actions of the refinery actors. This is an iterative and continuous process which results in highly volatile aggregate market behaviour.

Keeping external prices equal, the volatility remains within a stable bandwidth. However changes in external factors affect the final output of the aggregate behaviour caused by the actors. The actions of the actors cause the market behaviour to be characterized by large and frequent behavioural shifts in production and demand market parameters.

The presence of the interaction between producers and user agents benefits the hydrous using agents in terms of the price of hydrous fuel. Additionally, the interactions show a net benefit to refineries as these can react to the changing market conditions as opposed to a situation of a no interactions and thus no reactions to changing market conditions leading to a loss of income.

In the face of volatile external factors, the flexible nature of the internal system clearly shows a benefit to the system in terms of biofuel use.



Chapter 6

The BioJet Model

In this chapter:

- 6.1 BioJet Assumptions
- 6.2 BioJet System Decomposition
- 6.3 BioJet Concept Formalisation
- 6.4 BioJet Model Formalisation
- 6.5 Implementing the BioJet Model
- 6.6 BioJet Model Verification
- 6.7 Conclusions

6.1 BioJet Assumptions

The goal of this research is to be able to explore and investigate what measures may help to establish a biofuel supply chain in the aviation industry. With the Brazilian bio-ethanol model complete it is possible to implement an aviation and kerosene aspect in the model. In order to fully understand the implications of an aviation element in the BioJet model, it is important to take note of the major assumptions which are made and the justifications for making the assumptions.

Technical Capacity:

It is assumed that biokerosene production can be achieved from anhydrous ethanol. It is assumed that the ethanol to biokerosene pathway adds an extra chain (after the anhydrous phase) to the ethanol pathway; an illustration of this is shown in Figure 40.

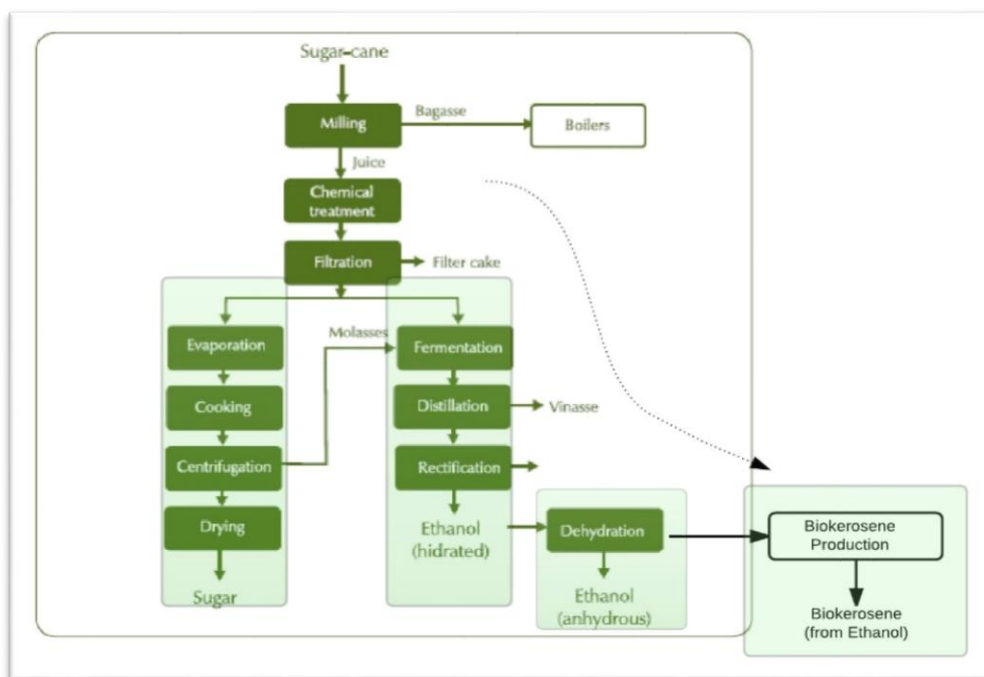


Figure 40: Proposed Ethanol based Biokerosene Production Chain, adapted from (BNDES & CGEE, 2008)

The first commercial tests have been conducted in Brazil on ethanol based kerosene which is sourced from ethanol. In addition to this, in Europe the first ethanol commercial flights have been undertaken (*Lufthansa Group, 2014*). However, it is not extensively known what the production costs are and how the engine performance relates to that of regular kerosene fuel. The production costs of most biokerosene products up until today have largely not been disclosed; however the main assumption within the field is that the overall price of biokerosene will consist primarily of the raw feedstock costs

once production of biokerosene has matured; which is not yet the case (*Boeing, Embraer, FAPESP, & UNICAMP, 2013*).

In the field of ethanol production, new developments are taking place, such as the commercial upscaling of cellulosic ethanol. However, in terms of the previously mentioned assumptions, it is not believed that a change in the ethanol pathway will mean a difference to the overall production cost in relation to regular ethanol and biokerosene. This is based on the assumption that biokerosene production is inherently more complex than regular ethanol production, the fact that biokerosene production will require an additional process step remains. The complexity of the biokerosene fuel arises from the energy density and fuel properties requirements (see Appendix B).

All in all, the energy equivalent unit of biokerosene from a sugar based feedstock will always be more expensive than the conversion of the biomass into relatively simple hydrous and anhydrous ethanol. This assumption is justified as any biokerosene product will require the addition of hydrocarbon chains which will incur extra costs (*IATA Fuel, 2014*). Also the energy density requirement of biokerosene (energy equivalence with current kerosene is required) will mean that more unit of biomass is necessary to provide for the additional energy in biokerosene versus regular biofuel based fuels.

The former aspects lead to the following assumptions for the implementation of the BioJet model;

1. *Biokerosene production cost (before commercial upscaling)*
 >
 Biokerosene production cost (after commercial upscaling)
 >
 Anhydrous production cost
 >
 Hydrous production cost
2. *Biokerosene energy density = Kerosene energy density*
3. *Unit Feedstock required per Unit of Biokerosene*
 >
 Unit Feedstock required per Unit of regular Ethanol

Kerosene Infrastructure Compatibility:

Any realistic implementation of large scale biokerosene use will require it to be able to make use of regular kerosene infrastructure, see Figure 41. This assumption is validated when one considers the large costs which have been incurred with biokerosene usage at airports using separate fuelling facilities (*SkyNRG, 2014*). Indeed, the recent tests carried out by SkyNRG in supplying KLM (*Royal Dutch Airlines*) with used cooking oil learned that much of the costs are due to the distribution costs of the kerosene; the biokerosene used could not be mixed with regular kerosene fuel supply due to different certification

requirements (SkyNRG, 2014). Also, considering the relative small volume of biokerosene used in comparison with regular kerosene any separate infrastructure facilities from the existing situation will incur higher costs to the biokerosene, which is already at a cost disadvantage (IATA Fuel, 2014). Also the logistic difficulties of having to manage a separate biokerosene stream (different storage tanks, trucks and pipelines) will significantly inhibit the potential to upscale the use of biokerosene at airports; particularly at large hubs (Lufthansa Group, 2014).

At the moment it is unknown from a technical point of view whether the ethanol derived biokerosene damages (corrosion) pipelines and other infrastructural elements. The first ethanol pipelines have been put into operation in Brazil and there have been no reports of any issues in this regard (ANFAVEA, 2013). However, the strict requirements which are imposed on kerosene infrastructure mean that any new fuel making use of this pipeline infrastructure will need to be approved through an extensive testing scheme. Also, the separation of different fuels through a pipeline is difficult and this is very expensive; this imposes another requirement on biokerosene in that it must be able to mix with the regular kerosene without the need for having to keep track of the stream through the logistic processes. This means that it must be accepted by all parties at the airport side, that there is a possibility of the presence of biokerosene in the fuel being used. A cost competitive scenario is that of the possibility of feeding in biokerosene at the beginning of the kerosene supply chain.



Figure 41: Feed in of Biokerosene in Existing Kerosene Infrastructure, adapted from (Defensie, 2014)

A significant advantage of kerosene use is that the distribution cost per unit of fuel is much lower than that for automobile distribution. This is largely due to the centralized nature of airport fuel distribution and the subsequent high volume infrastructure facilities which follow from that. This aspect presents biokerosene with a significant opportunity in comparison with regular biofuels for road transportation assuming that it can be used in existing kerosene infrastructure. If one considers the typical fuel distribution network one can clearly see the potential benefits of the centralized distribution network versus the scattered network of the automobile fuel supply chain, see Figure 42.

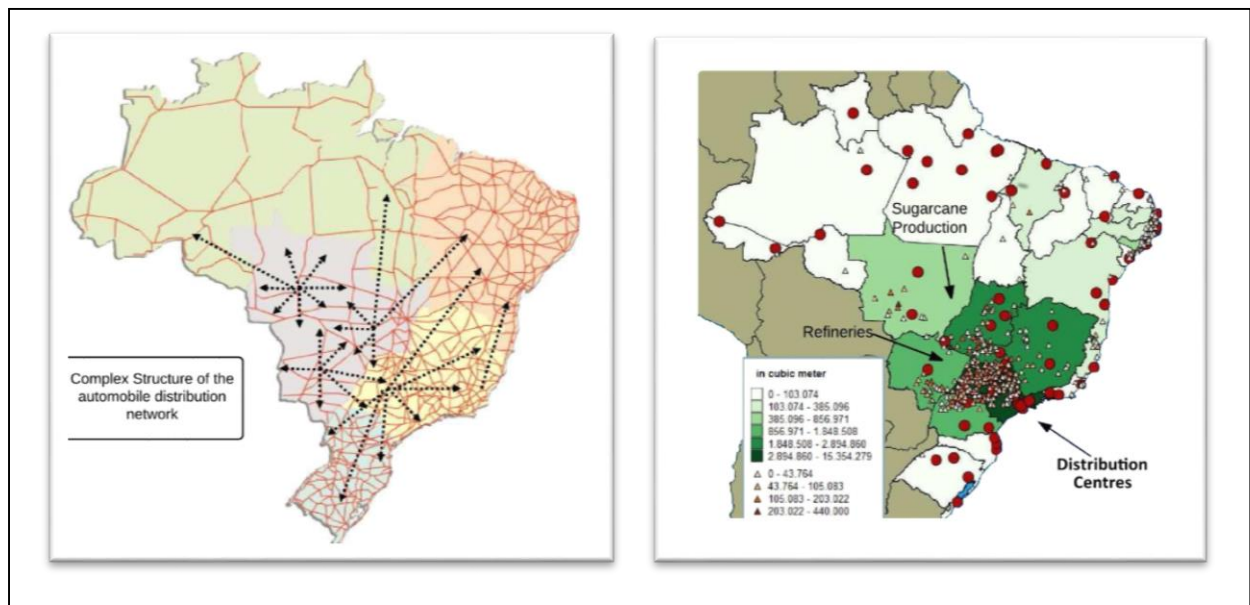


Figure 42: Illustration of the Decentralized Car Fuel Distribution in Brazil with the Complex Network Structure which is typical of a road-based supply chain network. Adapted from Petrobras, 2014.

The former discussed aspects lead to the following assumptions in regards to (bio) kerosene infrastructure compatibility;

4. *Logistic Cost of Biokerosene = Logistic Cost of Kerosene*
5. *Logistic Cost of Biokerosene < Logistic Cost of regular Ethanol*

Kerosene Market:

The kerosene market in Brazil is considered to be external to the base model; that is, changes in demand and supply for kerosene, do not affect the price of the kerosene. This is a reasonable assumption as is the case in the base model, the oil market clearly is not influenced by the Brazilian market due to it being a global market (*Energy Charter Secretariat, 2007*). The prices of kerosene are relatively uniform

around the world. Variations in the price are almost entirely determined on an infrastructure and geographic basis than on market forces (see Appendix B). It is also important to realize (as was previously explained) that the kerosene market runs on low profit margins; in many instances a loss is made by refiners (*Energy Charter Secretariat, 2007*). This is inherently due to the fact that kerosene in most cases is a refining by-product of crude oil; this is in stark contrast to biokerosene which is a premium bio-product under technical pathways which are currently available (*Carriquiry, Du, & Timilsina, 2011*). The former justifies the assumption that the kerosene market prices are not affected by a relatively small volume of biokerosene supply and demand as kerosene prices are fixed to crude oil prices.

6. *Kerosene Price* $\neq f(\text{Biokerosene Production, Demand})$

7. *Kerosene Price, Gasoline Price* $= f(\text{Crude Oil Price})$

Aviation Demand:

In light of the scope of this research and the underlying reason for researching the problem of biokerosene implementation, it is assumed that the aviation demand for biokerosene drives the increase in biokerosene production. Furthermore, the aviation demand element in the model is assumed to be willing to and able to pay the premium which is required for biokerosene over regular kerosene. This assumption is in line with the many off-take agreements which have been made between airlines and biokerosene producers which guarantees the producer a market to which it can supply (*SkyNRG, 2014; Lufthansa Group, 2014; EC, 2013*). The willingness to pay the premium however does not follow from a real-world assumption, however as the model is intended to gain an insight into *how and when* a biokerosene supply chain arises, the assumption is necessary. The result of the model output should be able to show a user what conditions (including which premium is required) are necessary to facilitate the biokerosene production from a market perspective.

8. *Biokerosene Demand* $\neq f(\text{Biokerosene Price})$

9. *Biokerosene Demand* $\geq \text{Biokerosene Production}$

Technological Learning:

An overriding assumption in the field of biokerosene production and use is that an increase in volume of biokerosene (upscaling) will lead to a lower cost of the fuel. The reduction in the cost of production as a function of increasing volumes is proposed to come predominantly from (*Junginger, Faaij, Poot, Van den Wall Bake, & Walter, 2009*);

- i. Economies of scale, an increase in volume with a fixed operating cost inherently leads to lower costs per unit of production

- ii. Experience Curve, increases in the cumulative production of a product leads to a better understanding (learning) of the production processes which can lead to improvement in process efficiencies. This in turn leads to a lower production cost.

Assuming that these propositions can be applied to the production of ethanol based biokerosene, the following assumptions are made in the model. Furthermore, it is assumed that the production of regular ethanol is fully matured and therefore no technology learning is present.

10. *Current Biokerosene Production Cost < Previous Biokerosene Production Cost*

11. *Current Ethanol Production Cost = Previous Ethanol Production Cost*

6.2 BioJet System Decomposition

For the implementation of the aviation and biokerosene aspects in the original base model system decomposition, it is necessary to identify the new proposed system elements. It is important to note that the BioJet model is an add-on to the base model and as such the system decomposition should be treated in this way. For a further understanding of complete system, one is referred to the base model system decomposition.

Biorefineries (Agent)

Biorefineries are refineries that are exactly the same as the refinery agents except that they are able to produce biokerosene. The biokerosene that is produced is supplied to the kerosene market. As the biorefinery is in essence a copy of refineries it is possible to identify when the producer market of ethanol products decides to produce biokerosene.

The production price (internal price) of biokerosene is defined in the same way as regular ethanol. However, based on the assumption that biokerosene is inherently more expensive to process and that more feedstock is required to produce the same amount of fuel, the following definition for the internal biokerosene price is given.

$$I_B = \frac{(P_{SC} + C_B)}{Y_B} \quad (18)$$

Where I_B is the internal price of biokerosene (measured in \$ / L), Y_B is the yield of biokerosene (measured in L / Tonne) and C_B is the processing cost of biokerosene (measured in \$ / Tonne). The processing cost of biokerosene is composed of two parts; the first being the minimum achievable cost of processing sugarcane to biokerosene (technology learning has been completed fully). The second part is related to the processing cost due to the degree in which maturation of the production of biokerosene still needs to be done. An increase in production volumes will reduce this aspect eventually to zero; implying a maximum learning has been reached and the production cost is at a minimum.

$$C_B = \min C_B + \text{Prod}_{curve} \quad (19)$$

Where $\min C_B$ is the minimum biokerosene processing cost, and Prod_{curve} is the production curve value measured in (\$ / Tonne). The manner in which the production curve behaves as a function of production volumes is assumed to follow a typical experience curve pattern, a common function to use is Henderson's Law (Junginger, Lako, Lensink, van Sark, & Weiss, 2008).

$$\text{Prod}_{curve} = \text{initialProd}_{curve} \times \text{Prod}_{total}^{\text{TechLearning}} \quad (20)$$

Where $\text{initialProd}_{curve}$ is the production curve at the start of technology learning, Prod_{total} is the cumulative production of biokerosene (measured in Liters) and TechLearning

The technology learning parameter will be further discussed in the BioJet model formalisation section of this chapter. It is important to realize the uncertainty surrounding the technology learning assumption, it should be treated as a qualitative concept as opposed to a quantitative concept.

In the decision making regarding biokerosene production by the biorefineries, the same assumptions hold as with the refineries. The biorefineries are thus profit seeking agents; in terms of the decision making regarding the production ratios, there is an added choice in the ethanol based concept: *Biokerosene Ratio*, see Figure 43.

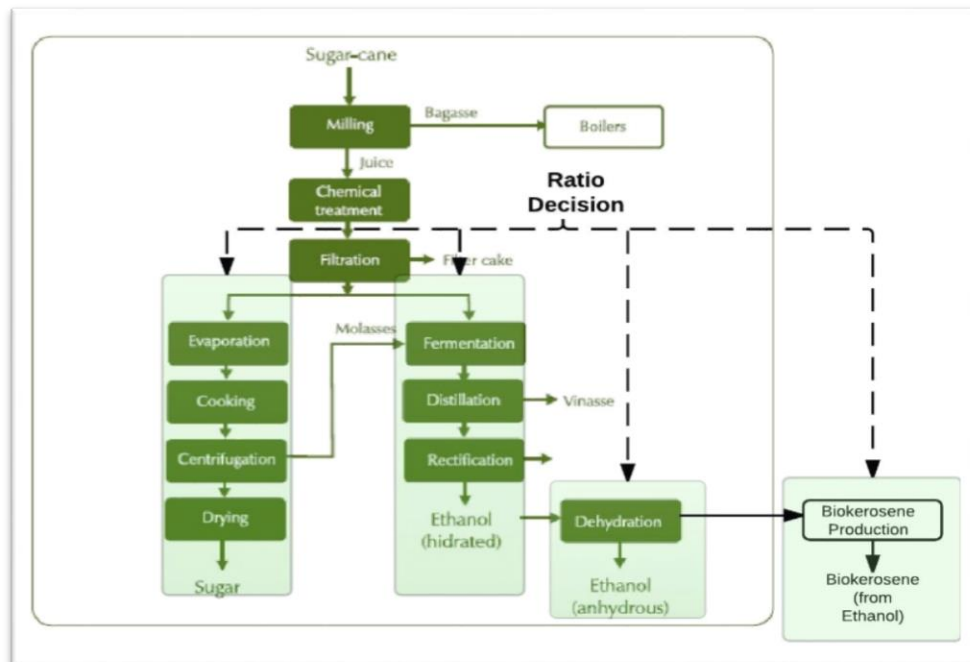


Figure 43: Production Ratio Decision Making for Biorefineries

Kerosene Centre (Agent)

Biorefineries do not supply biokerosene to regular distributors, the biokerosene is supplied to the so-called kerosene centre. The kerosene centre is the main collection and distribution point of all aviation fuel. It is assumed that there is only a single kerosene centre in light of the centralized kerosene network assumptions which have been made. In terms of differences with the regular distributor agents, the kerosene centre is responsible for supplying kerosene to the aviation sector. However, as there is no standard demand for biokerosene (no mandatory blend with biokerosene), the kerosene centre is not responsible for the supply and demand of biokerosene in that sense that it can influence the demand market through price setting. In the BioJet model, the assumption is made that the aviation sector will demand biokerosene in such a way that biokerosene production must follow. This inherently means that demand will always be larger than supply, in contrast to the situation in the car market where user dynamics create changes in the supply and demand gaps.

Biokerosene Margin:

The responsibility of the kerosene centre is to set biokerosene prices in such a way that biorefineries are incentivized to produce biokerosene. Therefore the kerosene centre has a margin setting function to ensure biokerosene production from biorefineries. It is assumed that the price premium (margin) does not affect the demand for biokerosene as was explained in the BioJet assumptions. The requirement to incentivize biokerosene production means that the biokerosene margin must be higher than the margins for hydrous and anhydrous ethanol. An illustration is shown of how the kerosene centre differs from the regular distributor agents.

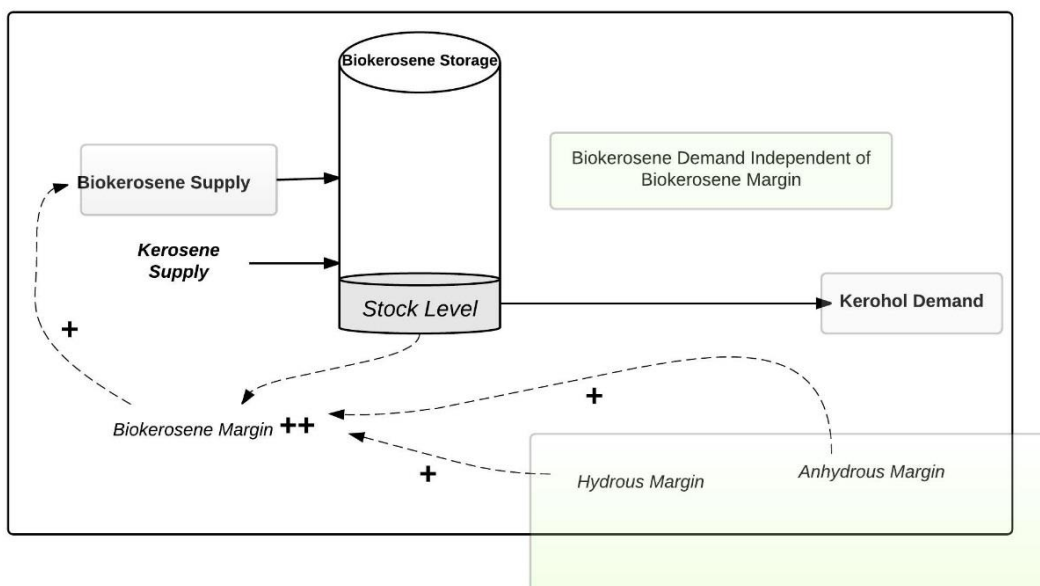


Figure 44: Biokerosene Margin Setting by Kerosene Centres

Airport (Object)

The airport is defined as an object; this indicates that it has no decision making capacity. It is the representation of the demand for biokerosene. From a real-world perspective it is composed of the different airlines which will consume biokerosene and kerosene as one group. This implies that biokerosene consumption is done by all airlines at an airport as opposed to a single airline or aircraft. This assumption is directly related to the assumption that biokerosene will make use of the existing kerosene infrastructure which means that differentiation of biokerosene use and kerosene use within the airport is not possible. The airport owns a constant kerosene energy equivalent demand; that is to say, the total amount of fuel demand does not change in spite of changes within the airport fuel demand composition (biokerosene and kerosene ratios).

Kerohol Demand and Kerohol Price:

In accordance with the current tests being carried using biokerosene, where airlines are making use of a biokerosene blend with regular fuel, it is assumed in the model that the fuel used by the aviation object is a blend of biokerosene and kerosene, from now on known as *kerohol*. Furthermore, as is the case with the automobile market, the price breakdown of kerohol will follow from the gasohol breakdown. As such the price of kerohol is proportionately composed of the price of kerosene and biokerosene. Furthermore, there is no tax on the aviation fuel, this is in line with the worldwide policy in the aviation which prevents taxing kerosene (*ICAO, 1944*). The latter aspect presents as a controversial agreement as it is argued by some that this implies a subsidy on aviation fuel in relation to other forms of energy (*IATA Fuel, 2014*). This latter assumption has implications on the model exploration which will be discussed later.

Demand Pull:

The airport acts specifically as a demand pull element in the fuel market. It can be argued that this is necessary assumption based on the fact that by definition, producers will not be incentivized to produce biokerosene unless they are moved to do so by demand. Therefore in the BioJet model, the actual demand for biokerosene (through kerohol demand) will be larger than biorefineries are able to produce, this implies an infinite demand. The demand for biokerosene will also not change unless specifically stated in an experiment in the BioJet model. This will be further discussed during the exploration of the BioJet model.

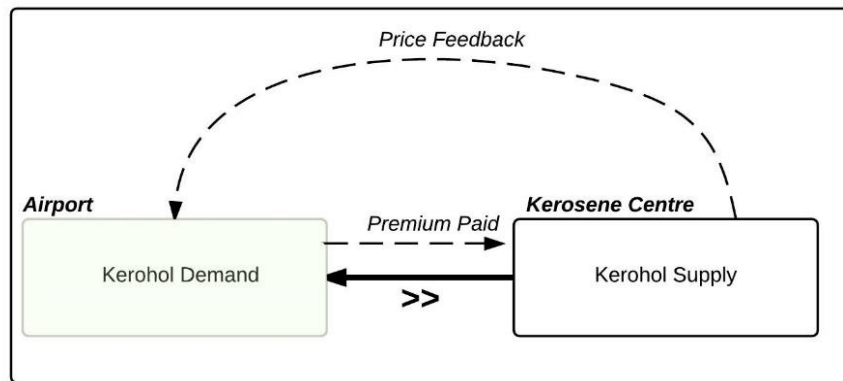


Figure 45: Demand Pull by the Airport Object in the BioJet System

The BioJet Environment

The environment of the base model system, is modified only by the addition of the external kerosene price. As discussed previously, this system element is independent of the other factors in the system. However, there is a clear relation between gasoline prices and kerosene prices (as both are determined by the crude oil price) and therefore in the experimentation of the BioJet system, these prices are linked to each other. This implies that a unit increase in gasoline price will also cause a unit increase in kerosene price. This latter aspect is important to realize as if this is not taken into account, significant market distortions may occur due to the unrealistic playing field (ATAG, 2009). The BioJet system does not include any tax elements or governmental policy elements in the baseline environment, however in the exploration of the model these may be experimented with. This will become clear in the exploration section of the BioJet model.

BioJet System Element Summary

The original bio-ethanol system has been expanded with the previously discussed BioJet proposed system elements. An illustration of how this changes the original system structure is shown in Figure 46.

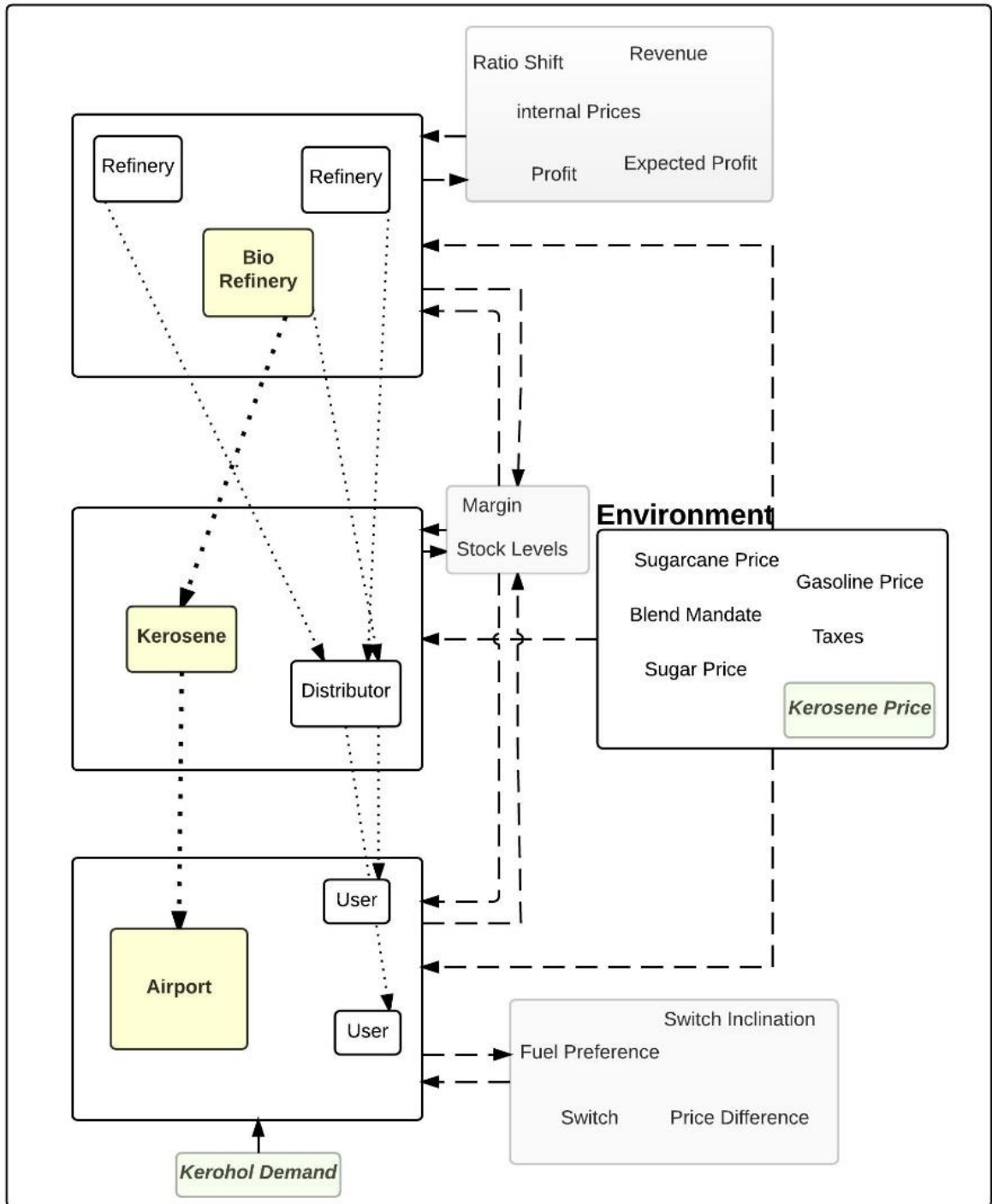


Figure 46: Representation of the System Elements and their Relationships in the BioJet Market Model

6.3 BioJet Concept Formalisation

As was the case in the base model of the bio-ethanol market, it is necessary to make a formalisation of the BioJet concepts in order for them to be incorporated in the Agent Based Model.

BioJet Data Structure

An overview of the BioJet concepts which are added to the base model and their corresponding primitive type is given in Table 8. A full description of all the variables used (in addition to the base model), their values and their unit is shown in Appendix F.

Table 8: BioJet Main Data Structure

Concept Variable	Data Type	Unit
Internal Biokerosene Price	double	[\$ / L]
Biokerosene Processing Cost	double	[\$ / Tonne]
Biokerosene Yield	double	[L / Tonne]
Production Curve	double	[\$ / Tonne]
Technological Learning	double	[-]
Biokerosene Margin	double	[\$ / L]
Kerohol Demand	double	[L]
Kerosene Price	double	[\$ / L]
Kerohol Price	double	[\$ / L]
Biokerosene Ratio	double	[-]

BioJet Ontology

The additions of the BioJet concepts to the original base model concept formalisation is nearly complete. The final step is to determine how these concepts fit into the existing base model ontology. An overview of how this is done is given in Figure 47.

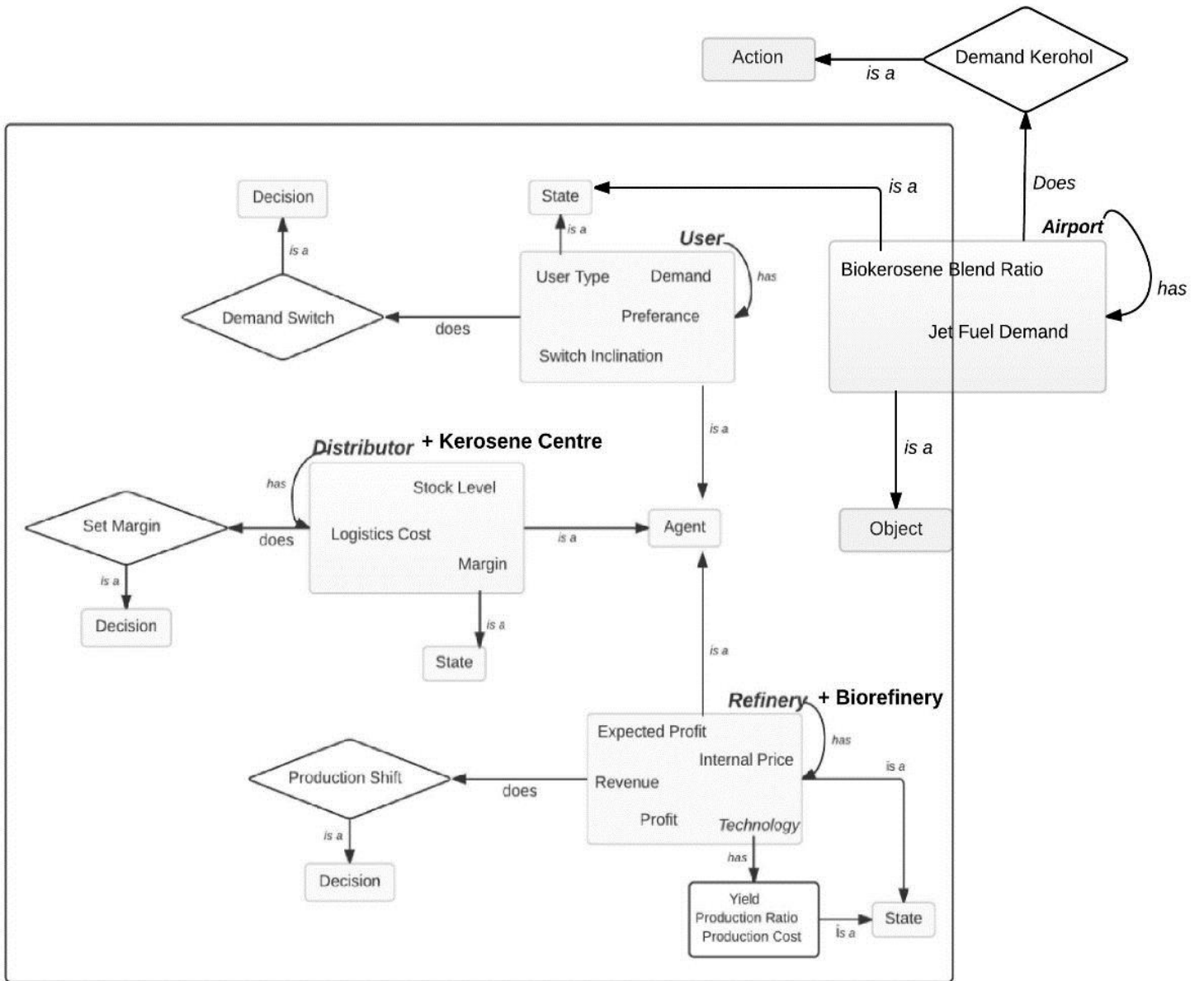


Figure 47: BioJet Adaptation to the System Ontology

6.4 BioJet Model Formalisation

BioJet Model Narrative

With the addition of the BioJet system elements, the model narrative is also extended. In essence, the base model will run unchanged, the only difference being that a biokerosene element also runs parallel to the original elements. The BioJet system elements do not affect the original base model narrative as the biokerosene market is assumed to be negligibly small to the existing sugar and ethanol markets. However, during the exploration of the BioJet model, it is possible to test the behaviour of the system in case of a widespread diffusion of biorefineries, this latter scenario will be further explained in the experimentation of the BioJet model. Unless specifically stated otherwise, it is assumed that the biorefineries remain small compared to the conventional bio-ethanol market.

A simplistic overview of the incorporation of the BioJet model with the base model is shown in Figure 48. This model narrative refers to the latter scenario of a relatively small scale biokerosene market.

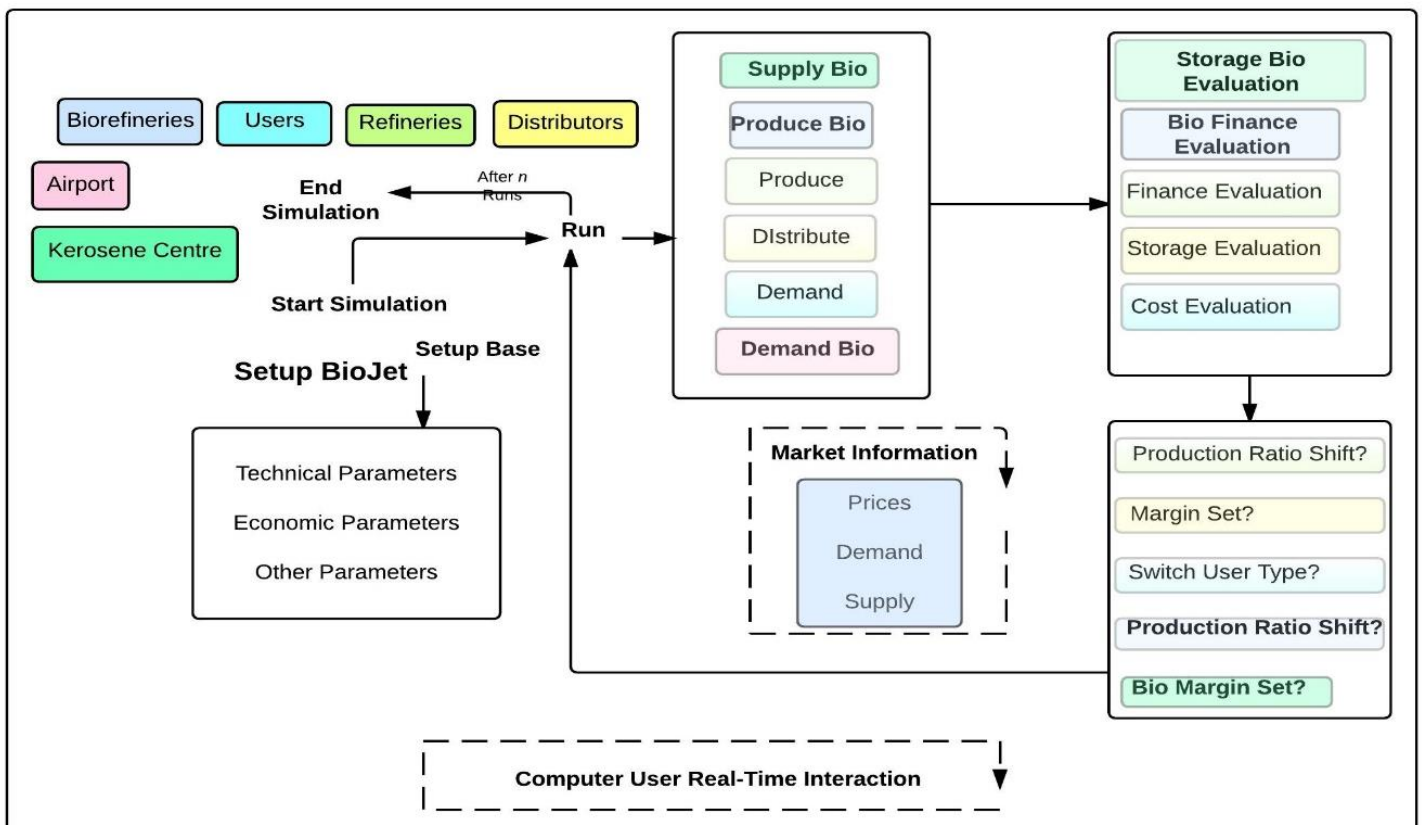


Figure 48: Model Narrative in Flow Chart Form of the BioJet Model Implementation

Pseudo Code

The adaptations to the algorithms in the model for the BioJet model are shown in Figure 49. As the BioJet model is designed in such a way that the core elements of the base model remain, there are no significant changes to the decision making by the agents in the model. The main additions are related to biokerosene production ratios at the biorefinery level, the bio margin setting at the kerosene centre level and the production curve mechanism. The technology learning element is adapted from Henderson's Law to accommodate the iterative nature of Agent Based Modelling. The parameters will be discussed in the model implementation section for the BioJet system.

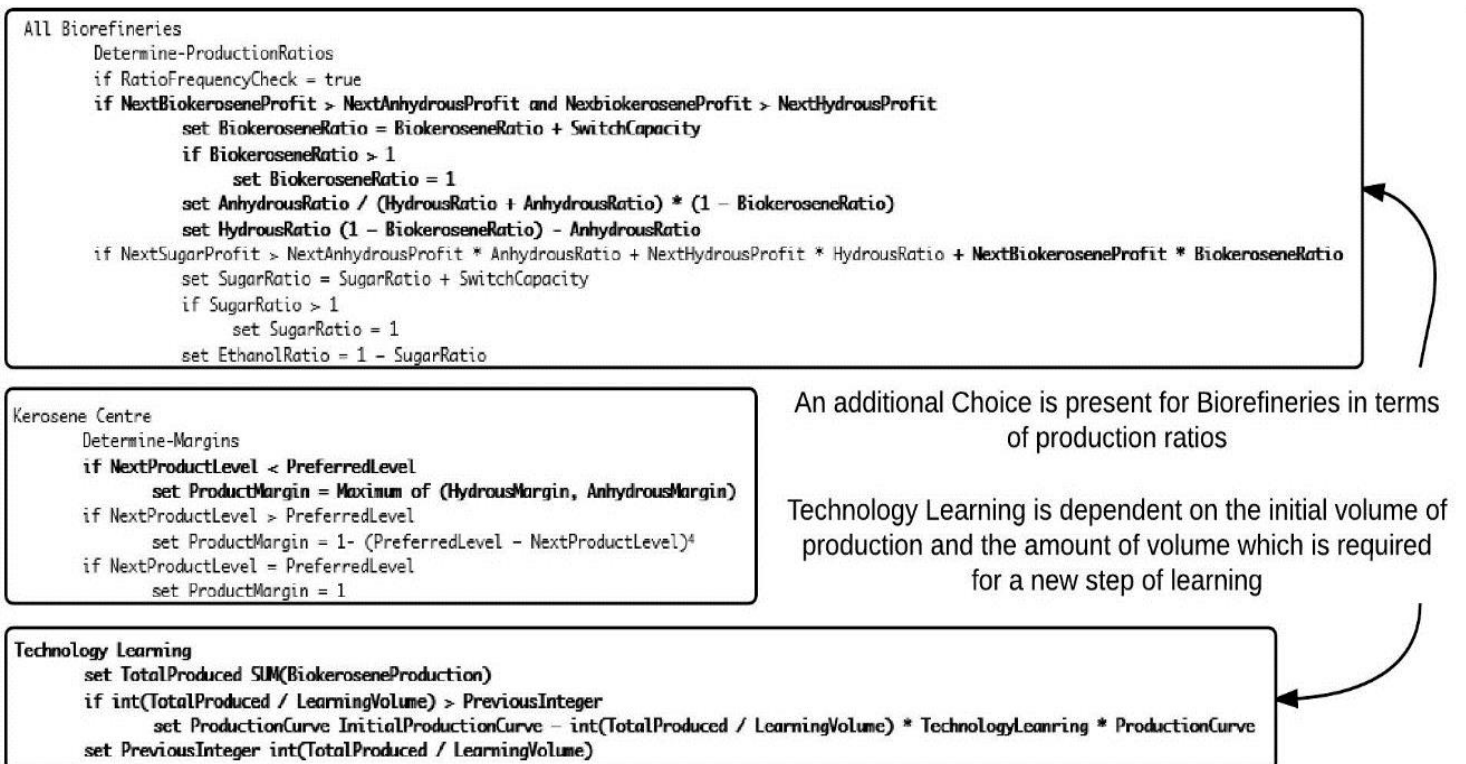


Figure 49: Pseudo Code of the Most Important BioJet System Element Additions to the Base Model

6.5 Implementing the BioJet Model

After the BioJet concepts have been formalised the implementation of the BioJet model can be done. In this section the implementation aspects are discussed; for a further understanding of NetLogo and its procedures as well as for a clear understanding of the core base model, one is referred to Chapter 5 (implementation of the Base Model in NetLogo).

6.5.1 NetLogo BioJet Model Elements

A full overview of the source code of the model (basemodel with BioJet model) can be found in Appendix K.

Agents

An addition to the model is the presence of two extra Agent *breeds*: Kerosene Centre and Biorefineries. Furthermore, another breed is used to represent the object, Airport. The logic behind the latter aspect is to be able to let the Airport agent be connected to the kerosene centre in the same way as that is the case for the users breed. This means that the kerosene centre can be modelled in the same manner as the regular distributor breeds from the base model.

Setup Procedure

NetLogo offers the user the possibility to create “*switches*” in the user interface. This means that it is possible to switch on (or off) a certain model setting. This greatly enhances the different scenarios under which the model can be used to do experiments, particularly when one wants the model to be used by non-modellers. In the base model this aspect has not been extensively discussed as it is not relevant due to the limit in the base model scenarios, but for the BioJet model this is an important element. The most important switches are discussed below. A full overview of the switches (and all other model interface elements) is shown in Appendix G.

BioPort Switch:

The BioPort switch is essentially the link between running the base model or the BioJet model. If this switch is turned on, the BioJet model will be run and all BioJet concepts are active. If it is switched off none of the BioJet elements are active.

Learning Switch:

The Learning switch activates the technology learning concept in the model. When this is switched off, no technology learning occurs and the biokerosene production costs are not reduced as a function of cumulative production.

BioPortDiffusion Switch:

The BioPortDiffusion switch refers to the model setting in which biorefineries can spread across the model; that is to say, refineries can opt to convert into becoming a biorefinery if the refinery agents

perceive (profit decision) that biorefineries are more profitable. This would imply that the bio-ethanol market, unlike in the original BioJet assumption, is strongly affected by the biokerosene market.

Note on the BioJet Setup

The setup procedure, when the BioPort is switched on, also assigns all BioJet parameters to the respective objects and breeds. The values of these parameters will be discussed in the variable input section later in this chapter. Furthermore, the setup procedure, unless specifically stated otherwise, ensures the setup of a single biorefinery agent. This is in line with the small scale biokerosene market assumption. The BioPortDiffusion scenario also entails the setup of a single biorefinery, but in this scenario all refineries are “free” to choose for themselves to become a biorefinery or not. The latter scenario is intended to gain an insight into how the bio-ethanol market may behave considering an extremely large biokerosene (or competing) market for the same production resource.

Go Procedure

The main procedures which are BioJet specific are discussed below. It is important to realize that the BioJet model runs within the base model setting; that is to say that the BioJet procedures run in parallel with the original base model procedures.

Demand Bio Fuel (Airport):

This procedure ensures that the airport object demands an amount of biokerosene. The procedure is very straightforward; the demand for kerohol is assumed constant. However, the procedure is critical in the BioJet model as it ensures that there is a pull towards the BioJet model for biokerosene production.

Biorefinery Finance and Market Reaction (Biorefineries):

The finance procedure works the same as for the refineries finance procedure. However, the internal price of biokerosene is not constant in the case of technology learning as the processing costs decrease. The choice between production ratios also does not change; the biorefinery will increase the ratio of the most profitable product. In the case of biorefineries, the agent has more choice than with the refinery agents.

Bio Fuel Negotiate (Kerosene Centre):

The negotiate procedure for the kerosene centre is in line with the procedure for distributor agents. However, there is one crucial difference in that sense that when the stock level of biokerosene drops below the preferred level, the margin for biokerosene is not determined based on an exponential function as is the case with the distributor agents. Due to the competitive nature of bio-ethanol market with the proposed biokerosene market, the margin for biokerosene is set in such a way that it is higher than the hydrous and anhydrous margins. This ensures that the BioJet system actively incentivizes biokerosene production, which is in line with the focus of the model.

Produce Biokerosene (Biorefineries):

The Produce Biokerosene procedure for biorefineries is the same as the procedure for the normal refineries. However, during the biokerosene procedure the biorefinery agent updates the processing costs of biokerosene. This latter aspect is due to the variable nature of the processing cost as a function of technology learning. The minimum processing costs will however always remain higher than the cost of anhydrous processing which is in line with the previously discussed assumptions in this regard.

To Convert (Refineries):

Depending on whether the BioPortDiffusion switch is turned on, refineries evaluate whether the achievable profit of biokerosene production is higher than for their current products. If the latter is the case refineries will convert into biorefineries. This latter aspect means that refineries add the technical possibility to produce biokerosene. The investment decision itself is basic; based on current profit potential the refinery will decide to convert or not. A more sophisticated investment decision making process, for instance through using the Net Present Value which takes into account future costs, is deemed to be beyond the scope of this model as the level of uncertainty (regarding quantitative aspects) in the BioJet model are such that higher level financial optimisation techniques are irrelevant. In case of a more quantitative approach with the model however, these methods will be necessary.

Production Learning (Environment):

The learning procedure evaluates the total amount of biokerosene production during a single iteration and saves this to a list (*cumulative production*). The sum of this list indicates the total biokerosene production since the start of the simulation, this total production affects the production curve which is gradually reduced to zero eventually. The speed at which this occurs will be a focus of the experimentation of the BioJet model exploration.

Supply Bio Fuel (Kerosene Centre):

The kerosene centre, based on the demand of kerohol and the stock level of biokerosene, will supply kerohol to the airport. The price of the kerohol is also determined which is directly proportional to the kerosene price and biokerosene price which itself is composed of the internal biokerosene price and the biokerosene margin. The supply of kerohol directly affects the stock level of biokerosene which itself affects the biokerosene margin setting which is modified during the *Bio Fuel Negotiate* procedure.

6.5.2 BioJet Model Variables and Inputs

As has been extensively discussed throughout the report, the BioJet system cannot be verified based on real-world data as the information surrounding many of the concepts introduced are either not publicly available or do not actually exist yet. However, as the scope of the BioJet model is to explore emerging behaviour, one is not interested in the actual quantitative output of the model but more interested in the qualitative aspects. Particularly the direction of the output (direction of parameter values) is of interest. In respect to the values used for the parameters in the BioJet model, the following section will provide an explanation of the most important values used and why these values are chosen. For a full overview of all BioJet parameters values which are used, one is referred to Appendix F.

Airport

Biokerosene Blend Ratio = 25 [%].

The biokerosene blend ratio can be chosen rather arbitrarily as it depends on the overall kerohol demand how much biokerosene demand this translates to. However, the ratio chosen does have implications on the premium paid by aviation for biofuel; a consumption of lower amounts of biokerosene spread out over the total fuel demand increases the likelihood that airlines are willing to pay the biofuel premium. Additionally, all flights which have been carried out with commercial airlines and biofuels have been conducted under a biofuel blend (*Lufthansa Group, 2014; SkyNRG, 2014*).

Total Kerohol Demand = 115,000 [L / Day].

The assumed demand by the aviation for a biokerosene blend in the BioJet setting is taken as the fuel demand of a single Boeing 747 per day (*note: the model runs in days*). As was made clear in the assumptions regarding kerohol demand, it is assumed that the demand is always at least as large or larger than the biokerosene production; the proposed biokerosene demand of in the order of a quarter (*note the blend ratio*) of the total kerosene demand for a wide-body airliners fits with current ambitions set out by airlines in terms of biofuel use. Again it is important to realize that the choice of the actual biokerosene demand only impacts the rate at which the biokerosene market will react, it will not affect the behavioural pattern.

Kerosene Centre

Maximum Biokerosene Capacity = 10 × Biokerosene Demand [L].

Margin Constant = 0.5 [-]

Preferred Stock Level = 0.5 [-].

As is the case with the distributor agents, the maximum capacity of the storage terminals is assumed to be large enough to contain 10 days' worth of the product in question. This number has been verified in the distributor agent section where it is shown that the actual size of the storage terminals does not have an impact on the pattern of the kerosene centre output. The same reasoning holds for the market power of the kerosene centres which is equal to the distributor agents ($= 0.5$) and the preferred stock level ($= 0.5$).

Biorefineries

Biokerosene Yield = 70 [L / Tonne].

The yield of biokerosene, meaning the amount of biokerosene which can be produced from a tonne of sugarcane, by definition is lower than that of anhydrous and hydrous ethanol (*on average 71 and 75 L / Tonne respectively*). However the degree of which this is lower is highly uncertain. The different yields for biokerosene will be a significant area of focus in the experimentation of the BioJet model. Furthermore, the processing cost for biokerosene is expected to be the main driver in terms of biokerosene production efficiency meaning that the yields obtained for biokerosene, relative to ethanol yields, is assumed to be of less importance. Nevertheless it is important to realize that the proposed parameter value is highly optimistic in the baseline case, indicating efficient conversion of plant sugars to fuel which may arise in the case of maturation of cellulosic ethanol.

Minimum Biokerosene Processing Cost = 1.5 [-].

The minimum biokerosene processing costs indicates the cost of biokerosene production assuming a total maturation of the biokerosene production process relative to conventional biofuels. The parameter value indicates the factor of which biokerosene processing is more expensive as anhydrous processing. This follows from the assumption that biokerosene production is by definition always more expensive than anhydrous processing due to the complex properties of biokerosene.

Environment

Initial Production Curve = 5 [-].

The initial Production Curve parameter indicates the factor of which biokerosene processing is assumed to be more expensive than anhydrous processing before any technology learning has taken place. The value again is arbitrarily chosen in that sense that it does not impact the BioJet system in terms of behaviour but only speeds up or slows down system output. It has often been cited however, that the

cost of biokerosene relative to kerosene is at the moment in the order of 3-6 times as expensive (ATAG, 2009).

Learning Volume = 1,000,000 [L].

The learning volume corresponds to the amount of biokerosene needed in order to achieve the technology learning effect (which is determined by the technology learning parameter). This parameter value is entirely uncertain and will be further dealt with during a sensitivity analysis of the technology learning element.

Technology Learning Parameter = 0.1 [-]

A technology learning parameter of 0.1 translates to a 10 percent decrease in the production cost of a product for every doubling of the learning volume. This feature will always be dealt with during the sensitivity analysis of the technology learning concept. The main assumed parameter values in the BioJet model are summarized in Table 9.

Table 9: Main Assumed Parameter Values in the BioJet Model

Parameter	Value	Unit	Description
Biokerosene Blend ratio	25	[%]	Kerohol : blend of biokerosene and kerosene
Kerohol Demand	115,000	[L / Day]	Biofuel demand for aviation per day, B747
Maximum Biokerosene Capacity	287,500	[L]	10 day demand equivalence of biokerosene storage
Preferred Stock Level of Biokerosene	0.5	[-]	Preferred Stock / Maximum Capacity
Biokerosene Yield	70	[L / Tonne]	Biokerosene Yield per Unit of sugarcane
Minimum Biokerosene Processing Cost	1.5	[-]	Processing cost ratio time anhydrous processing cost

Variable BioJet Parameters

The BioJet system operates in the same system setting as the base model, therefore the same variable parameters are present; sugarcane price, sugar price, gasoline price. Furthermore, as was stated in the assumptions of the kerosene market, the kerosene price is fixed relative to changes to the gasoline price (both oil products). Therefore, the experimentation of the BioJet model, changes made to either gasoline or kerosene will affect both prices. The base line value which is assumed for kerosene, is:

Kerosene Price: 1.00 \$ / L (Shell Aviation, 2014).

6.5.3 BioJet Model Interface and Output

For a full overview and description of the interface and output of the BioJet model (extended to the base model version), one is referred to Appendix G. The most important modifications to the base model are described below.

“World” NetLogo Visualisation of the BioJet Output

As was the case with the base model, a strong feature of the BioJet model is the visualisation of the different supply chain links in the bio-ethanol and biokerosene market. As an addition to the base model, the BioJet visualisation clearly shows an extension of the world with a visual representation of the airport, kerosene centres and biorefinery (biorefineries in the case of diffusion). Furthermore, it can be seen, through the visualisation of a green link between the different elements whether there is sufficient biokerosene supply to meet the set out kerohol demand in the model. An explanation of the visualisation is shown below, see Figure 51. It is stressed that the visualisation is mostly relevant for the testing of the model per run interactively by a human user in order to gain an understanding of the real-time impacts of different scenario changes.

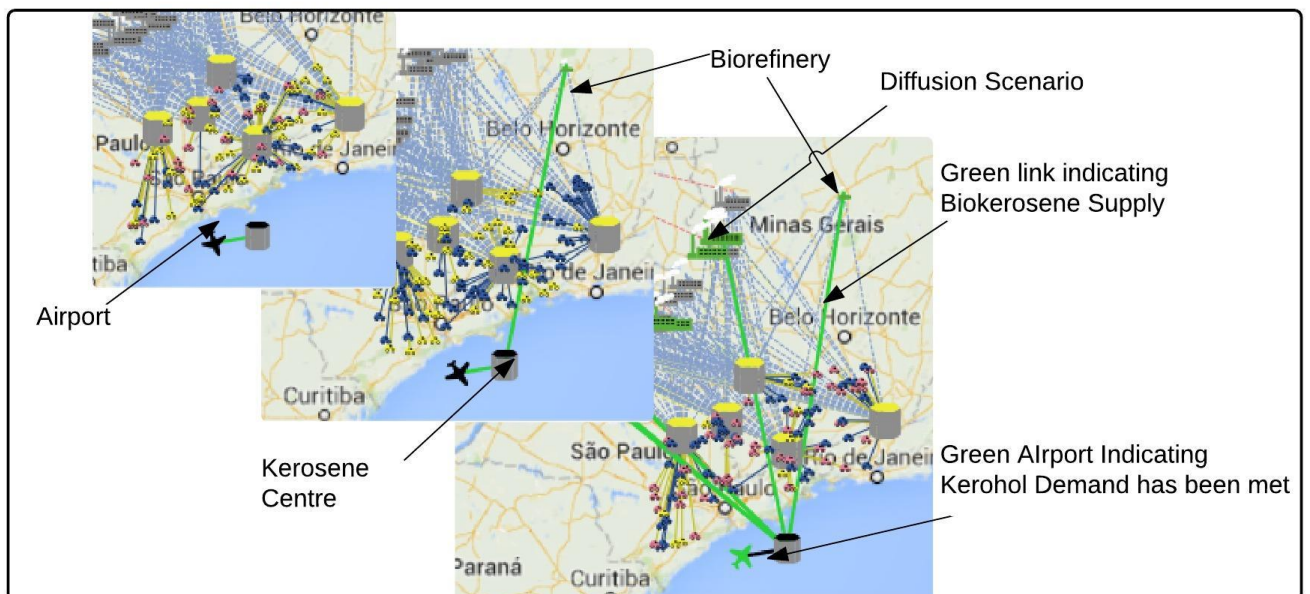


Figure 51: World Visualisation of the BioJet Model Supply Chain Concepts

Data Output of the BioJet Model

The data output which the BioJet model generates in addition to the existing base model data output is primarily related to the biokerosene production ratio of the biorefineries, the price development of kerosene and in the case of biorefinery diffusion, the amount of refineries which have decided to convert to biorefineries. A summary of the main output data which is of interest in the testing of the BioJet model is shown in Table 10.

Table 10: Overview of the System Output Parameters in the BioJet Model

Parameter (system indicator)	Unit	Description
Kerosene Price	[\$ / L]	Price of biokerosene and kerosene Blend
Biokerosene Production Ratio	[-]	Biokerosene Production / (Sugar + Hydrous Anhydrous + Biokerosene) Production
Biorefineries Ratio (Diffusion)	[-]	Number of biorefineries / (number of refineries + biorefineries)
Internal Biokerosene Price	[\$ / L]	Zero profit price of biokerosene at biorefinery level. This changes as function of tech. learning

BioJet Software Implementation Summary

The modifications of the BioJet system to the NetLogo bio-ethanol base model have been largely described. Where the base model was primarily focussed upon the modelling of the bio-ethanol markets, the BioJet model is a much more experimental based approach. This has been translated into the use of different scenario options, of which the most important have been described in the previous section. An overview, of all the different NetLogo possibilities in terms of the BioJet model use, is shown in Appendix G

Again it must be stressed that this aspect of the model is more relevant towards a user testing approach where a human being can interact with the model in real-time to gain an understanding of the system in an interactive way. In light of the research area of exploring the proposed BioJet system, the next sections of the thesis are focussed on the generated data of the model and as such the visualisation features of the model will be treated.

6.6 BioJet Model Verification

As has been done in the base model, before the exploration of the BioJet model it is necessary to verify that the constructed model has been properly incorporated into the existing base model.

6.6.1 Model Testing

Extreme Condition and Boundary Testing:

In these tests the boundaries within which the model is expected to be able to run correctly is checked; furthermore the limits to which the model can handle system inputs are tested. The tests are run specifically for the BioJet model elements.

Result

- i. For all values of biokerosene blend ratio (between 0 and 100) and kerohol demand, the model runs without a problem. However, as these parameters dictate the rate at which the model will behave in terms of biokerosene behaviour, it is important to note that, with the original run time of 1000 ticks, biokerosene demand in the order of less than 10,000 Litres a day does not show any biokerosene production as the this demand is simply too low from the biorefineries point of view. The same is true for very high levels of biokerosene demand, in this case the biokerosene production is nearly immediately visible which defeats the purpose of studying the model behaviour. As such, from this boundary tests it is concluded that the original base line values of a blend ratio of 25% and a kerohol demand of 115,000 Litres a day are fit for the purpose of the BioJet model.
- ii. In line with the previous discussion, the run time of 1000 ticks (days) is sufficient to study biokerosene behaviour. In the non-diffusion scenario the biokerosene production reaches its equilibrium before the end of the run. The parameter values used in the BioJet model do not affect the ability of the model to run, this makes sense as the core procedures in the BioJet adaptation are the same as in the base model.
- iii. It is important to note that the “switches” cannot be turned on or off during a simulation run, this will give a run time error as the switches are necessary to setup up the model correctly.
- iv. Changing of the prices during an iterative exploration (real-time testing) of the model is dealt with correctly by the model as long as it is made use of the “sliders” to change parameter values. This is visible in Appendix G. The use of sliders forces a human user to only change parameters values within a certain range. This makes it impossible for instance to change prices to negative (which the model can handle, but this makes absolute no sense compared to the real world). The airport demands kerohol even if there is no biokerosene production, it is therefore important to realize that demand is not equal to consumption when making model assumptions. This in line with the model formalisation.

Sanity Tests:

The initial behaviour which is shown by the base line values in the BioJet model is discussed below in terms of whether the behaviour makes sense from the model formalisation point of view.

Result:

- i. Under the non-diffusion scenario, the data output regarding the existing bio-ethanol market elements shows no change from the base model behaviour. This is indeed to be expected as the biorefinery sector is considered very small relative to bio-ethanol markets.
- ii. In the diffusion scenario however, it is clearly seen how an increase in the amount of biorefineries indeed affects the prices of the other sugarcane products. This indicates that the BioJet model correctly incorporates competition for the same sugarcane which leads to higher overall prices of all products; the competition for (and shortage of) sugarcane requires distributors to increase the market margins for all products.
- iii. The price of biokerosene is higher than for other sugarcane products, this is due to the emerging nature of the market; in order for the biokerosene production volumes to significantly increase a premium is unavoidable based on the assumption that biokerosene internal prices are always higher than for anhydrous ethanol. As such biorefineries will only increase biokerosene ratio based on a competitive (higher than) price.
- iv. The price of kerohol directly follows the price of anhydrous ethanol (in terms of the overall price levels). This indicates that the kerosene centres correctly implement a biokerosene margin which is set at just above the margin of anhydrous and hydrous ethanol. Note that the kerohol price is still significantly higher than regular kerosene price. These aspects are further illustrated in Figure 52.

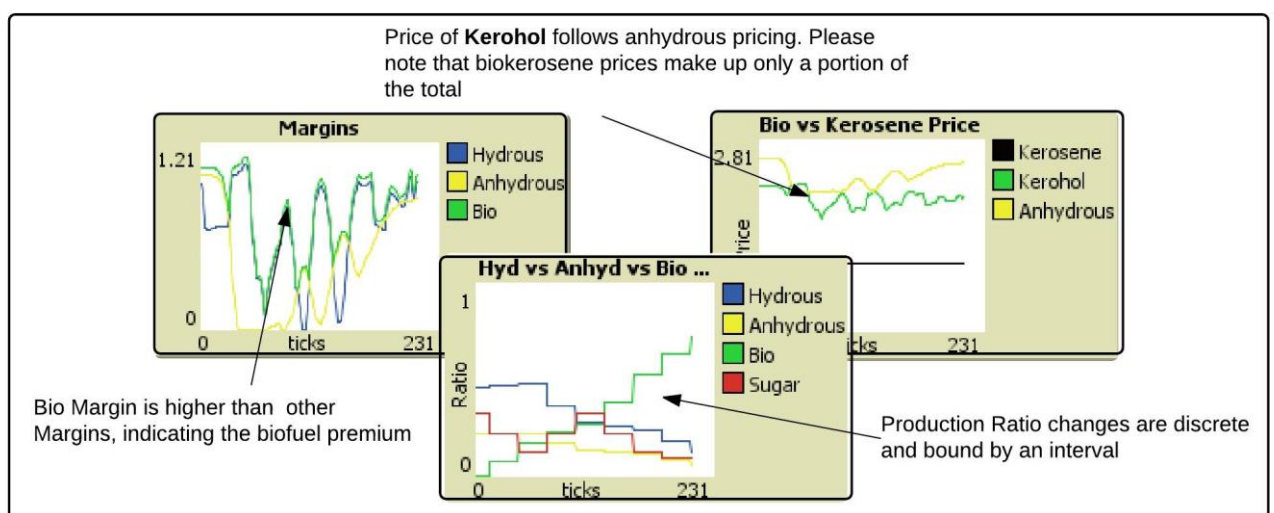


Figure 52: Biokerosene System Elements in the BioJet Model

6.6.2 Technological Learning Parameters and Biokerosene Yields

As has been stated earlier in the report, there is a high level of uncertainty regarding the parameter values chosen for the technology learning and biokerosene production aspects. As these concepts are not observed in the real-world yet, a test in the BioJet model is carried out to explore what the impact of the uncertainty of these parameters is to the global biokerosene behaviour. The design and execution of this test is explained in the following section.

Verification Experiment: Technology Learning and Economies of Scale

A significant assumption within the field of biokerosene production (and any biofuel production for that matter), is that an increase in production volumes will lead to a decrease in production prices per unit of production [ATAG, 2009]. This experiment will investigate this assumption, and its impact on the baseline BioJet system, using the best case and worst case scenario where the parameters used in this scenario are the following;

Best Case Scenario (lower bound):

Using a typical Progression Rate of 0.1 (Junginger et al, 2009), a learning volume of 1,000 litres is chosen which means that every 1,000 litres of biokerosene production decreases the unit price of this production by 0.1 (10 %) up until the hypothetical minimum biokerosene production cost of 1.5 times the cost of anhydrous ethanol production (Junginger et al, 2009; QANTAS, 2013). In addition to this, the starting point of the production curve is taken as a factor of 2.0 times the minimum biokerosene production cost. This means that the initial cost of biokerosene production is assumed to be twice to that of anhydrous production.

Worst Case Scenario (upper bound):

Again using a typical Progression Rate of 0.1 (Junginger et al, 2009), a learning volume of 10,000,000 litres is chosen. This is a very substantial amount of biokerosene production which implies a very slow experience effect on biokerosene production and the requirement of large scale production in order for any experience curve effects to take place. Additionally, in the worst case scenario the initial biokerosene production cost is a factor twenty times more than the cost of anhydrous ethanol production. This represents a scenario in which the initial production of biokerosene is extremely difficult and intensive. The numbers used in this scenario correspond to algae biofuel production (Junginger et al, 2009) which may provide as an interesting backdrop to the research due to the willingness by the aviation industry to use algae as a feedstock for biokerosene in the future (IATA, 2013; QANTAS, 2013).

The area of interest in this experiment is to see how the production cost of biokerosene may behave using these parameters. Also the impact in this has on the overall kerohol price is measured.

Figure 53 shows the cumulative production of biokerosene over time. Figure 54 shows the plot of the biokerosene production curve as function of time for different levels of learning volume and initial production costs. The different shades of blue represent the many different number of simulation runs (= 50). Baseline values are used (see Appendix F) with only a variation in technological learning parameter values.

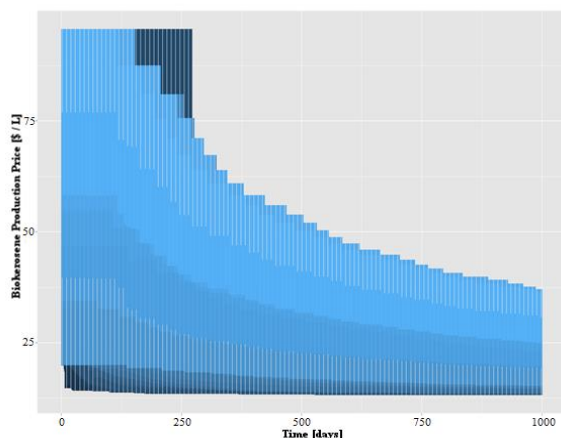


Figure 53: Cumulative Production of Biokerosene as a function of time for the Different Technology Learning Parameter values.

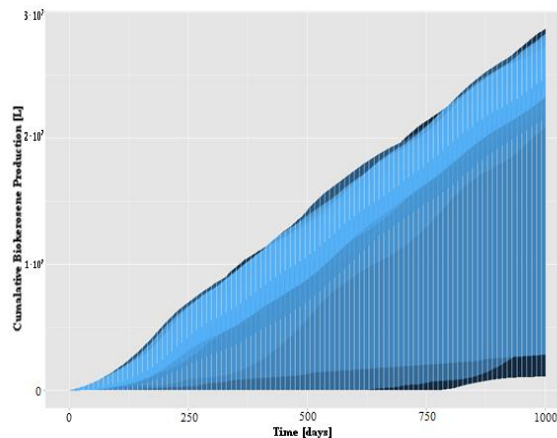


Figure 54: Biokerosene Processing Costs as a function of time for the different Technology Learning Parameter Values

Pattern Visualisation, Identification and Discussion: Biokerosene Production Costs

- i. The typical decreasing curve characteristics of the experience curve can be observed in the graph. This makes sense as this shape of the curve has been defined in the design of the model (Junginger et al, 2009). However, the speed at which the production costs decreases for different curve settings shows the level of uncertainty which surrounds the experience curve and economies of scale assumption made within the biokerosene and biofuel settings.
- ii. The mentioned best-case scenario seems highly unlikely as it implies an almost immediate optimization of the biokerosene production costs. The other parameter combinations however show much more realistic behaviour; indicating that the biokerosene system indeed exhibits technology learning behaviour, however the significance of this learning may be much smaller than generally assumed, this will become clear when considering the impact on the kerohol price.
- iii. The different ranges, as expected, do not structurally affect the behaviour of the biokerosene production output and the processing cost of biokerosene. Therefore it can be concluded that the choice of the technology learning parameters are not a driving system element in the decision making by the biorefineries to produce biokerosene. The time scope for the experiment of 1,000 days is very short in terms of the time that is usually required to experience a significant degree of technology learning (multiple years). However, as the rate of learning which has been implemented in these experiments is extremely high compared to normal, this more than compensates for the short duration of the simulations. Furthermore, one can observe in Figure 55 that a “completed” technology learning has a limited effect on overall kerohol prices.

Figure 55 shows the plot of the kerohol price over time for the many different levels of learning volume and initial production costs. The different shades of blue represent the many different number of simulation runs (=50). The upper bound corresponds to the worst case scenario and the lower bound corresponds to the best case scenario. Baseline values are used (see Appendix F) with only a variation in technology learning parameter values.

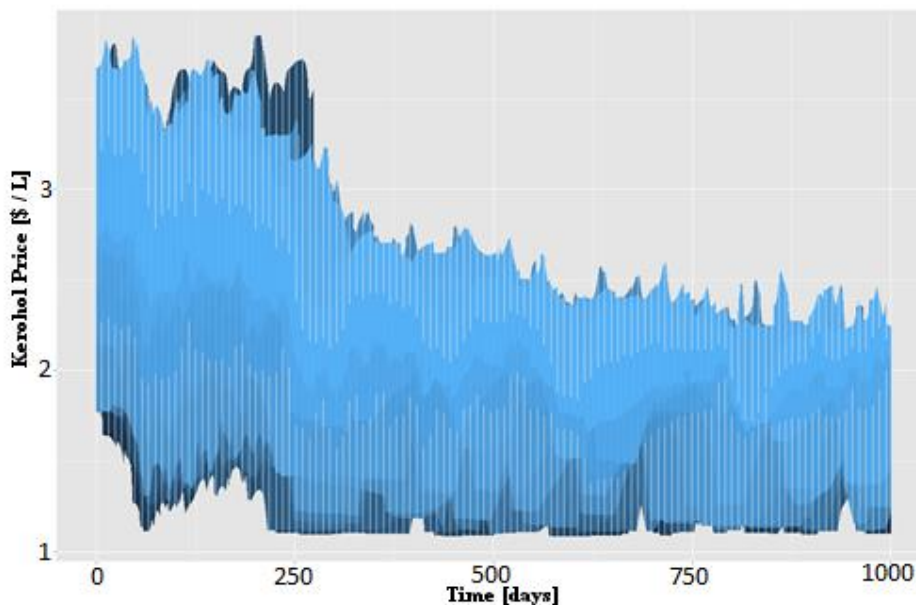


Figure 55: Kerohol Price over time as a function of the different Technology Learning Parameter Values

Pattern Visualisation, Identification and Discussion: Kerohol Price

- i. The kerohol price shows a pattern which matches the learning curve. However, the volatility of the kerohol price means that the experience curve effects are less obvious.
- ii. Also, the best case scenario and worst scenario show much less of a strong impact in this plot. This shows that the technology learning and economies of scale do affect the price of kerohol, but that it is not the dominating factor. In some runs it is even possible that there is no price change at all, this indicates that the market dynamics overrule any production learning effects.
- iii. A leading conclusion which can be made on the basis of the technology learning effects is that biokerosene market dynamics dominate the changes in price due to technology learning. This follows from the competitive nature of the different products for sugarcane.

Experiment Conclusion

Even under a worst case scenario setting, the BioJet system exhibits the start of technology learning in biokerosene production. The speed in which the curve behaves however is highly uncertain; as a broad range of parameters also create an equally broad range of possible experience curve impact levels. Therefore, the technology learning aspect of the biokerosene debate should be treated with much caution when *projections* of biokerosene prices are made. Considering the relatively short term scope

of the simulation runs, significant technology learning effects in the BioJet system should not be expected and considered in light of overall biokerosene costs. It must be noted that they will have a significant impact on biofuel prices when biofuel competition is disregarded (waste streams, by-products). As can be seen, disregarding market dynamics, the technology learning impacts the overall price of biokerosene significantly. This latter aspect will be further dealt with during the exploration of the BioJet model.

Model Settings

In light of the previous observations and conclusions, for future experiments, a base case scenario is defined for the technology learning where the parameters used are 0.1 for the Progression Rate, 1,000,000 litres for the learning volume and an initial production cost of five times the cost of anhydrous ethanol production (*Junginger et al, 2009*). The base case scenario will be used for other experiments in the BioJet model. The selection of these values is roughly based on similar learning experiences for Brazilian ethanol (*Junginger et al, 2009*); however it is important to realize the high level of uncertainty regarding these parameters as no commercial biokerosene production is currently underway and the current values are based on regular ethanol learning effects.

Table 11: BioJet Baseline Parameter Values for Technology Learning

Parameter	BioJet Baseline Value	Unit
Technology Learning Parameter	0.1	[-]
Learning Volume	1,000,000	[L]
Initial Production Curve	5	[-]

Verification Experiment: Low versus High Biokerosene Yields

In addition to the actual cost of processing sugarcane into biokerosene, one needs to take into account the volumetric efficiency of biokerosene production from sugarcane (or any other feedstock for that matter). As is the case with anhydrous and hydrous ethanol, the yield of all products depends on the efficiency of the extraction process and the quality of the sugarcane. This test will explore how a significant change in biokerosene yields (either through sugarcane quality changes or production technology changes) may affect the total kerohol price. It is important to take note that the price of kerohol is directly determined for 25% by the price of biokerosene; this is due to the assumed blend-ratio of 25% (*Boeing et al, 2013; IATA, 2013*).

The values used for the biokerosene yield parameters are;

Low: 40.0 Litres / Tonne sugarcane
 Medium: 70.0 Litres / Tonne sugarcane (baseline yield, UNICA, 2014)
 High: 100.0 Litres / Tonne sugarcane

The area of interest in this experiment is the change in kerohol price as function of the different yields over time.

Figure 56 shows the different simulation runs for the kerohol price for different biokerosene yields (low to high) as a function of time. The upper bound represents the low biokerosene yield and the lower bound represents the high biokerosene yield. Baseline values (see Appendix F) are used with only a variation in biokerosene yield parameter values.

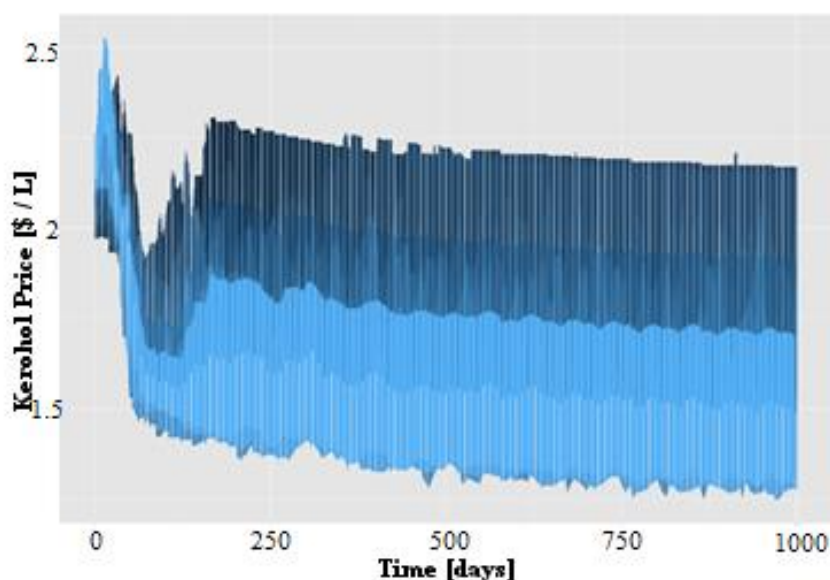


Figure 56: The Kerohol Price as function of time and the different Biokerosene Yield Parameter Values

Pattern Visualisation, Identification and Discussion: Biokerosene Production Costs and Kerohol Price

- i. The change in biokerosene yield causes the bandwidth in which the kerohol price changes to widen. This is expected behaviour as an increase in yield should proportionately decrease the price of kerohol. It is important to note that there is no significant change in the *mode* of behaviour during the runs for a different biokerosene yield scenario; this indicates that the yield of biokerosene only marginally influences the kerohol system behaviour.
- ii. As was the case in the technology learning test, the change in Biokerosene yield proportionately affects the overall price of kerohol. There is no change in the mode of behaviour (same qualitative patterns) which can be expected.

Experiment Conclusion

A change in the yield of biokerosene per tonne of sugarcane only proportionately affects the price level of kerohol. No change in price behaviour can be observed. It can thus be concluded that the increase in sugarcane yields for biokerosene, or the increase in efficiency at the refinery in producing biokerosene, does not significantly affect the overall system behaviour. The yields used in the test are quite unrealistic and as such it seems that an increase in sugarcane to biokerosene volumes have only a marginal effect on lowering kerohol prices; a proportionate effect at best. Considering that the extraction of ethanol from sugarcane is at a very mature stage (*UNICA, 2014*), there does not seem to be much margin to be gained from yield increases using the conventional sugarcane-to-ethanol processes. However, technical breakthroughs which may significantly increase overall ethanol yields (cellulosic ethanol) do have a large potential to decrease biokerosene prices, and also other ethanol prices.

As the focus of the research is into the biokerosene production behaviour changes and not in the exact price levels of the biokerosene, the baseline value which was already assumed in the BioJet formalisation section remains. This is a baseline value for biokerosene yield of 70 litres per tonne of sugarcane. It must be stressed that this is an upper bound when compared to the yield of anhydrous ethanol and the assumption that biokerosene from sugarcane will require a higher unit volume of sugarcane. In conjunction with this latter aspect, the proposed minimum processing cost of biokerosene follows the same conclusion as it only affects overall price levels of kerohol and not the behaviour (it is linked to biokerosene yield), therefore the assumed parameter value remains.

Table 12: Baseline BioJet Biokerosene Yield and Cost Parameter Value

Parameter	BioJet Baseline Value	Unit
Biokerosene Yield	70.0	[L / Tonne]
Minimum Biokerosene Processing Cost	1.5	[-]

6.6.3 BioJet Model Sensitivity Tests

As was the case in the base model, it is necessary to investigate if the different model runs with the BioJet show corresponding patterns to each other and whether the results of the BioJet model output can be considered to be robust to minor system irregularities (through for instance the random initialisation of parameter values).

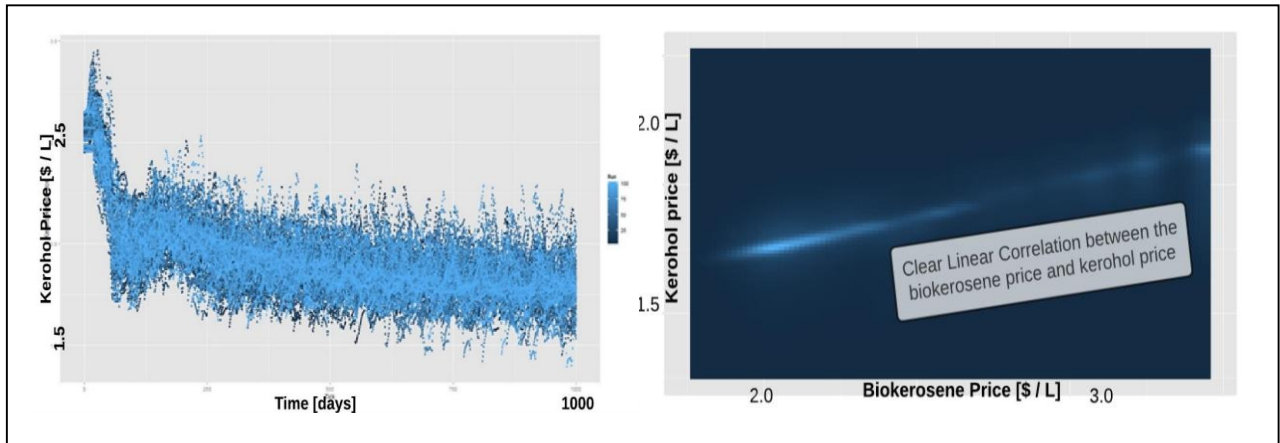


Figure 57: Sensitivity Runs for Kerohol and Biokerosene Prices

From the plots regarding the kerohol price as function of the many different runs (see Figure 57), one can clearly observe how the price, even though being quite volatile, remains within a clear bandwidth. This is in line with the results from the base model runs and indicates that the kerohol pricing mechanism has been modelled correctly. Additionally, from the heat map (*the light areas indicate a high concentration of values*) on the right side of the figure, the correlation between biokerosene price and kerohol price shows a clear one on one relation. This indicates that the main driver in the change of overall *price levels* of kerohol (assuming oil prices remain constant) are indeed determined by the internal biokerosene prices which change as function of the technology learning element.

This latter aspect presents as an important conclusion regarding the sensitivity of the system output; even though prices are highly volatile between different runs, the overall underlying behaviour is stable. This increases the robustness of the results in the exploration of the BioJet model as one can, with relative certainty rule out that system outliers (due to modelling elements) are a prime driver for system patterns.

6.7 Conclusions


The third research sub-question can be answered on the basis of this chapter.

“What are the implications of introducing a bio-ethanol based kerosene niche-market within the existing bio-ethanol market in Brazil?”

The *implications* of adding a biokerosene market to the bio-ethanol market are that there is an additional choice by refinery actors in producing a product if they choose to. In addition to this, there is an emergence of price competition between the existing bio-ethanol market and the new biokerosene market which leads to higher prices for both products, but particularly for biokerosene. It is shown how this overshadows any clear price decreases due to technology learning or an increase in biokerosene yields. The underlying reasons for these price increases are the decrease in the stocks of distributors, caused by a relative decrease in supply (larger ethanol market) which result in higher margins.

In terms of the *existing bio-ethanol market* the addition of the (relatively small) biokerosene market has no significant impacts and implications apart from a minor increase in bio-ethanol competition. This is due to the government policies which enforce biofuel use. A significant increase (through diffusion) in biokerosene demand and supply however leads to a much higher competition for sugarcane and as such leads to higher overall prices. Two additional actors are present with the addition of the biokerosene market; these are the Kerosene Centre actor (biokerosene supply) and the Biorefinery actor (biokerosene producer). The kerosene centre serves the same purpose as the regular distributor agents, while the biorefineries has the same purpose as the regular refinery agents.

The airport object ensures the demand for biokerosene, where it is assumed to be able to pay the biokerosene price which is necessary in the market. In real-world terms this scenario is unlikely as long as biokerosene prices are significantly higher than regular kerosene prices. However, this goes to show what is necessary at the minimum from the demand side in order to incentivize biokerosene production.



Chapter 7

BioJet

Model Exploration

In this chapter:

- 7.1 BioJet Experimentation
- 7.2 Experiment Results and Data Analysis
- 7.3 BioJet Model Validation
- 7.4 Reflection on the Model
- 7.5 Conclusions

7.1 BioJet Experimentation

The purpose of the Agent Based Model is to explore the system behaviour of the Bio-ethanol market in terms of measures to implement a biokerosene supply chain. In order to use the model in to gain an insight into emergent system behaviour it is necessary to pre-determine a series of appropriate experiments (*Van Dam, Nikolic, & Lukszo, 2013*). The focus of the experiments will be to investigate under which set of possible conditions, what kinds of regularities might emerge and how they behave in an aviation biokerosene supply chain setting.

7.1.1 BioJet Experimental Design

Considering the generative nature of Agent Based Modelling and the emergent characteristic of the biokerosene supply chain model, the *following type* of hypothesis testing can be formed (*Van Dam, Nikolic, & Lukszo, 2013*).

“A range of clearly identifiable emergent behaviours and regularities can be established from this Agent Based Model of a system.”

This type of hypothesis is used to explore in which possible worlds (or settings) a desired emergent behaviour may occur, through which mode and which factors may influence the emergence of that behaviour. In the scope of this research the desired emergent behaviour is the emergence of a biokerosene supply chain. This entails the increase in production of biokerosene by refineries, the associated price dynamics and the impact this has through the different chains in the supply chain. Also the impact of the existing ethanol system can be explored to investigate *if* and *how* this affects the emergence, and if the emergence of the biokerosene supply chain itself may affect the existing bio-ethanol system.

Emerging Biokerosene Supply Chain

The BioJet model is typified by the addition of a new system element, *biorefineries*, which can produce biokerosene. However, the decision to increase the biokerosene production ratio is dependent on the same decision making criteria which are present in conventional refineries. As such, it is of importance to investigate under which conditions the refineries will opt to increase the production of biokerosene (*profit maximizing*). These conditions will thus present the user with an insight into what may be necessary to facilitate the emergence of the biokerosene chain. These conditions will consist of the combination of external prices (sugar, sugarcane and oil) and different environmental aspects such as a change in policy by the government. The practical likelihood and realism regarding these conditions will be discussed in the next chapter.

7.1.2 BioJet Experiments

Following from the research formulation, there is a desired emergent system under study within the model; the biokerosene supply chain. This element is essentially an add-on to the existing production and users ratio system and as such the same type of experiments for the baseline model are used. However, a significant additional number of scenarios are required due to the added uncertainty regarding the implementation of a biokerosene supply chain.

An important assumption is that the biokerosene implementation does not affect the existing refinery and user behaviour due to the small scale of the biokerosene market in relation to the car market. However, there will be one scenario (experiment) in which both markets are assumed equal in size; this scenario assumes the possibility of wide spread diffusion of biorefineries and the significant increase in demand for biokerosene from the aviation market.

Experiment A: Free Market

A particularly relevant experiment from a practical viewpoint, is to investigate the effect of governmental policies on the system behaviour. The literature has shown that the Brazilian ethanol market is a product of strong government intervention; both in terms of setting up of the system and in maintaining the system (*ANFAVEA, 2013; Cortez & Rosillo-Calle, 1998*).

Also, the Brazilian ethanol market is mentioned frequently as a success story in terms in of a biofuel market (or indeed any renewable energy market) which does not need a subsidy based structure in order to maintain itself (*Charlita de Freitas & Kaneko, 2011*). Therefore in this experiment, it is tested what may happen to the system when all forms of tax, subsidies and mandates are abolished.

The area of interest in this experiment is the shift in production ratio by the biorefineries. It is explored whether a true level playing field in terms of biofuel production can affect the increase in production of biokerosene or not. Also the impact on the kerohol price is investigated.

Experiment B: Government Automobile Policy Shift

A follow up to experiment A is the exploration of what may happen to the system if the government were to actively discourage the use of ethanol for car transport and as such leave the possibility free for the aviation sector to use the available biofuel capacity. In this experiment the following parameter sweep will be conducted, see Table 13.

Table 13: Parameter Sweep Variables for Blending Mandate and Hydrous Tax

	<i>Blending Mandate [%]</i>	<i>Hydrous Tax [\$/L]</i>
<i>Minimum</i>	0	0.2
<i>Maximum</i>	25	0.8
<i>Increment</i>	5	0.2
<i>Baseline Value</i>	25 (UNICA, 2014)	0.26 (UNICA, 2014)

The area of interest is the Price Difference between kerohol prices and regular kerosene prices (1.0 \$ /L). It can be expected that the oversupply in ethanol will significantly lower overall ethanol prices. Also the competition for ethanol will be lower which should lower market prices.

Experiment C: Biorefinery Diffusion

As mentioned before, the baseline BioJet model assumes that the biokerosene supply chain, due to the relatively small volume of the market in comparison with the car market, does not influence the rest of the system. This assumption is realistic if one takes into account the small scale of the biokerosene market. However, it is worthwhile to investigate the hypothetical situation where biokerosene production and demand may become substantially large enough to be considered to be equal to the car market size. In that case one can think of a significantly large scale biokerosene demand domestically in Brazil by the aviation sector or even the export of biokerosene globally.

In conjunction with the increase in demand for biokerosene, is the possibility by refineries to transform into biorefineries based on expected profits in biokerosene production which in itself is based on the performance of existing biorefineries (diffusion). In this scenario it is therefore possible that all refineries switch towards becoming biorefineries or that they do not. The desired emergence of an increase in biorefinery units is the focus of attention in this experiment together with the effect of the biokerosene market on the conventional supply (*sugar, hydrous and anhydrous ethanol*) and demand elements.

Experiment D: Sugarcane, Sugar and Oil Shocks

The previous experiments have tested the impact of a different initial parameter setting on the system behaviour. However, as is the case in the real-world, often there are sudden shocks to the system which are not anticipated. This experiment will explore the behaviour of the system in reaction to a sudden increase/decrease in prices for sugarcane, sugar and gasoline/kerosene. The experiments are conducted as follows;

Sugarcane Shock: The sugarcane price increases from the baseline value (56.11 \$ / Tonne) to an increased value (100 \$ / Tonne) at the midway point of an experiment run (500 ticks out of 1000 ticks).

Sugar Shock: The sugar price increases from the baseline value ($1.0 \text{ \$ / Kg}$) to an increased value ($1.5 \text{ \$ / Kg}$) at the quarter point of an experiment run ($250 \text{ ticks out of } 1000 \text{ ticks}$) and subsequently a return to the baseline level at the three quarter point of the experiment run ($750 \text{ ticks out of } 1000 \text{ ticks}$). This test thus explores two shocks in the opposite direction, in a particular run.

Oil Price Shock: The gasoline and kerosene prices increase from the baseline value of ($1.05 \text{ \$ / L}$ and $1.00 \text{ \$ / L}$ respectively) to an increased value of ($1.50 \text{ \$ / L}$ for both) at the halfway point of an experiment run ($500 \text{ ticks out of } 1000 \text{ ticks}$).

The area of interest in this experiment is the dynamics of all ethanol product prices in light of these sudden price shocks.

BioJet Model Settings

As was the case in the in the base model settings, all the experiments are run with the baseline values unless stated otherwise. The complete set of baseline values can be found in Appendix F. The different scenario parameter settings are the only variable parameter variables between runs. Furthermore, the number of runs per experiment setting is taken as 10 runs in order to mitigate any irregularities arising from the random initialisation of the technical agent parameters.

7.2 Experiment Results and Data Analysis

Experiment A: Free Market

Figure 58 shows the total production ratios (stacked area plot) of ethanol related products as a function of time, (Biokerosene ratio = red, Hydrous ratio = green, Anhydrous ratio = blue). Figure 59 shows a scatterplot of the number of hydrous flex users in the system as a function of time. In the model runs all forms of tax and blending mandates have been removed.

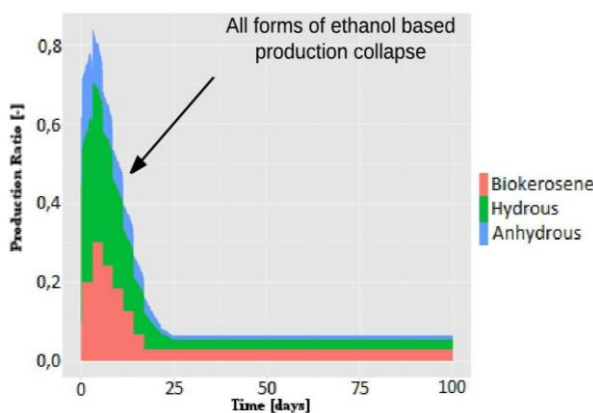


Figure 58: Number of Hydrous Users as function of Time in the Level Playing Field Scenario

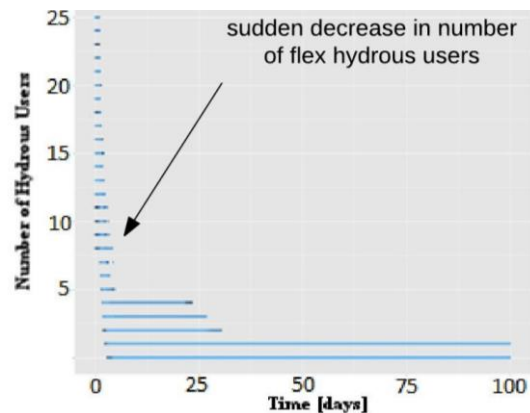


Figure 59: Biorefinery Production Ratios as a function of Time in the Level Playing Field Scenario

Pattern Visualisation, Identification and Discussion: Hydrous Users and Production Ratios

- i. Clearly the removal of all government policies significantly reduces the profits which can be made by biorefineries and refineries with ethanol related production. The total system thus immediately switches away from ethanol towards sugar production. This implies that without government policies, the demand and supply for ethanol is very much lacking.
- ii. The lack of government policies in the bio-ethanol market also affects the demand for ethanol fuels as one would expect. Indeed, hydrous users switch away en masse from hydrous fuel use indicating that the preference for hydrous fuel is gone. This is most likely due to the lack of hydrous ethanol production (see Figure 59) which causes a significant shortage of hydrous ethanol, this in turn leads to higher prices for hydrous fuel.
- iii. The fact that the hydrous user switch is not complete in one step but in two, clearly indicates the homogenous distribution of user's preferences within the user agents group.
- iv. Part of the scenario is that there is no blending mandate for anhydrous ethanol with gasoline. This naturally eliminates much of the demand for anhydrous ethanol. The car users are likely to switch to pure gasoline use as this is now very competitive due to the abolishment of the rather high gasoline tax. This fact indicates that the hydrous competitiveness with gasohol/gasoline fuel is very much dependent on the large gasoline tax. Even though there is no subsidy on hydrous ethanol, the high gasoline tax ensures that users find hydrous ethanol to be cheap relative to gasoline.

Figure 60 shows a scatterplot of the kerohol price as a function of time for a scenario in which all government policies have been abolished (free market).

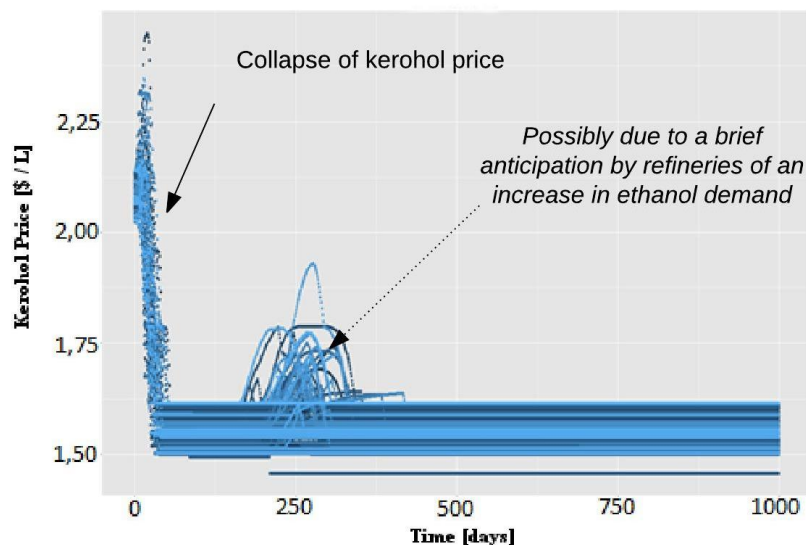


Figure 60: Kerohol Price as a function of Time in the Level Playing Field Scenario

Pattern Visualisation, Identification and Discussion: Kerohol Price

- i. Interestingly, the price of kerohol significantly drops in the face of zero government interference in the fuel market. An explanation for this is that the decrease in production of competing ethanol products, hydrous and anhydrous, results in a lower necessary price to maintain biokerosene production at the biorefineries. Without any competition market pressures, the kerohol price nears the base price level implying that refineries make zero profits. Also, it is clear by the plot how much the market pressures dominate pricing.
- ii. It is not immediately clear what the chaotic behaviour which is present at around the quarter way mark, represents. It is possible that this coincides with the second “wave” of hydrous flex users switching. Concurrently it is possible that this coincides with the reaching of the minimum production ratio levels which temporarily may raise the price for these products as the agents anticipate the arrest in the fall of the ethanol production ratio’s; refineries may believe the prices will rise.

Experiment Conclusion

The Free Market experiment very clearly shows that the government system of taxes on hydrous, gasoline and anhydrous fuel in combination with the setting of a blending mandate is a driving factor for maintaining a stable bio-ethanol fuel market. The loss of such measures immediately causes the system to move away from ethanol production. This is explained by the fact that the gasoline tax, which is relatively high, is an important measure for the government to make hydrous ethanol use attractive. Were the fuel products to compete with each other without government interference, it seems that the fuel market would revert to a regular gasoline driven system.

On the other hand, the crisis in ethanol demand and corresponding lower margins resulting from the new free market system, may work in favour of increasing biokerosene production as it need not compete with the other sugarcane derived products (which are unprofitable), which implies a lower required price by the aviation sector for increasing the biokerosene volume.

Experiment B: Government Automobile Policy Shift

Figure 61 shows a boxplot of the kerohol price as a function of time for the 16 combinations of scenario parameters. Where the horizontal shift represents a different blending mandate for anhydrous ethanol and the vertical shift represents a change in hydrous tax. The width of the boxplots indicates an interval of 100 days, the height of the boxplot indicates the range within which 50% of the values (thus 50% of the runs values) is found. The black “whiskers” indicates the range of the outlier runs.

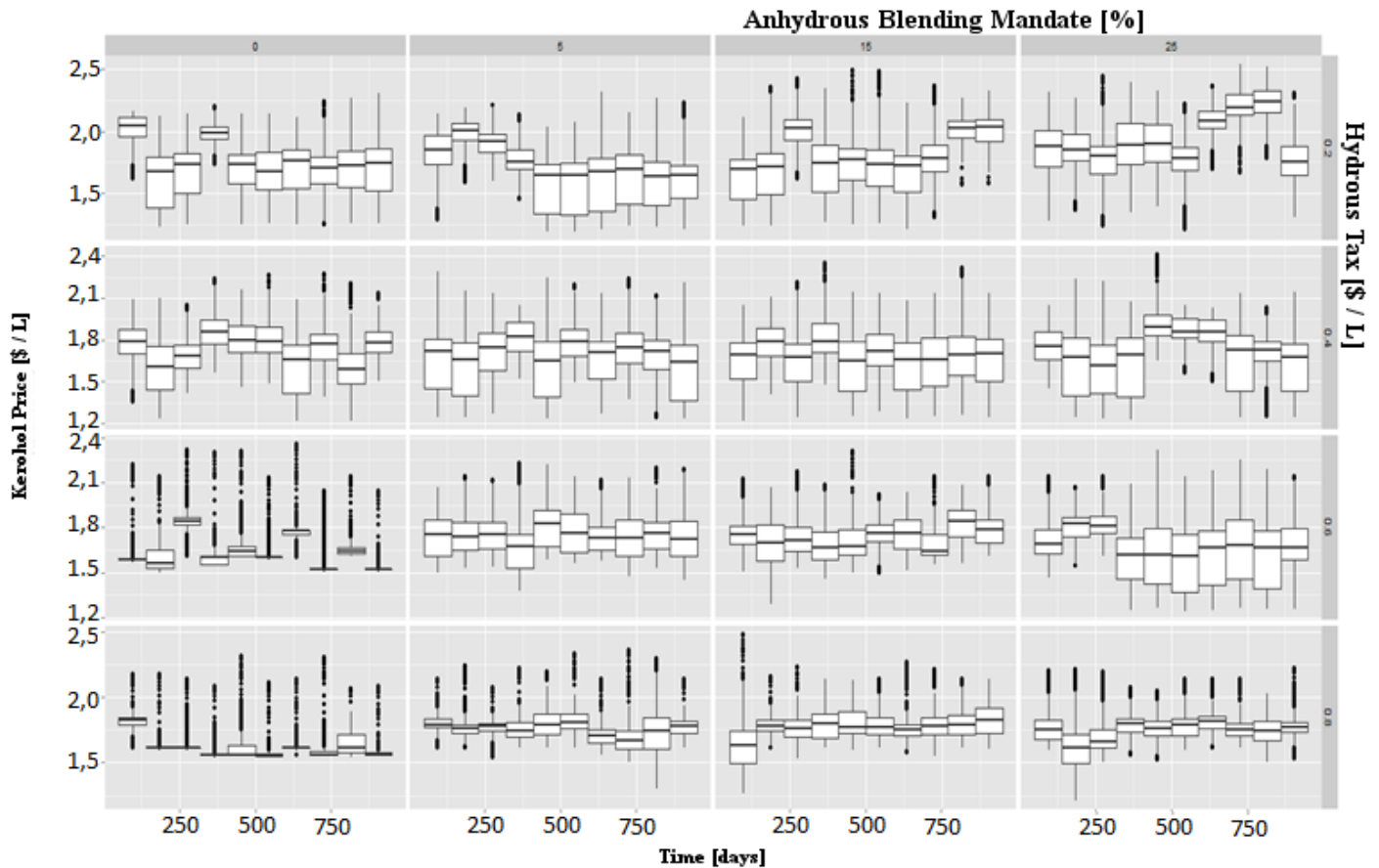


Figure 61: Boxplots of the Kerohol Price Distribution as a function of time for Different Combinations of Blending Mandate and Hydrous Tax

Pattern Visualisation, Identification and Discussion: Kerohol Price

- i. What Figure 61 shows is how the policies which negatively affect car ethanol fuel prices, help to reduce the price of kerohol. This can be seen at the bottom left corner, where the boxplot graph clearly shows that the majority of kerohol price runs is at the lowest end as opposed to the other scenarios where the kerohol price is on average much higher.
- ii. The mechanism of the lowering of the kerohol price is the fact that in these scenarios (bottom left), car users are switching towards pure gasoline, there is no blend mandate, and as such kerohol does not need to compete with other ethanol products. Furthermore, even when the blending mandate remains intact, the kerohol price is significantly lower for the higher hydrous tax scenarios. The switch by flex users away from hydrous fuel means the oversupply in ethanol can be used for cheaper kerohol production as indicated in the figure.

Experiment Conclusion

A scenario in which the Brazilian government would actively discourage the use of ethanol for car transport may seem highly unrealistic. However, what experiment B clearly shows is how effective such policy may be in light of a widespread implementation of biokerosene (or any other non-car ethanol related product). Also what the experiment shows is how the price of kerohol is dominated by the competition with the other ethanol demand elements in the market, particularly in relation to the actual production cost of kerohol.

Experiment C: Biorefinery Diffusion

Figure 62 shows a boxplot of the biokerosene production ratio of all biorefineries as a function of time. Figure 63 shows the final prices of each simulation run for kerohol, indicated by a dot. In the simulation scenario the biorefineries can increase; thus the plots indicate a bio-ethanol market with an equal biokerosene demand market.

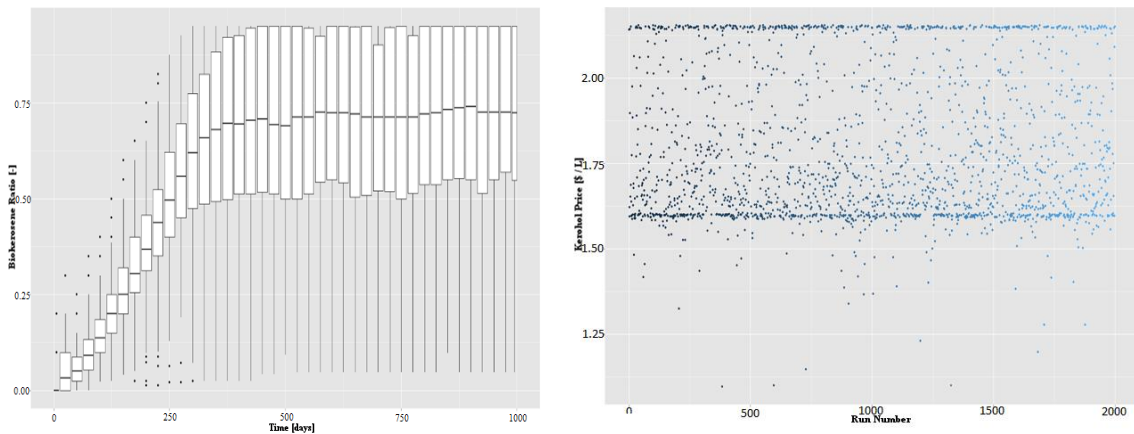


Figure 62: Boxplot of the Distribution of the Total Biokerosene Ratio of biorefineries for the different runs Figure 63: Scatter Plot of the Different Kerohol Prices at the End of the Different Runs

Pattern Visualisation, Identification and Discussion: Biokerosene Ratio and Kerohol Price

- i. In a scenario where the biokerosene demand is equal in size to the regular automobile ethanol market, the biokerosene ratio of biorefineries clearly shows a significant increase over time up until an equilibrium which differs per run. This implies that biorefineries find the biokerosene market more profitable than the regular market, however as can be seen in Figure 63, this profitability is a function of the prices in the region between $1.6 \text{ \$ / L}$ and $2.2 \text{ \$ / L}$; indicating the premium necessary. The relative size of the boxplot boxes does indicate that the degree to which refineries find biokerosene profitable to produce, is highly variable between different simulation runs.
- ii. A leading conclusion is the fact that assuming the base line BioJet parameter value of a blend ratio of biokerosene of 25% and the assumptions regarding the yield or production cost for biokerosene, a price for kerohol in the order between $1.6 \text{ \$ / L}$ and $2.2 \text{ \$ / L}$ needs to be paid in order to incentivize biorefineries to increase biokerosene production. As is visible in Figure 64 ,

the lower bound is clearly visible indicating that the kerohol prices are well above the standard kerosene price of $1.0 \text{ \$}/L$.

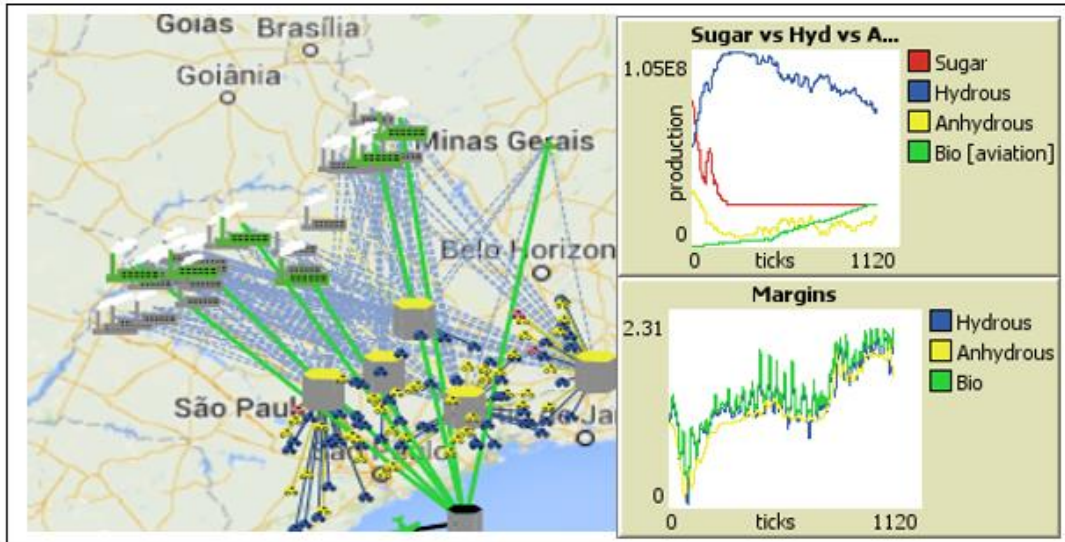


Figure 64: "World" representation of a single Biorefinery Diffusion Run with corresponding System Information

Pattern Visualisation, Identification and Discussion: Biokerosene Refinery Number

- The *World* view (Figure 64) of the supply chain system shows how the biorefineries have spread through the supply chain. The green refineries and green links indicating that biokerosene is produced and supplied. The BioJet model is set up in such a way that it is assumed that the airport agent will incentivize, through the setting of a premium, the production and in this case diffusion of biokerosene. As such, a leading conclusion from the Biorefinery diffusion scenario is that as long as the premium is available, biorefineries will spread in the face of a significantly large biokerosene demand. More important still is the corresponding conclusion that biorefineries will *not* spread when this premium is not available.

Experiment Conclusion

The experiment shows that, given a scenario in which diffusion is possible and market demand can accommodate the significant growth, the increase of biokerosene production may certainly be possible. In conjunction with the profitable biokerosene market for refineries however, is the fact that the scenario assumes that the aviation biokerosene demand can offtake the volume of biokerosene (essentially unlimited) and that the aviation demand can afford to pay a premium for the kerohol product. The degree to which this premium will be necessary is dependent on the used blend ratio in kerosene, and the state of the regular car ethanol market (as has been shown in the experiments).

Experiment D: Sugarcane, Sugar and Oil Shocks

Figure 65 shows the kerohol price and Figure 66 shows a scatterplot of the hydrous price as a function of time for the scenario where the sugarcane price suddenly increases.

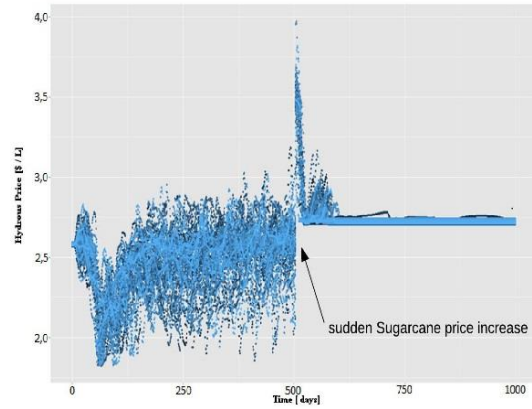
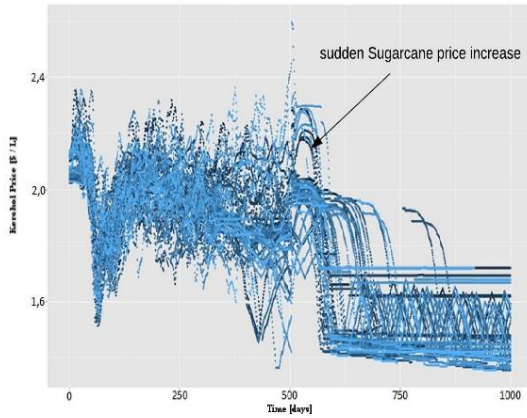


Figure 65: Kerohol Price as a function of Time in a Sugarcane Price Shock Scenario (200 Runs)

Figure 66: Hydrous Price as a function of Time in a Sugarcane Price Shock Scenario (200 Runs)

Pattern Visualisation, Identification and Discussion: Sugarcane Shock, Kerohol Price and Hydrous Price

- i. It can be clearly seen how a sudden shock to the system immediately impacts the prices for both hydrous ethanol and kerohol fuels. The price shock seems to compress the hydrous price bandwidth into the higher overall price level. This can be expected as the price of sugarcane determines for a large part the price of hydrous fuel. Furthermore, the initial peak in the hydrous price after the shock indicates that hydrous market needs some time to adjust to the new conditions (shift of production ratios and users car users switching).
- ii. On the other hand, the kerohol price is decreased significantly. As mentioned in the other experiments, this is most likely due to the high hydrous price causing users to switch away from hydrous ethanol use which then creates an over capacity from which the kerohol price profits.
- iii. The noise in both plots after the sugarcane price hike is both very much different relative to before the price hike. This indicates that the system is pushed into a less volatile state; most probably as car users are now less inclined to switch prices.

Figure 67 shows the users ratio as function of time (Regular gasohol = red, Flex gasohol = green, Flex hydrous = blue) with a sudden increase of sugarcane prices at the halfway mark of the simulation. The plot type is a stacked area plot.

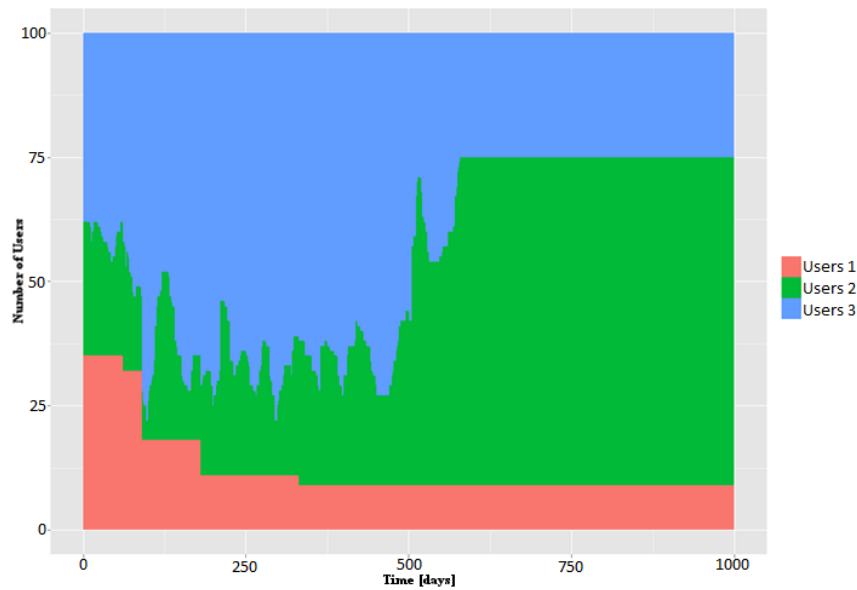


Figure 67: Users Ratio as a function of Time in a Sugarcane Shock Scenario

Pattern Visualisation, Identification and Discussion: Sugarcane Shock, Users Ratio

- i. The sugarcane price hike clearly discourages the use by flex car users to use hydrous ethanol. Almost immediately the flex car users who would otherwise frequently switch fuel use choose to permanently use gasohol fuel. This makes sense considering the price sensitive behaviour of flex car users.
- ii. The fact that for the extreme sugarcane price shock scenario not all hydrous flex users have switched indicates that the sugarcane price alone does not impact the hydrous price relative to gasohol enough to discourage all flex users to use hydrous fuel.
- iii. Prior to the sugarcane shock, the regular gasohol users are incentivized towards flex fuel vehicles (red portion decreases). This indicates that the sugarcane price at that level (base line value) is sufficiently low for a healthy hydrous market.
- iv. After the start of the sugarcane shock, there is still some flex fuel behaviour visible, indicated by the last spike before the user ratios reach an equilibrium. This implies that the fuel prices respond in a delayed fashion towards the sugarcane price; this is in line with the supply chain dynamics of the model formalisation.

Figure 68 shows the kerohol price as function of time for a sudden increase in sugar price and sudden decrease in sugar prices. The sugar price increase occurs at time is 250 days, the return to baseline prices occurs at time is 750 days.

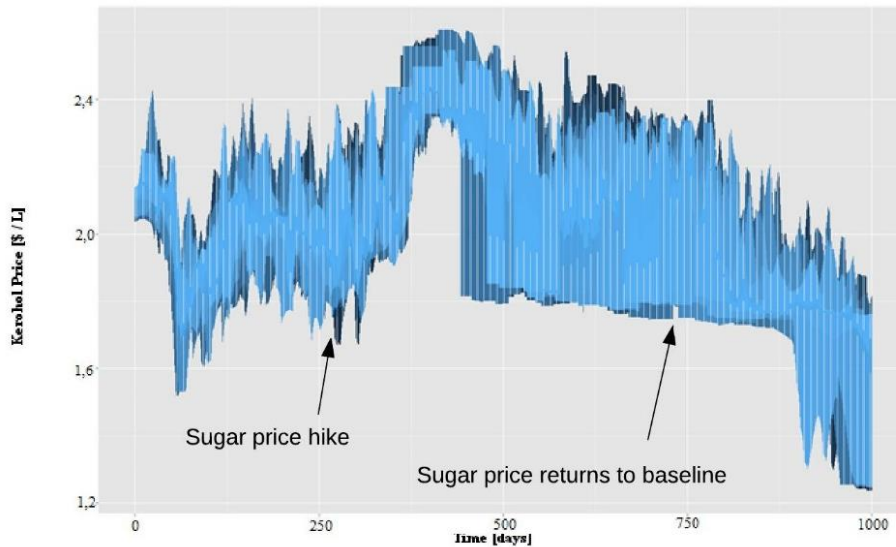


Figure 68: Kerohol Price as a function of Time with a sudden increase and subsequent decrease in Sugar Price at the quarter and three quarter mark respectively (200 Runs)

Pattern Visualisation, Identification and Discussion: Sugar Shock, Kerohol Price

- i. In the sugar price hike scenario, one can observe how the price of kerohol immediately increases (sugar is a competitor to biokerosene), however the price gradually seems to go down indicating that the refineries are adjusting to the new situation; also the car users are adapting to the new situation most likely through the switching towards gasohol fuel.
- ii. In reverse one also sees how the sudden drop in sugar price also immediately lowers kerohol prices. This is directly due to the lower profitability and thus lower production volumes of sugar at the refineries and the corresponding sudden availability of production capacity for biokerosene and ethanol. It is very clear that kerohol prices are directly related to sugar market dynamics.
- iii. The impact on the kerohol price is delayed indicating that the BioJet model requires time to react to the sudden change in external sugar prices.

Experiment Conclusion

As expected, a sudden change in the price of sugarcane or sugar can cause the system to strongly react. In terms of kerohol pricing, higher sugarcane prices may lead to lower kerohol prices up until a certain point. This seems paradoxical but has everything to do with the intra-ethanol competition with hydrous ethanol, see Figure 67. The high cost of hydrous fuel and the corresponding reduction in its demand lowers the margins required for biokerosene production as more refinery capacity becomes available. Higher sugar prices however do raise kerohol prices, as expected as sugar directly competes with kerohol as well; there are no demand shifts such as is the case in the hydrous market.

Figure 70 shows the price of hydrous fuel as a function of time with a sudden increase in external gasoline prices at the halfway mark (500 days). Figure 69 shows the gasohol prices as a function of time with the same increase at the same time of external gasoline price.

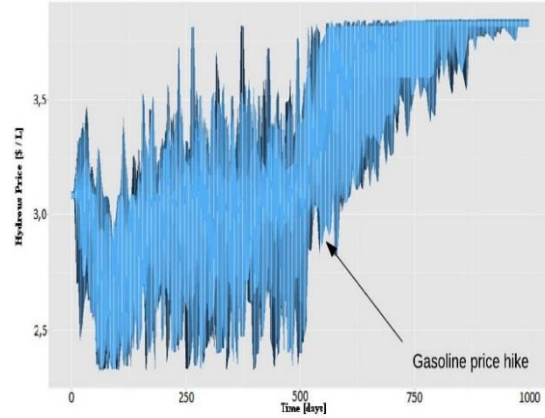
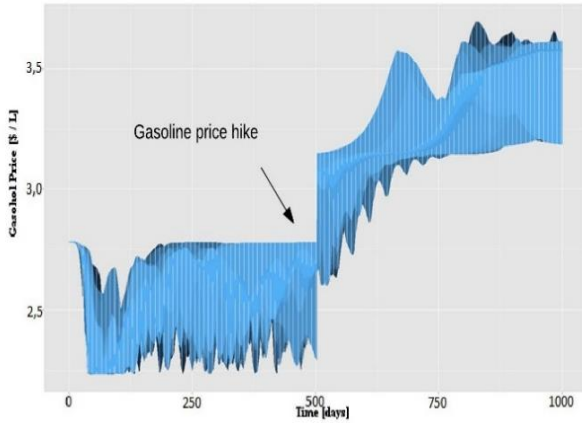


Figure 69: Gasohol Price as a function of Time in a Gasoline Price Shock Scenario (200 Runs) Figure 70: Hydrous Price as a function of Time in a Gasoline Price Shock Scenario (200 Runs)

Pattern Visualisation, Identification and Discussion: Oil Shock, Hydrous Price and Gasohol Price

- i. The sudden increase in gasoline price clearly shows an increase in the price of hydrous. The price of hydrous ethanol seems to converge to maximum price, indicating that the market is close to a maximum accepted ethanol price (before supply cannot meet demand).
- ii. The price of gasohol is immediately affected by the gasoline shock; this makes sense due to the 25% blend mandate. An equilibrium seems to occur for the gasohol price indicating a reaction by the market to the increase in gasoline price.
- iii. The increase in gasoline prices appears to decrease the volatility of the ethanol market prices. This may indicate that the gasoline prices dominate over the marketing aspects set forth by the distributor agents.

Figure 71 shows the price of kerohol fuel as a function of time with a sudden increase in external kerosene prices at the halfway mark (500 days).

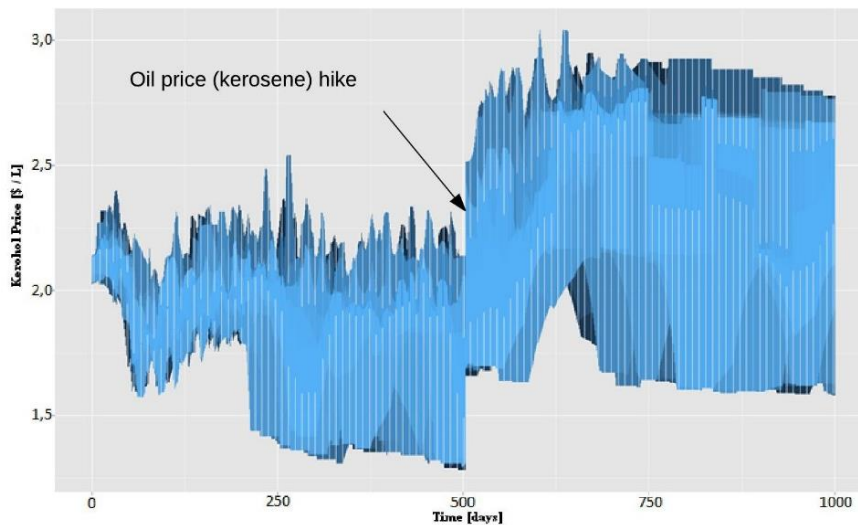


Figure 71: Kerohol Price as a function of Time with a sudden increase in Kerosene Price (200 Runs)

Pattern Visualisation, Identification and Discussion: Oil Shock, Kerohol Price

- i. As expected the sudden increase in kerosene price, increases the kerohol price as well. However, after an initial phase of significantly higher prices, the number of runs showing lower kerohol prices returns. This is due to the fact that the ethanol market has switched away from hydrous fuel, and the overcapacity effects reduce the kerohol price once again.
- ii. The sudden increase in kerosene prices causes a divergence of the kerohol price level across the different runs. However, the main change in kerohol is clearly attributed to the kerosene component with the 25% biokerosene blend in kerohol.

Experiment Conclusion

The sudden increase in external commodity prices indeed impacts the ethanol prices as one would expect. The sudden shock to the system initially moves the price dynamics away from any equilibrium, however after some time the price stabilize although at a higher level. In all cases, the phase in which the prices are changing in overall price levels, the degree of market volatility is reduced. This implies a uniform reaction by all market agents to the external shocks. From the experiment where the sugar price returns to normal, it can be observed that the kerohol price overshoots (in negative direction) the original pre-sugar level equilibrium. An explanation for this behaviour is that the sudden decrease in sugar causes an overcapacity for sugarcane as many fuel users at this point have already switched towards gasohol use, which leads to lower ethanol prices. Additionally, in all plots the bandwidth of price variations within simulations is increased after the price shock indicating that a shock to the system increases the level of uncertainty in terms of pricing.

7.3 BioJet Model Validation

The BioJet model cannot be compared to a real-world situation in the absence of any significant biokerosene market. Therefore a validation on the basis of a “historic replay” is not possible. However, the model may, to a certain degree, be validated using a comparison of existing literature in relevant fields (*Van Dam, Nikolic, & Lukszo, 2013*). The core of the BioJet and Base model, is the change in production ratios and demand throughout the supply chain as a function of external price conditions. As such the Agent Based Model can be viewed as a market model.

In the formalisation of the main market concepts of the bio-ethanol model, much use has been made of *De Gorter, Drabik, Kliaugas, & Timilsina (2013)*. In their analysis of the Brazilian bio-ethanol market, they conclude the following:

1. The Brazilian bio-ethanol market is unique in that sense that government policies regarding taxes and blending mandates, have a distinctly ambiguous impact on the prices of bio-ethanol (biofuel). This is directly related to the unique biofuel market structure in which *producers and users* are flexible in choosing between biofuel products. The complexity on the demand side arises through the mutually competing products for sugarcane; hydrous ethanol and anhydrous ethanol. Any initial change in the price of ethanol can be offset by the demand market shifts in hydrous ethanol.
2. A lower tax on gasohol fuel results in lower ethanol prices while higher mandates and lower taxes for hydrous fuel results in higher ethanol prices.

In terms of the Agent Based Model, regarding the *demand and producer switch behaviour*, the conclusions drawn by *De Gorter, Drabik, Kliaugas, & Timilsina (2013)* are in line with results of the experiments of the previous section. Indeed, in the Agent Based Model it has been shown how any encouragement by external policies for the demand market to switch demand towards the gasoline (gasohol), results in overall lower ethanol prices. As was explained in this report, this is primarily due to the fact that the demand of ethanol is reduced from a 100% ethanol composition (hydrous fuel) to a 25% blend (gasohol); causing an oversupply in ethanol and low prices. Furthermore, in terms of a higher blend mandate, which seems as a policy which helps the ethanol market, it is shown that this cause the ethanol prices to increase. A comparison is made to the United States (the largest ethanol market in volume in the world) where a lower tax in gasoline always causes an increase in ethanol prices, a direct consequence from the fact that there is a blend mandate with no alternatives for the demand market.

The Agent Based Model clearly follows the main conclusions drawn by *De Gorter, Drabik, Kliaugas, & Timilsina (2013)* particularly in terms of the flex user car market. As it is concluded that the behaviour of the Brazilian bio-ethanol market is a direct consequence of the *flexible* nature of the market, one may conclude that the addition of an extra competing product for sugarcane may follow the same conclusions, which has been shown in the BioJet Model. It is important to note however, that in comparing the results of the BioJet model and the conclusions drawn by *De Gorter, Drabik, Kliaugas, & Timilsina (2013)* there is a large difference in the method used. First of all, in the BioJet model, the time scope is in the order of a few years (1000 days) whereas *De Gorter, Drabik, Kliaugas, & Timilsina (2013)* have modelled the Brazilian market based on a change in market price levels with an interval of one year. Also, the BioJet model has kept the price and supply of sugarcane external while *De Gorter, Drabik,*

Kliauga, & Timilsina (2013) have incorporated the change in sugarcane price as an internal concept. The repercussions of this may be that increase in overall ethanol prices is not reflected back into an increase in sugarcane prices which may mean that the overall ethanol prices are lower than they should be (if one assumes an internal sugarcane price). However, as the base model has experimented with changes in sugarcane prices, and the effects of the increase in these price did not produce pattern changing results, it is assumed that this does not matter in terms of the validity of the BioJet system behaviour.

The time scope of the model however, it is acknowledged, does increase the chance of missing out on other external real-world factors; that is to say, it is unrealistic to assume constant external parameter values for such a long time. It is therefore important that the user of the model realizes this aspect; the model is not intended to forecast long term price levels but its purpose is to show, with external inputs are held constant, how a flexible biofuel market may behave under certain scenarios.

Agent Based Modelling of a Biofuel Network

The BioJet model shows very volatile behaviour, the reason for this has been explained to be the combination of the flexible nature of the biofuel market and the behaviour of the distributor agents in reacting to this flexibility. *Ferreira & Borenstein (2011)* have used Agent Based Modelling to simulate the behaviour of a normative agent; the case study used in their research is the biodiesel supply chain in Brazil. An interesting result which arises from this work is how indeed the distributor agent causes a volatile market pattern which affects the production and demand of biodiesel. Based on the results of this work, see Figure 72, the underlying notion of the BioJet model in regards to the volatile aggregate behaviour of the agents in response to the different levels of stock in the supply chain seems validated. However a true validation of a real-world situation remains elusive, an aspect which the user of the BioJet model should not forget.

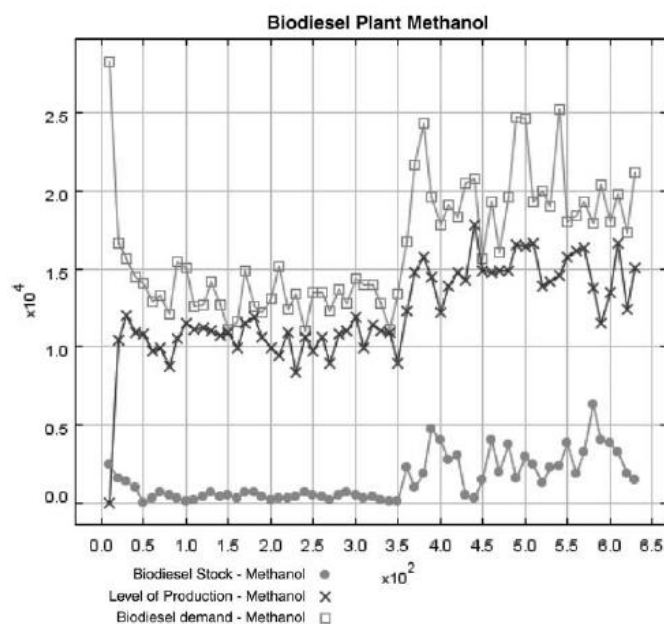


Figure 72: Biodiesel Plant Stock, Demand and Production Volatility (Ferreira & Borenstein, 2011)

Another example of an Agent Based Model in which market volatility is an essential part of the system behaviour patterns is shown in the work by *Augusdinata, Lee, Zhao & Thissen (2014)*. In this work the system behaviour of a biofuel supply chain is modelled. A main result arising from this model is that it shown how the agents decisions in terms of whether to adopt a biofuel demand/production or not affects each other's decision making leading to chaotic behaviour, see Figure 73. This result is very much in line with the BioJet model and base model results and adds further confidence to the overall system patterns which are simulated in these models. Again, true validation in terms of the real-world is not possible, however within the field of Agent Based Modelling, the BioJet model shows the typical behaviours which have also been observed in different biofuel case studies indicating a level of validity in terms of the modelling itself.

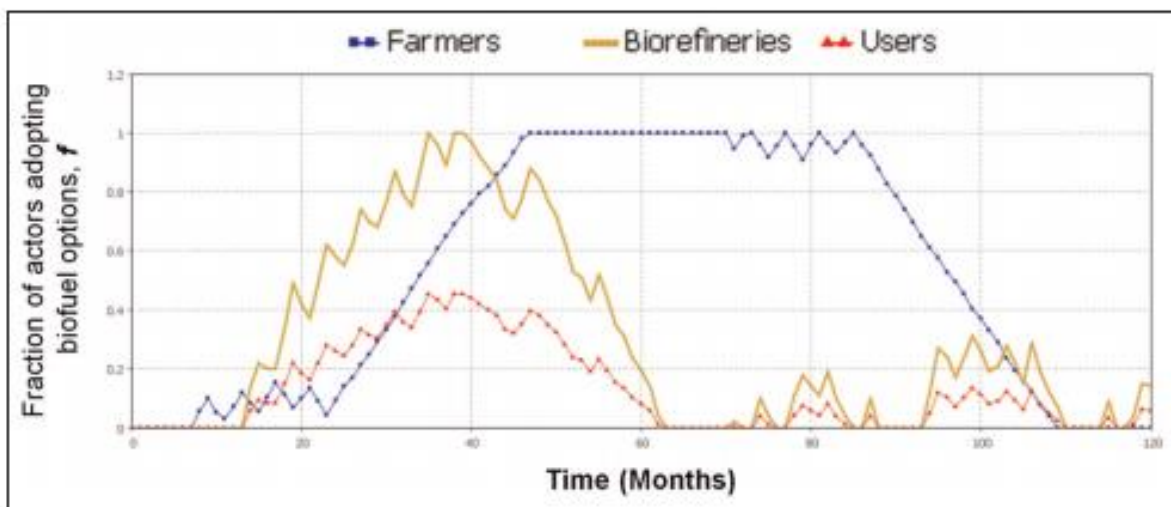


Figure 73: Interaction of the Decisions made the by Supply Chain Biofuel Actors towards Adopting Biofuels or not (*Augusdinata, Lee, Zhao & Thissen, 2014*)

Finally, in terms of the validity of the BioJet results, one final remark which can be made is that the fact that no real-world validation was made possible indicates how uncertain assumptions being made by real-world actors in the field of biokerosene implementation are. This presents a significant problem in policy making by governments and industry leaders alike; the BioJet model adds a new viewpoint on the basis of which the biokerosene and (other biofuels for that matter) can be debated in the absence of real-world data.

7.4 Reflection on the Model

This thesis has extensively described the conceptualisation, formalisation, implementation and experimentation of the base model and BioJet model of the proposed biokerosene and bio-ethanol markets in the Brazilian setting. However, how should the model be used? How should one interpret the actual results of the model? What do these mean and how does this help in answering the research problem?

7.4.1 Limitations of the Core Model Assumptions and Simplifications

During the formalisation of the model, as is always the case in the modelling of the real-world, assumptions and simplifications have been made in order to be able to formulate a workable model. However when making assumptions, one is deviating from the real-world and therefore it is important to realize this aspect when interpreting the results of the model simulations. The core assumptions and simplifications which have been made in the BioJet (and Base) model are described in below, along with the motivation for making these assumptions and the impact that they have on the model results.

i. The Feedstock (sugarcane) is External

Reasoning: The sugarcane supply to refineries is assumed to be constant (independent of market changes). This assumption is made with the reasoning that sugarcane farmers will always try to produce as much sugarcane as possible in a year as they are incentivized to do so; farmers are guaranteed the off-take of sugarcane however they do not know the price which they will receive for it.

Impact: This assumption implies that sugarcane supply does not react to the total demand for the sugarcane product. However, in the real-world sugarcane supply over the years has been shown to steadily increase in *conjunction* with the increase in ethanol and sugar demand (possible correlation); the *direction* of this causal relation is difficult to establish (further research on this is recommended). The fact that sugarcane prices do not follow the ethanol market changes means that one needs to take into account that a higher demand volume for sugarcane products (sugar and ethanol) in reality should be expected, in the longer term, to increase the price of sugarcane as the market adjusts to this.

Conclusion: Significant increases/decreases in total ethanol and sugar volumes in reality are expected to increase/decrease the price of sugarcane. The degree to which this happens is uncertain; but should be related to the price levels of sugar and ethanol. In terms of the short term (less than a year) market this is not an issue.

ii. Agents (within the Refinery, Distributor, User groups) are Equal in Size

Reasoning: For comparison reasons, where the area of interest is in the decision making of agents per available unit of sugarcane, it is assumed that no differentiation exists between agents in the same system element. This implies that the agents cannot obtain any competitive advantage derived from

their capacity or size (market power, economies of scale). The assumption ensures a level playing field for the agents where the differentiation between the agents is based on the technical and social aspects unrelated to capacity.

Impact: The assumption has the consequence that the agents are not incentivized to become larger (by upgrading capacity) and that no single agent can dominate the market. In real-world terms this is far from realistic as particularly in the fuel markets, conglomerates are present. The assumption therefore, excludes a significant portion of fuel market strategy; to become a dominant player in order to dictate the setting of prices.

Conclusion: Economies of scale in the market (excluding biokerosene production which is also due to technology learning) are not present. The model therefore misses out on competing behaviour in terms of capacity growth; in the short-term scope (less than a year) this should not be an issue as in the real-world the increase in capacities takes an amount of time (and financial investment). However, as there is no significant *direct* competition between agents in size, the commodity production costs also remain unchanged which may mean that the model falsely has constant production costs. This is a point of interest which is discussed in the recommendations for further research section, see Chapter 9.

iii. Distributor Agents are Supply and Demand stabilizing Agents

Reasoning: It can be argued that the “core business” of distributors is to manage the supply and demand of a product; this is in line with the assumption. However, distributors, being companies, also seek profits and therefore in the real-world are likely to use certain strategies in order to maximize profits. In the model this element is excluded entirely due to simplicity reasons and the lack of available information regarding these strategies. It has been assumed that distributors will increase the price of their products in times of a shortage of the products and decrease the prices in times of an oversupply of the product.

Impact: As the distributors are not profit seeking actors, the revenue of producers and costs of users are very likely to be higher (revenue) and lower (costs) than in a situation in which distributors were to be profit seeking. Furthermore, the manner in which distributors regulate the supply and demand is very basic (as explained in Chapter 5); this causes the volatile prices in the model.

Conclusion: For simplicity reasons the distributor decision making has been kept very basic in the conceptualisation of the model. The core assumption that prices will increase when supply is low and prices will decrease when supply is high make sense. However, as there are no contracts in this system, the price levels change unrealistically quickly compared to a market based on contracts. The volatility in the model is thus most likely to be exaggerated compared to the real-world; that is not to say that in the real-world fuel markets, volatility always exists to some degree and the model is able to simulate this principle in conjunction with maintaining the balance between supply and demand. Further research is necessary into fuel market price setting in order to draw definitive conclusions regarding this aspect.

iv. *Oil/Gasoline and Sugar Markets are External*

Reasoning: It has been assumed that the changes in the system in terms of ethanol prices and production volumes do not affect the price of sugar and gasoline. The reason for this is that these markets are global markets and as such are affected by many different local markets.

Impact: The consequence of this assumption is that the prices for gasoline and sugar are held constant unless the user chooses to change them (for instance in an experiment). The prices of are the drivers of the behaviour in the model and any change in these prices has large consequences in the system. The assumption therefore is very important for the overall model results; these are a function of these prices.

Conclusion: The assumption that the price of gasoline and sugar is not affected by the system seems realistic when one considers the large scale and scope of these markets. However, there are two aspects which require further notice. The first is that Brazil is the single largest sugar producer in the world; therefore it is likely that *large changes* in the supply of sugar will affect prices. However, this required the change in sugar prices to be very substantial. Secondly, in the gasoline market, it is possible that the price of gasoline follows the price of ethanol in order to remain competitive; gasoline products generally are able to respond to market forces as the profit margins on gasoline are relatively high. In interpreting the results of the simulations, it is imperative to take into account the price level of sugar and gasoline and ideally, one should run the simulations for different price levels for these commodities as has been done in this thesis.

7.4.2 *The Use and the Value of the Model*

The NetLogo model itself has two main functions. First of which, is the generation of results under the defined simulation settings; this has been documented already in this report. The purpose of these results is explore the BioJet model in order to answer the underlying research question of how the bio-ethanol market may behave in terms of biokerosene implementation in Brazil. Based on these results, certain conclusions and policy recommendations may be made. These are presented in the next Chapters (8 and 9).

However, the NetLogo model has an added purpose which has not been extensively discussed in this report and that is that the NetLogo model should show a human user, in real-time, how the model and system behaves in an interactive setting; this is the so-called “model play”. The main advantage of this element is that users can find out for themselves how certain policy changes or other external changes (commodity prices) directly affect the system behaviour. This interactive element can act as an educational tool for the user in the sense that it makes assumptions regarding biofuel markets more explicit. Even if the NetLogo model shows behaviour which the user does not expect or understand, it encourages a discussion and further thinking, into the previous assumptions of the user him/her self and others. This process may facilitate the gaining of new insights for the user which may not have arisen without the explicit use of the model (*De Bruijn & Ten Heuvelhof, 2008*).

The BioJet Model has incorporated the use of individual actors (agents) to simulate the behaviour of a biofuel market (Brazilian Bio-Ethanol). The use of ABM enables the user to analyse how the low level decision making assumptions (of individual refineries, users and distributors) facilitate the emergence of an aggregate market pattern. The ABM methodology has enabled the assigning of individually different social and technical properties to actors in a relatively straight forward manner; particularly the flex nature of the car users in Brazil has been adequately modelled using this element that is characteristic for ABM. The unique contribution therefore of this model, relative to existing research on the biofuel market, is the local scale (individual perspective) modelling of a multi-actor market, which is composed of actors with a high variation in individual properties. The insights gained during the conceptualisation and the running of the model, which would not have been possible using a top-down perspective, can be regarded as the main *beneficial result* of this model.

Interpretation of the BioJet Results

Considering the scope of this research, the underlying research problem and the problem owner, a full discussion of how the results of the previously discussed experiments should be interpreted and what the implications are of these results, is warranted in Chapter 8.

7.5 Conclusions


The fourth research sub-question can be answered on the basis of this chapter.

“What production and consumption patterns arise of bio-ethanol based kerosene in Brazil in terms of volume and pricing relative to fossil fuel kerosene as a function of different measures?”

The production of biokerosene is shown to increase given a certain price level for biokerosene. In relation to the consumption of biokerosene, the assumption is made that all production volumes are consumed (equal). The price of biokerosene is shown to strongly correlate to the price for other biofuel products in the system; hydrous and anhydrous ethanol. Relative to kerosene the price of biokerosene is significantly higher, even when considering a highly optimistic assumption on technology learning and economies of scale.

Government measures which discourage automobile biofuel use show to be effective at reducing biokerosene prices. An abolishment of government measures collapses the biofuel market in terms of demand, decreasing the price of biokerosene until close to raw production prices.

Biokerosene prices are strongly affected by external price increases of sugar, sugarcane and oil. However the behavioural patterns are unchanged.



Chapter 8 Implications & Opportunities

In this chapter:

- 8.1 Scenario Feasibility Discussion
- 8.2 Biokerosene Policy Implications of the Model Results
- 8.3 Transferability to a Different Setting
- 8.4 Opportunities Discussion
- 8.5 Conclusions

8.1 Scenario Feasibility Discussion

In the previous Chapter, a description is made of a number of scenarios which were investigated in the BioJet model. The results of these experiments are discussed, particularly in terms of the overall system behaviour and system patterns. Considering a defined set of conditions, it is concluded how the bio-ethanol market and biokerosene market may behave. However, the feasibility of the scenarios which were defined and experimented with has not been discussed; this is precisely what this section of the thesis will aim to explore. How realistic are the sets of conditions on which the BioJet model results are based? When would these conditions arise in the real-world, and how realistic are the system patterns shown in the model in the real-world?

8.1.1 Free Market Scenario

The sets of conditions in this scenario, which entails the complete elimination of all government policies in the fuel market are very unlikely from a *political point of view*, but very well possible from a *technical point of view*. Policies regarding the fuel market are always a matter of great political complexity. Given the natural inelasticity of fuel demand, fuel taxation is a prime means for governments to increase revenue (necessary source of government income). At the same time, the taxation of fuel is highly criticized by citizens as it is often unavoidable as citizens are highly mobile; this explains the inelasticity principle of fuel (*Charlita de Freitas & Kaneko, 2011*).

In the Brazilian setting, it can be argued that the military junta governance at the time of the introduction of the bio-ethanol market in the fuel market, was a main facilitator in order to be able to proceed with the aggressive sets of policies which helped achieve a strong bio-ethanol market in Brazil. The same is true given the aggressive policies set out by the United States and European Union governments in terms of biofuels; this is driven by a political ambition to be more fuel independent (from imports) and to strengthen the respective agriculture markets (*Banse, Kemfert, & Sorda, 2010*). Given the current government situation, it remains to be seen whether the government would be able to proceed with such measures in the modern day setting. Particularly increasing taxes on ethanol fuels in parity with the tax on gasoline (level playing field) would increase the prices of fuel altogether which may lead to strong public resistance. On the other hand, a decrease in gasoline taxes to reach parity with ethanol taxes would lead to a significant drop in tax revenue for the government (*Cortez & Rosillo-Calle, 1998*).

In the scope of government policy with the implementation of biokerosene, the results of the BioJet model indicate that a level playing field in fuels may indeed cause biokerosene prices to be more competitive with regular kerosene. This is in part due to the “loss” of the car ethanol market, which cannot compete with regular gasoline on level playing terms and also due to the fact that kerosene fuels already are untaxed (*ICAO, 1944*). Furthermore, were the government to strive to maintain a car ethanol market, it is clear that a blending mandate is absolutely necessary. Considering other biofuels markets around the world, this latter aspect seems to be the main necessary element in any government policy for implementing a biofuel market.

All in all, the free market scenario certainly is possible from a technical point of view, however given the political ramifications of an entirely liberal fuel market to the current taxation system, it is concluded that the feasibility of a free market situation in a real-world setting is extremely low. However, what the BioJet model does show is, how “unfree” the fuel market is in terms of biofuels. The much discussed subsidy free “success” of Brazilian biofuels (*Banse, Kemfert, & Sorda, 2010; ANFAVEA, 2013*) is not what it may appear to be as is made clear in Figure 74.

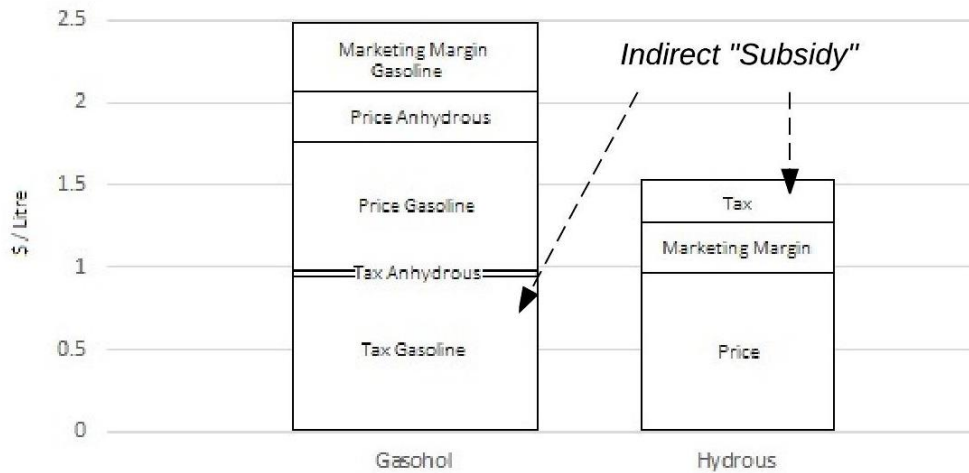


Figure 74: Price Breakdown of Gasohol and Hydrous Fuels in Brazil in 2011 (UNICA, 2014)

8.1.2 Automobile Shift Scenario

Given how politically unrealistic a free market in the fuel sector may be, how does the set of policies aimed to discourage biofuel use in the car sector fit in? From a technical point of view, as is the case with the free market scenario, the implementation of policies which increase hydrous taxes and decrease blending mandates are certainly possible. Politically, the situation may be more complex given the same aspects mentioned in the free market scenario. However, considering the automobile shift policy, it is assumed that a government may do this in order to prioritize and incentivize biofuel production for other means (aviation in this case). Politically, such government ambition may seem much more likely given that the effects of the policies do not mean a lower revenue from automobile taxes, as a matter of fact tax income may even become larger for governments as users are paying a higher tax for hydrous fuel.

Furthermore, if one would consider the current policies around the world by governments to incentivize electric cars, this scenario seems more plausible; a shift will occur from biofuel cars to electric cars which are deemed more sustainable from a greenhouse gas emissions perspective, assuming the electricity is generated by sustainable means (*Ziolkowska, 2013*). Essentially the biofuel market would by then be encouraged to use the available biofuel capacity in order to generate biokerosene. In addition to this,

such policy would also enable the aviation sector to be able to achieve its ambitions of reducing the carbon footprint of its operations; something which is assumed can only be achieved through sustainable biofuels.

The feasibility of this scenario, hinges entirely on the fact whether actors within the biofuel system is willing to finance the added costs of biokerosene in relation to kerosene. Even though the results of the BioJet model show that the scenarios significantly decrease biokerosene prices, the fact remains that the price of biokerosene will always be higher than kerosene (given no unprecedented increases in kerosene prices).

All in all, the feasibility of this scenario is considered to be relatively likely, also from a political point of view given that from the perspective of the most important actors in the biofuel market, the negative impacts can be mitigated. For some actors the scenario presents clear opportunities, particularly from a sustainable energy perspective.

A schematic overview of the real-world positions in which the scenario may be feasible is shown in Figure 75. The underlying notions in this respect are based on the perspective and interests of each actor (*De Bruijn & Ten Heuvelhof, 2008*).

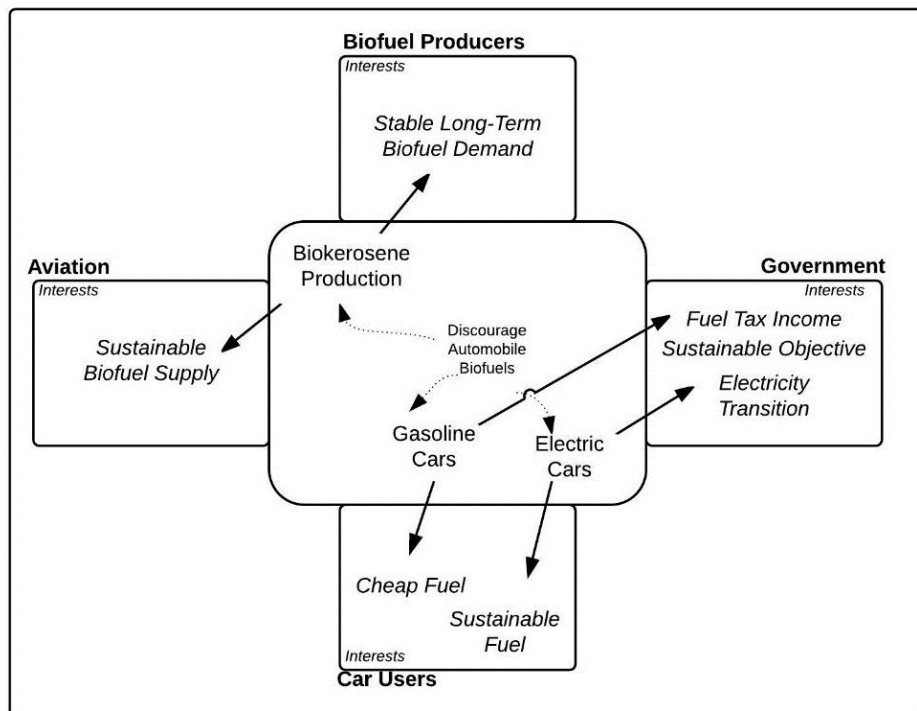
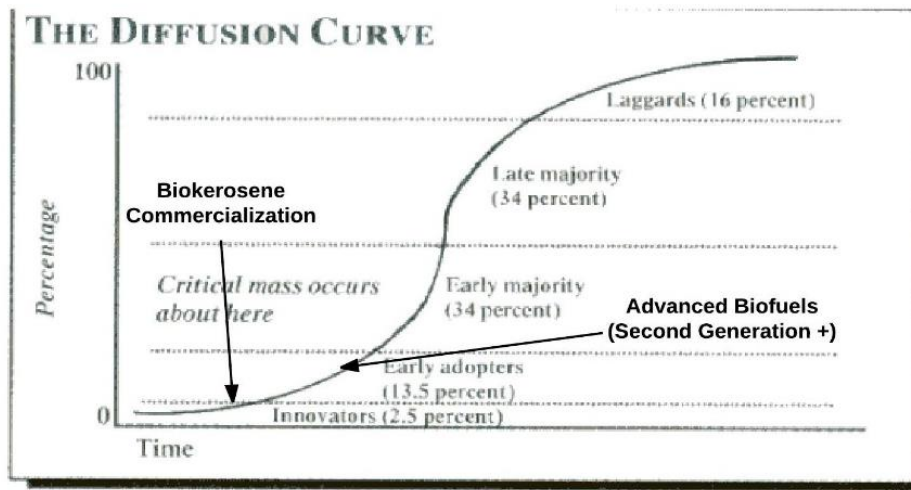


Figure 75: Biofuel Actors, their Positions and Their Implications for a Non Automobile Biofuel Scenario

8.1.3 Biorefinery Diffusion Scenario

The diffusion of biorefineries throughout the biofuel market is entirely feasible from the political point of view, in essence the government has no control over this aspect. However, the technical capacity, high level of economic uncertainty and the large investments required for implementing biorefineries (facilities which produce biokerosene) means that this scenario is not straight forward. However, at the moment there are relatively many initiatives underway for building biorefineries. A full overview of these initiatives, their capacities and the feedstock used is shown in Appendix E. Furthermore, the pioneering of commercial cellulosic ethanol production is seen as a crucial step towards the widespread adoption of biorefineries around the world (POET-DSM, 2014).



Source: Based on Everett Rogers, *Diffusion of Innovations*, 1995 (pp. 262, 314)

Figure 76: Diffusion Curve, Indicating the assumed early steps of biokerosene production in relation to the "mature" biofuel market.

In the real-world setting, considering the typical stages of diffusion of innovations, the commercial development of advanced biofuels is at a very early stage, see Figure 76. It remains to be seen if indeed the development of advanced biorefinery facilities will push through the market, something which has been assumed to be able to happen in the BioJet model. Much of the potential for diffusion of biofuel production technology hinges on the presence of open innovation; technology learning on a large scale (throughout markets) can only be significant if firms are willing to share technical developments in the field of biotechnology. This aspect is highly complex as the relatively large upscale investments which are required in biotechnology, naturally lead to a business stance of protecting investments (patent oriented). This dilemma has been widely observed in the field of biofuels (Mabee, Saddler, Sims, & Taylor, 2008) and poses as a critical inhibitor to the assumption of technology diffusion throughout the biokerosene market. Nevertheless, as Ziolkowska (2013) points out, merely the knowledge of a successful commercial application of biokerosene production may be the catalyst which is needed to attract larger scale investments and government/industry attention which is needed for significant growth in the biokerosene sector even when the technology itself remains confidential.

All-in all, as is usually the case with novel commercial applications of technology (*Mabee, Saddler, Sims, & Taylor, 2008*) a widespread diffusion of biorefineries is difficult to predict. However given the scenario used in the BioJet model, which assumes diffusion based on the economic success of existing biorefineries, any commercial scaling up of biokerosene production with price competitive fuel is assumed likely to lead to a diffusion of biokerosene production given the significant demand market which is already in place in the aviation industry. The demand for the product, given a condition of price competitiveness to kerosene, relative to the size of the current biokerosene market (non-ethanol based) is significantly large; this presents as a opportunity for the drive towards biokerosene production should this become economically viable as the demand market has already guaranteed, in essence, the off-take of price competitive sustainable biofuels (*SkyNRG, 2014; Lufthansa Group, 2014; IATA Fuel, 2009; ATAG, 2009*).

8.1.4 Sugarcane, Sugar and Oil Price Shocks

It goes without saying that the prices of commodities, particularly oil, are highly volatile and unpredictable in the real-world (*Energy Charter Secretariat, 2007*). Therefore a scenario in which prices suddenly shift is very likely ; as such any study of biokerosene (and biofuel) prices must incorporate the effects of these external prices to demand and production dynamics of these biofuels, particularly as the prices of the biofuels are largely directly correlated (*BNDES & CGEE, 2008; ATAG 2009; Carriquiry, Du, & Timilsina, 2011*). The price shocks which have been conducted in the BioJet model indicate indeed that these shocks have significant impacts on the overall price levels of kerohol. However, the system has shown that, considering no further price changes, the prices reach a certain equilibrium which is lower than the initial prices directly after the price shocks. This results indicates that the market is able to react to a changing pricing environment; particularly in terms of sugarcane prices (and as such any feedstock source for biofuels) this aspect is critical to the overall price levels of biofuels.

In terms of a sugarcane price shock, in the real-world the actual monetary price level of sugarcane does not behave as volatile as the oil price, this is a direct result of the CONSECUNA system which means that sugarcane price is in fact an internal pricing element in the bio-ethanol market (*Cortez & Rosillo-Calle, 1998*). However, as has been explained throughout the report, the changing supply of sugarcane through weather factors and other external factors means that in real terms (in terms of available supply); sugarcane prices are highly volatile. Therefore a true sugarcane price shock is highly likely as can be seen by the 2011 sugarcane crisis in Brazil which causes significant supply shocks to the system, and caused the Brazilian to have to import at a high cost, ethanol from abroad (*De Gorter, Drabik, Kliaugas, & Timilsina, 2013*).

Regarding the feasibility of the sudden price shocks which have been used in the scenario, an example of such an event occurring can be found in the Appendix I. It can be concluded that the price shocks are a highly realistic scenario.

8.2 Biokerosene Policy Implications of the Model Results

A recap of the BioJet results and the main conclusions which can be drawn from them is given below in Figure 77. It is important to note that these are overly simplified conclusions; for a full background on how these conclusions have been drawn and base on what system conditions and assumptions one is referred to Chapter 6 and Chapter 7.

System Assumptions	<p>Processors of feedstock can choose to produce any type of biofuel</p> <p>Processors of feedstock are profit seeking</p> <p>\$ biokerosene production >> \$ regular biofuel production</p> <p>Distributors (biofuel suppliers) avoid supply shortages at all cost</p>	<p>Users of biofuels will choose the cheapest alternative, even if its non-biofuel</p> <p>If biokerosene is produced, there is a demand for that fuel, independent of cost</p> <p>Technology Learning is an Open Innovation; the whole system profits</p> <p>Biokerosene is a true drop-in fuel</p>	<p>Feedstock Prices are independent of demand, Feedstock supply is fixed</p> <p>Fuel Demand is fixed; inelastic</p> <p>Sugar Price and Oil Price is external</p>
Main Conclusions	<p>Flexible Production and Demand is essential for lower biofuel prices</p> <p>Automobile Fuel Market is not a Level Playing Field; Biofuels have policy support</p> <p>The competition for the same feedstock is the main driver for higher than production cost biofuel prices</p>	<p>→</p> <p>→</p>	<p>Biofuel pricing behaviour is not affected by external pricing</p> <p>Government Policy is biofuel Price driver</p> <p>Biokerosene prices will not reach regular biofuel price parity, and thus also not kerosene price parity</p>

Figure 77: Main Conclusions of the BioJet Model

8.2.1 Government Point of View

The government influence on the biofuel markets is not surprising; much of the implementation of biofuels in Brazil (and around the world for that matter) is driven by strong governmental support (Banse, Kemfert, & Sorda, 2010). However, in terms of the motivation of governments in supporting a car biofuel market, the following three concepts are strongly present (Banse, Kemfert, & Sorda, 2010; Carriquiry, Du, & Timilsina, 2011).

1. Energy Supply Independency
2. Utilisation of agriculture economy
3. Sustainability

When one considers the historical timeline of biofuel policies in terms of these three motivations, the following steps can be observed in Figure 78, particularly when one considers the Brazilian, U.S and EU cases (Banse, Kemfert, & Sorda, 2010; Cortez & Rosillo-Calle, 1998; Carriquiry, Du, & Timilsina, 2011).

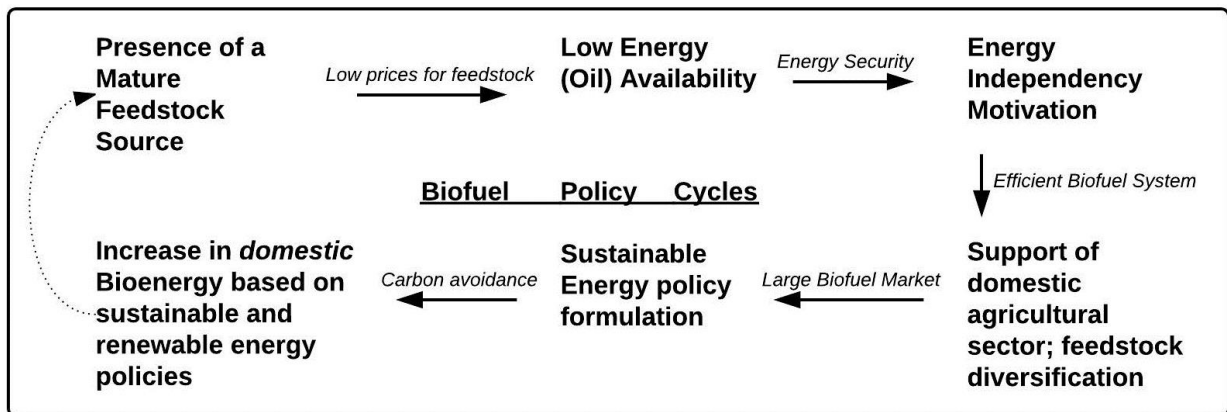


Figure 78: Biofuel Policy Cycles from a Government Point of View

From a government viewpoint, the implementation of biokerosene in the aviation sector affects all three main policy drivers. The willingness by airlines to consume (sustainable, price competitive) biofuels and the projection that aviation biofuels are a transitional fuel for the coming decades, in conjunction with current kerosene consumptions adds a level of certainty to the biofuel market in terms of future demand. This is in direct contradiction to the policies regarding the car industry; as well as maintaining a strong biofuel directive for car transport, governments also support the adoption of electric vehicles in the car market. From a long term strategic perspective, these policies are competing with each other. A successful electric car market will hurt the automobile biofuel market and a successful biofuel market will hurt the adoption of the electric car market. This is in line with the results of the BioJet model which show that users who are seeking minimum costs, will demand the cheapest fuel product, with that fuel product being the product with the higher level of availability.

Furthermore, car users are shown to be strongly inelastic to gasoline price changes (*Jacobsson & Lauber, 2004*), which indicates that the demand for gasoline by the average car user is strongly independent of external factors such as price, but also sustainability aspects. It has also been observed that the sustainability behaviour of car users is predominantly caused by government measures which either encourage more sustainable (fuel efficient) cars or discourage unsustainable (fuel inefficient) cars (*Jacobsson & Lauber, 2004*). Additionally, the adoption by car users of electric vehicles is strongly based on government subsidies for the cars. In contrast to the car market, actors in the aviation industry are in the process of actively seeking to implement biofuel within their fuel portfolio. Airlines, being large and visible firms, are held accountable in their operations, specifically in terms of sustainability in order to maintain their organizational legitimacy (*Kostova & Zaheer, 1999*). This latter aspect is lacking in the individual car market and acts a significant policy opportunity to governments; a shift in biofuels towards an aviation market, while economically and technically more complex, has the advantage of creating a demand market which has for itself formulated an a policy drive towards biofuel use (*Climate-KIC, 2014; Lufthansa Group, 2014; SkyNRG, 2014; ATAG, 2009*). As the BioJet model has shown, this lack of a significant drive by the demand market for biofuels based on a pricing decision creates a highly volatile biofuel market, which without strong governmental support, can cease to exist in rapid fashion. Furthermore, the support of the automobile market creates an additional barrier towards the large scale use of biofuels by the aviation sector.

8.2.2 Aviation Industry Point of View

From the aviation industry point of view, the BioJet model shows how the implementation of biokerosene at cost competitive prices, considering the assumptions made in the model, is a very complex matter.

The BioJet model, from a market perspective shows how the competition with automobile fuels inhibits any possibility of a large scale biokerosene production. Following from other real-world observations, a number of reasons for this can be identified:

1. *Technical Requirements of Jet fuel versus car fuel*

As mentioned in this report, the technical requirement of a drop in biofuel imposes the production cost of biokerosene with a *price premium* over automobile biofuel.

2. *Kerosene Prices are lower than Gasoline Prices*

The fact that in the biofuels field, the price of biokerosene is higher than the price of regular biofuels is not reflected in the prices of the conventional oil based products. The nature of kerosene production, which in comparison to gasoline production is not significantly more difficult, in combination with the fact that most governments tax gasoline and not kerosene, means that the *price premium* for biofuels in the aviation sector is by definition always higher than that for cars.

3. Government Biofuel Policies

Point 1 and point 2 imply that the aviation use of biofuels necessitates a higher financial cost than is the case for cars. Furthermore, the fact that most gasoline must be blended with biofuel, ensures direct competition to the aviation sector for the biofuel. In the competition with the car market for biofuel, the higher premiums required for biokerosene and the inelasticity of car users fuel demand to fuel prices gives aviation biofuel demand a significant financial disadvantage.

4. Low Financial Capacity : Global competition

The aviation industry is a global market with high competition and very low margins. This latter aspect makes it nearly impossible, considering the mentioned points, for an individual airline to implement biokerosene on a large scale without incurring significant financial sacrifices relative to airlines who do not consume biokerosene. Furthermore, airlines are also unable to take large financial risks when investing in biokerosene (*Qantas, 2013*).

5. Sustainability Requirements

A point which has not further been mentioned throughout this thesis as the focus has been on the market dynamics of biofuels in general, is the fact that in conjunction with the push towards biofuel use on sustainability grounds is the high level of sustainability criteria imposed on biofuels by the aviation sector, especially when compared to the competing automobile market where noticeably lower levels of attention are paid to the strict sustainability of biofuels. This aspect leads to great difficulty in sourcing available feedstock for biokerosene implementation which incurs additional costs with respect to the conventional biofuels (*BNDES & CGEE, 2008; Ziolkowska, 2013; Mabee, Saddler, Sims, & Taylor, 2008*).

It is clear where the difficulty in biokerosene implementation arises in economic terms. With respect to the mentioned points, the BioJet model has shown two significant issues which are particularly relevant. The first being that it has been made explicit how the competition with the automobile market, which is directly and indirectly backed by government policies (this is true for the Brazilian case but also for all other major biofuel markets) means that biokerosene prices will not be able to reach kerosene price parity. The second issue which is made clear through the model is that an important driver for lower biofuel prices is the ability by producers to respond to changing market dynamics. In the potential implementation of biorefineries which can produce biokerosene and other biobased products, a clear point which can be taken by the BioJet model results is that these facilities need to be flexible in their production of feedstock output; additionally the aviation actors need to be flexible in its demand for the biofuels in terms of the volume consumed and the feedstock source.

Finally, the assumption that an increase in kerosene prices will eventually lead to biokerosene price parity does not hold as long as the same is true for the competing automobile biofuel market. Furthermore, considering the margins which are present in terms of crude oil prices, the historical movement of the oil price and the impact oil prices have on other forms of energy, any assumption made based on an expectation of future oil prices is by definition highly uncertain itself (*Energy Charter*

Secretariat, 2007; Cheze, Gastineau & Chevallier, 2011). One is further referred to Appendix I which illustrates the uncertainty regarding the oil pricing.

8.3 Generalisation of the Model

The research which has been conducted and described in this thesis, has used the Brazilian bio-ethanol market as case study in order to study the behaviour of a large scale biofuel market and the emergence of a new system element, biokerosene production and demand. As such, all conclusions based on BioJet model are only strictly valid when considering the assumptions which are derived from the Brazilian bio-ethanol market. However, from a practical point of view, one would want to extend conclusions made to other bio-ethanol/biofuel markets in other locations and under different settings.

Regarding the transferability of the results of the BioJet model, a simple illustration is shown which emphasizes the market elements under which the BioJet model has been implemented and under which the BioJet model holds for other settings. It is important to note that the BioJet model is in essence an economic Agent Based Model of typical market behaviour in terms of producers and consumer choice.

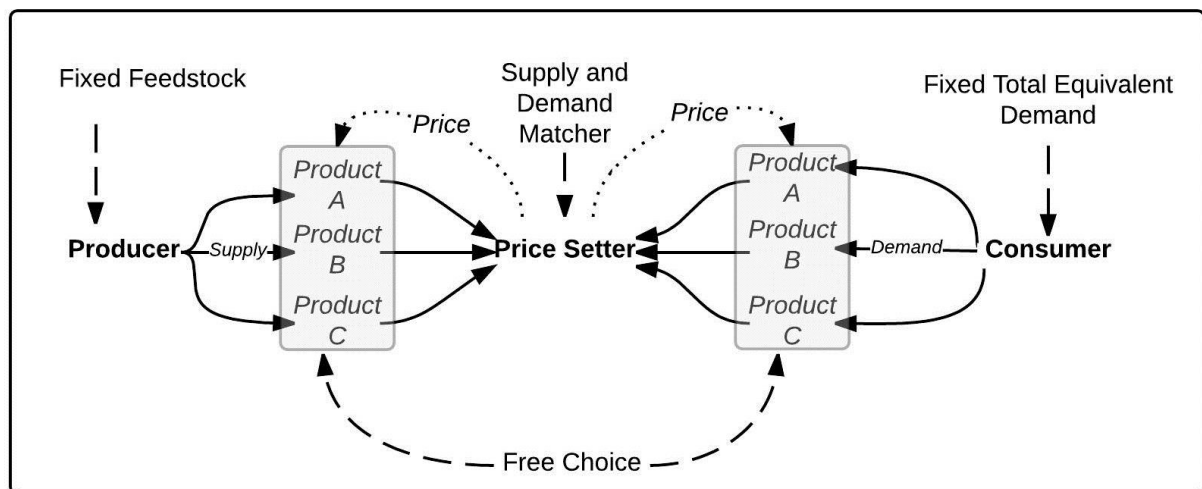


Figure 79: Most Important Conditions under Which the BioJet Model May Be Transferred

Regarding the conclusions which are made of the BioJet model, considering any biofuel market which makes use of a blending mandate and/or gasoline tax the overall assumptions holds that the competition for biofuels will raise the overall prices. The blending mandate, considering the obligatory nature of the policy, in a way enforces strong competition for the biofuel in the face of a different end-product for the same feedstock source. For a full overview of the assumptions under which the BioJet model has been made and under which the BioJet model may be valid in a different setting, one is referred to the model formalisation and conceptualisation Chapters (Part 2).

8.4 Opportunities Discussion

The high level ambition of this research and thesis is to gain an understanding into how biofuel implementation may arise in the case of the aviation sector. Following from the BioJet model background and exploration, the overall research into biofuel markets, and the in-depth analysis of the aviation biofuel setting, a number of opportunities have been identified. These can be split with regards to their relevance to the biofuel competition between automobile users and the cost competitiveness to regular kerosene.

8.4.1 In Relation to Biofuel Competition

Throughout the research the following opportunities and advantages have been identified with regards to the competition between automobile biofuels and aviation biokerosene.

- i. Decentralized versus centralized logistics of biokerosene poses as a potential advantage. The exact amount of this advantage is unknown, but assuming the use of existing kerosene infrastructure, a significant increase in biokerosene volumes will create ever increasing economies of scale gains in terms of logistics relative to automobile biofuels.
- ii. The increase in electric vehicles, and the proposed infrastructure transition towards electric energy, presents the biokerosene case with the possibility of an increase in biofuel capacity due to the switch by car users away from biofuel altogether. From a sustainability point of view, it can be argued that biofuels for cars only stands in the way of a potentially more sustainable means of car transport. The lack of alternatives in reducing greenhouse emissions and securing other fuel supply strengthens the case for biofuel use for aviation
- iii. The global and large scale nature of the aviation sector means that it is possible to establish certain Bioport locations around the world from which international airlines can receive biokerosene. This increases the flexibility of the system in terms availability; the feedstock is not evenly spread across geographic locations. Furthermore, the producers of biokerosene are guaranteed of a large, stable (aviation is in principle committed to biofuel use) and predictable (scheduled flights) demand market as opposed to the car market which depends on government policy, and individual human behaviour.
- iv. Low refinery margins in the downstream oil sector presents a potential opportunity for the petrochemical industry to explore the biokerosene production pathways and join in with the biokerosene implementation; the complex nature of biokerosene production, requiring highly specialized technical processes of which the refining industry has a lot of experience, presents the biokerosene case with a higher upside (and demand) for refineries, than the relative simple production of automobile biofuel.

8.4.2 In Relation to Kerosene Price Parity

In relation to the price parity with kerosene, the opportunities in regards to biokerosene implementation are much more limited. Price parity with kerosene entails that the biokerosene price nears (equals) the price of kerosene. As has been shown throughout the thesis, this situation is highly unlikely, even given a highly optimistic assumption regarding economies of scale and technology learning. As the BioJet Model shows, any competition with other biofuel markets causes the biokerosene price to even further depart from kerosene parity. Furthermore, when comparing biokerosene with regular kerosene, the fact that biokerosene is premium biofuel product meaning that it is more expensive than other biofuel alternatives and that kerosene is in essence a by-product of crude oil processing, presents the biokerosene implementation on a cost competitive level with further difficulties. From the BioJet model, two things are clear in order for biokerosene to potentially near kerosene prices.

- i. First is the elimination of the intra biofuel competition; this may be done by eliminating the other demand for biofuels altogether (as discussed in the thesis) or by differentiating the production of biokerosene from the other biofuels. For instance, a feedstock to biokerosene specific pathway, which is unique to biokerosene production may eliminate competitive pressures from other biofuels. Also, the development of a so-called biocrude, from algae or pyrolysis (*Carriquiry, Du, & Timilsina, 2011; Mabee, Saddler, Sims, & Taylor, 2008*) implies that biokerosene may follow the same pathway as conventional kerosene. In this scenario the price of the biocrude versus the price of crude oil is the determinant of kerosene parity. It must be noted that the latter scenario considers highly immature and uncertain technology and is not expected to be widely available in the near future at competitive prices (IATA Fuel, 2014).
- ii. The second point in biokerosene nearing kerosene price parity is related to developments in general biofuel production pathways. Any significant decrease in overall biofuel prices will also affect biokerosene prices, even under a competitive scenario with biokerosene and regular biofuels. A prime example of this latter aspect is the development of commercial cellulosic ethanol; the potential of this technology to significantly increase biofuel supply is expected to reduce biofuel prices. A significant increase in biofuel capacity, assuming the automobile market does not significantly increase (no change in blending mandate), will reduce biokerosene prices towards production prices; as has been shown in the BioJet exploration.

Considering the high level of difficulty of biofuels competing with oil based fuels on a price competitive basis and the fact that the automobile biofuel market is relatively mature and much larger than the biokerosene market, it should not be expected that biokerosene demand will be a main driver in the reduction of overall biofuel prices. Therefore, the most realistic gains which can be achieved in the biokerosene implementation is in the area of biofuel competition between aviation and other biofuel users and within the aviation industry itself. The fact that biokerosene is non-differentiable product from regular kerosene implies necessity of the price parity condition with kerosene in the first place. Would airlines be able to differentiate themselves in the eyes of the consumers through the use of biokerosene, the kerosene price parity conditions could be made redundant.


8.5 Conclusions

The fifth research sub-question can be answered on the basis of this chapter.

“What factors may significantly increase the production of bio-ethanol based kerosene?”

- i. Government policies aimed at *discouraging* automobile biofuels and generally avoiding large scale (unfair) competition for biofuel.
- ii. Electric transition of the automobile market; which leads to the loss of biofuel competition.
- iii. Flexibility of biokerosene production and consumption.
- iv. Overall; a price premium relative to kerosene for biokerosene is unavoidable. Therefore, large financial investment is a substantially important factor.

All in all, private investment and a change in government policy is imperative. Current policies in fact make it impossible for any biokerosene emergence which is price competitive to regular kerosene. These policies need not be focussed on aviation itself directly.



Chapter 9

Conclusions & Recommendations

9.1 A Conclusion to the Research Question

An in-depth analysis has been carried out on the Brazilian bio-ethanol market in conjunction with an analysis of a biofuel aviation demand stream within this setting. Considering the steps which are taken, it is easy to forget what the overall purpose of the research is.

This thesis started out with the main research question, which was formulated as the following:

What measures are necessary to establish a bio-ethanol based aviation kerosene supply chain within the existing bio-ethanol market in Brazil and what projected impacts might these have on the bio-ethanol market behaviour?

A simplified answer to this research question is the following;

- i. *(Measure)* Somebody or something in the system will have to finance the price difference between kerosene and biokerosene. This premium is unavoidable if one considers a competitive market; the size of the premium however can be affected.
- ii. *(Measure)* To affect the size of this price premium, a government measure is necessary; a level playing field for fuel is required either through a change in the competing road transport fuel market or through a change in the aviation market. Considering the global and extremely price sensitive nature of the aviation industry, policies aimed at the road transport market seem the most feasible from a political point of view.
- iii. *(Measure)* In the Brazilian ethanol market, the technical capacity of biofuel producers to be able to produce and choose to produce biokerosene is logically a strict requirement, related to technical readiness.
- iv. *(Impact)* The impact of the additional choice by Brazilian refiners to produce biokerosene leads to higher overall prices for biofuels if the biokerosene market is considered large enough (no upper limit); and with that higher overall profits for biofuel producers. A small scale biokerosene market with an upper limit to biokerosene demand will not impact the biofuel market, however the price for biokerosene remains high due to the road transport competition.

The overly simplified answer to the main research question, is for a large part obvious; it is widely acknowledged that the competition for biofuels, particularly on a non-level basis presents the aviation sector with a very difficult position in terms of the commercialization of aviation biofuels. Furthermore, it is already known that the implementation of biokerosene production is largely dependent on the technical development of the different pathways. Finally, the premium cost condition has already moved airlines into finding ways in order to finance this premium, be it through sponsorship programs, public relations opportunities or opportunistic investments and partnerships.

The question is thus raised; what has this research and thesis added to the information and insights which are already known across the industry?

In reaching the relatively simple conclusion to the main research question, an extensive Agent Based Model has been devised of the complex bio-ethanol market. Through the modelling approach of this market, a clear and explicit understanding has arisen of the unique flexibility of this market. Furthermore, it has been shown explicitly, how and why biokerosene competition with other biofuels causes a structural price premium which in the face of a government imposed fuel blend for regular road transport, makes the cost competitive implementation of biokerosene nearly impossible.

Furthermore, through the model conceptualisation and experimentation, an understanding is reached of how the external prices of not just the oil price, but more importantly the price of sugar (direct biofuel competitor) influence the supply, demand and prices of bio-ethanol and biofuels in general. It is shown that the flexibility of the biofuel market in terms of production is essential in order to maintain lower and more stable prices and in order for producers of biofuels to gain a healthy market position; and thus ensure a supply of biofuel.

The Brazilian bio-ethanol market, which is famous for being an example of a successful biofuel market, is shown not be able to exist without strong government policies. The most important set of policies being the blend mandate in conjunction with relatively high taxes on gasoline; this set of policies facilitates the choice of car users to opt for hydrous ethanol. Even at times of high ethanol prices, the government mandate ensures the existence of the bio-ethanol market. What is interesting about the latter conclusion is that the Brazilian market is not focussed on sustainability; the drive for biofuels is based on purely economic (lower fuel imports and healthy sugarcane industry) and political (fuel independence) motives. In conjunction with the favourable conditions in Brazil concerning the climate and the availability of a mature biofuel feedstock, the fact that the Brazilian biofuel market still requires strong policy interventions, as is explicitly shown through the model experiments, is a strong warning signal towards the hope of aviation biofuel players in establishing a large scale, price competitive, sustainable biokerosene market.

The contribution of this research can be summed up by the following;

1. The analysis from a system modelling perspective of the Brazilian bio-ethanol market in terms of economic market behaviour; the analysis of Brazilian bio-ethanol using ABM is novel. Furthermore, the use of ABM for market models is also relatively new, particularly in terms of price setting within a supply chain. The experimentation of an additional biofuel products (biokerosene) is also a new area of research within the existing biofuel market from a simulation modelling setting.
2. The explicit exploration of how biokerosene pricing interacts with an existing biofuel market is not seen in the current biokerosene paradigm. Most of the attention is on the technical production capability where the prominent assumption is made that the economics of biokerosene will improve once up scaling is completed. This research shows that this assumption may not entirely hold considering a competitive biofuel market with other purposes (road transport). Industry stakeholders are already aware of the road transport competition aspects, however this research makes this explicit through simulation modelling.

Thesis Perspective

To put this thesis into perspective, it is important to identify the fields which are related to the environment within which this research and the results are found. This can be seen in Figure 80. There are three main levels within this thesis finds itself. The direct level is in the field of biofuels for aviation; the topics which are highly relevant in this arena are based primarily on the economics, the technical capability and the sustainability of the biofuels. The sustainable aviation fields itself finds itself within the general biofuels field; in this field the relevant topics are more focused on feedstock aspects such as the sourcing, competition and scale of the feedstock. The biofuels field itself is part of the wider energy and climate paradigm; it is one of many avenues for a reduction of energy dependence and carbon emissions. Figure 80 shows some of the main relevant topics which are present in each field grouped according to their relevance to each other; red fields correspond to *market* related aspects, blue fields correspond to *technological/technical* aspects and the yellow fields indicate a more *institutional/public* relevance.

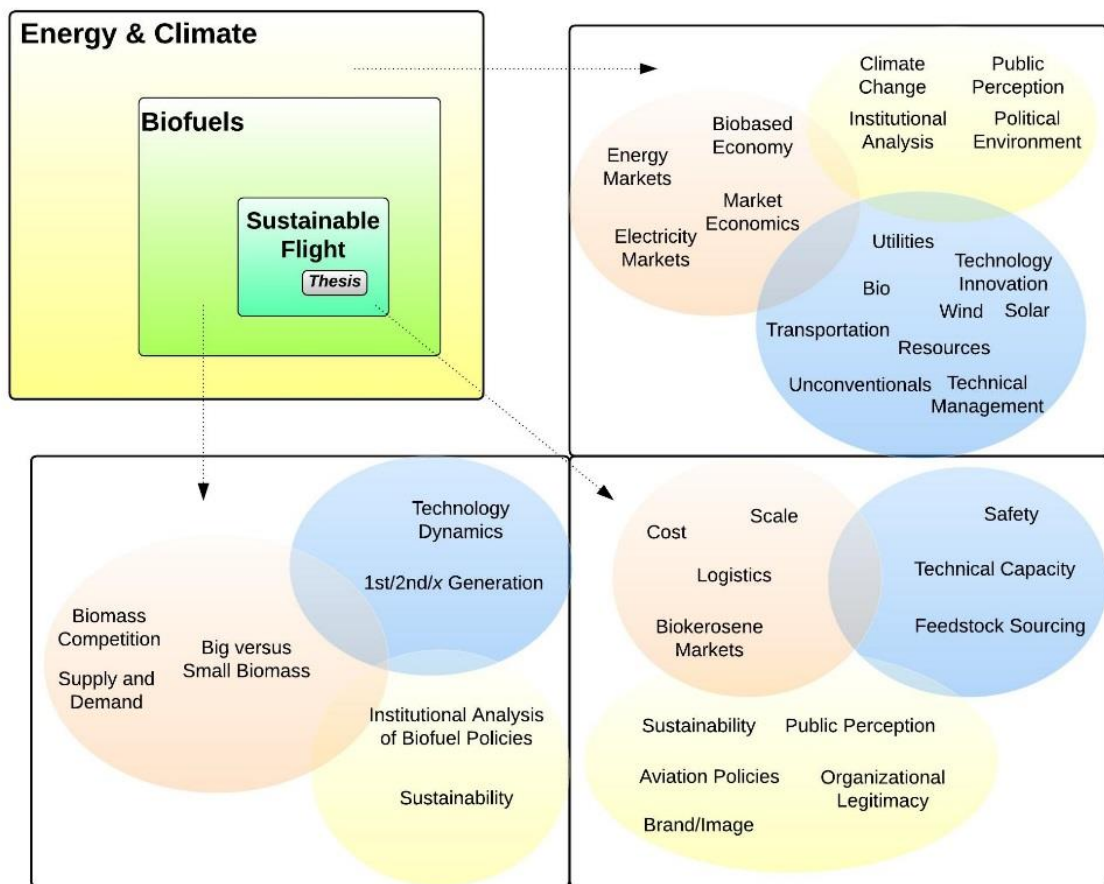


Figure 80: Thesis Put into Perspective with the Greater Energy and Climate Field

The conclusions from this thesis are not only relevant for the low-level field of aviation biofuels, but they transcend across all layers. This is important to realize and this also further affects the perspective from which the recommendations are made with regards to further research and the application of the results in the industry and public policy.

9.2 Recommendations for Further Research

In terms of the academic research which has been conducted throughout this thesis, two different areas are identified which warrant further research; this is visualized in Figure 81. The core elements of the research are present and can be roughly divided between the modelling aspects of the thesis, and the total system analysis of the biofuel environment on which the modelling was based.

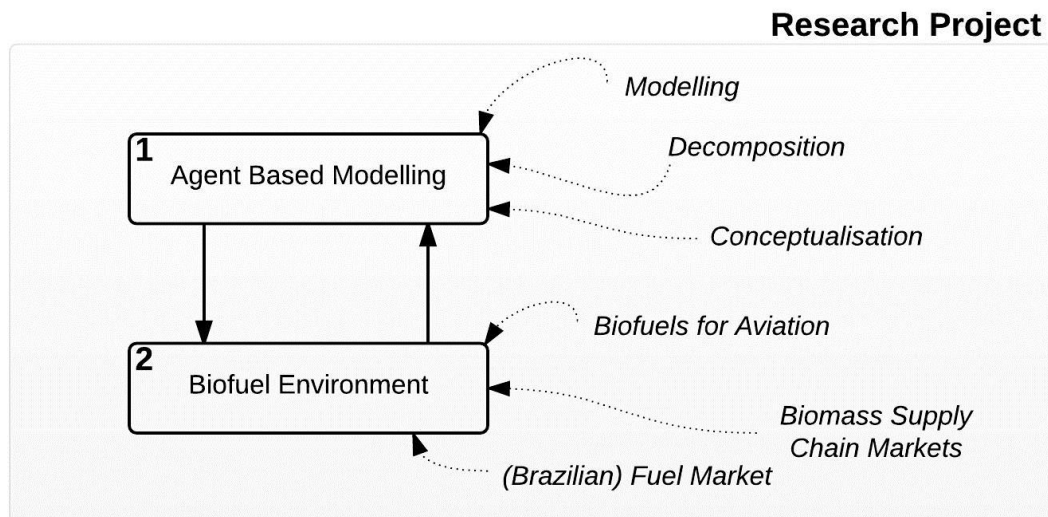


Figure 81: Research Topics of the Thesis

1. Agent Based Modelling

The first area of interest is in the implementation of a modelling methodology (Agent Based Modelling) on a real-world problem. In this thesis, the contribution of decomposing a system into lower level blocks has been clear. Through this decomposition, the competitive nature of the biofuel market has been made explicit; without the decomposition and the simulation of the biofuel market, one would not as easily have realized on a very basic level how in a free-market, any demand for the same biofuel feedstock will inherently lead to higher prices on the user side. Furthermore, something which has explicitly been lacking in the biofuel for aviation paradigm, is the realisation that the global biofuel

policies of governments directly enforces this competition; whether this be intended or not. In general, biofuel competition in a market setting is relatively unexplored in an academic sense and particularly in terms of modelling. Therefore, it is recommended to further explore the use of ABM in (biofuel) commodity market competition, it may be particularly worthwhile to combine the ABM methodology with Game Theory elements as the market competition of commodities shows many elements which are suitable for a Game Theory approach (pay-offs, cooperation between actors).

On the use of Agent Based Modelling, it is suggested to further explore the practical use of the methodology in policy analysis, market analysis, scenario planning, and supply chain management. ABM has become a large field within the TPM (TU Delft) faculty; however, many of the academic work which has been carried out up until now has been focussed on the modelling itself. The emphasis has been put on detailed decomposition, ontologies and formalisations. It seems that the line between the model being a tool in order to reach a goal and the model being the goal itself is very thin. Furthermore, after the conception of the model the emphasis is put on how does the model behave, under what conditions and how does it deal with deep uncertainty. It is not implied that these former aspects are unimportant; they certainly are, however the practical goal of the model should be to gain insights into a real-world problem. At the faculty of TPM this usually means in terms of policy making, societal changes through technology developments and complex arenas involving a multitude of different actors.

Agent Based Modelling is relatively new in the field of economic market behaviour; particularly in terms of volatile markets which are directly affected by relatively simple choices, this research along with similar work carried out at TPM (*Bas, Van der Linden, Vannieuwenhuysse, Oudshoorn & Van der Lei, 2014*) presents as a novel approach and a potential stepping stone into further use of ABM in the field of economic markets. A prime strength of the methodology in this economic field is the fact that it forces the user to decompose a system into very small pieces which forces the researcher to investigate the very basic economic system elements and how this affects higher level aggregate behaviour and causes market volatility. Directly following from the BioJet model, it is recommended to further investigate how agent based modelling can be further used to understand volatile markets which are based on flexible supply and demand on a higher level; particularly in the field of scenario planning.

On a technical note regarding Agent Based Modelling, during the conceptualisation phase of the BioJet model, it has been determined that due to the highly uncertain nature of the distribution behaviour of distributor agents and also the high uncertainty regarding biokerosene technology, it is very important to treat these uncertain aspects with great caution when one tries to derive quantitative conclusions from the simulation results. In this thesis, the uncertainty has been dealt with using a relatively straight forward approach; sensitivity analyses using a parameter sweep with a set of pre-determined input increments. The latter method is sufficient in light of the scope of the current thesis, however it is recommended to further explore the impact of the uncertainty of technology and market behaviour using the *Exploratory Modelling and Analysis* workbench (*Simulation TBM, 2014*). Using this methodology, the robustness of the conclusions drawn from the model simulations in terms of quantitative output can greatly increase; furthermore, if one would attempt to take the model a step further and use the model to formulate and test actual specific policy measures in the field of biofuel (and biokerosene) markets it is necessary to deal with the model robustness with more importance. The EMA workbench can assist in this through the exploring of a set of plausible models (within which the BioJet model can be present and may be combined with other models), the exploiting of the information

contained in such a set through a relatively large number of computational experiments and the analysis of the results of these experiments (*Bankes, 1993*). As such, using the EMA workbench within the BioJet Model may generate a more in-depth and broad insight into the behaviour(s) of the biokerosene market under different technology and policy scenario's; an aspect which has only just been introduced and tentatively explored in the scope of this research. Furthermore, the workbench is now also compatible with the NetLogo software and the use of the workbench in ABM presents as an addition (focus up until now is primarily on System Dynamics) to the ABM methodology being used at the TPM faculty (*Simulation TBM, 2014*).

2. *Renewable Energy, Carbon Avoidance (Biofuel) Policy Making*

The second field in which this thesis shows highly relevant results is the field of biofuel policies; particularly in large scale biofuel markets such as the U.S and the E.U. The overall result of the thesis is that any significant biofuel implementation on a large scale in the aviation sector will necessitate a change in the institutional environment within which the aviation biofuel implementation finds itself at the moment but also in the future. However, this thesis is only an introduction into this paradigm; further in-depth analysis is essential in order for all parties (policy makers, biofuel users and producers) to be able to make informed decisions regarding their respective strategies, ambitions and goals within this field.

Considering the complex nature of the biofuel institutional environment, the multiple actors and the corresponding different interests which are present in this arena, it is strongly suggested to further analyse this setting in terms of typical multi-actor, policy analysis and actor decision-making methodologies. It is clear that an in-depth analysis of the biofuel arena is crucial in order to further explore the implementation of a new breed of biofuels such a second generation biofuels and biofuels for aviation, road and sea transport. On a higher level, considering the overall goal of biofuels being the avoidance/reduction of carbon emissions and the encouragement of the use of renewable energy sources, the biofuel institutional environment must be put into this perspective as well; how does biofuel policy fit in the greater policy field of renewable energy and climate change and what are the implications for government and industry ambitions? Answers to these questions can only be obtained with a thorough institutional analysis across all layers in this field, where the implementation of biofuels for aviation is just one of these many layers.

Figure 82 shows the proposed change from the initial background environment (from a public and private policy perspective) on which the master thesis was initially focussed on towards the change in background perspective with the insights gained during the thesis.

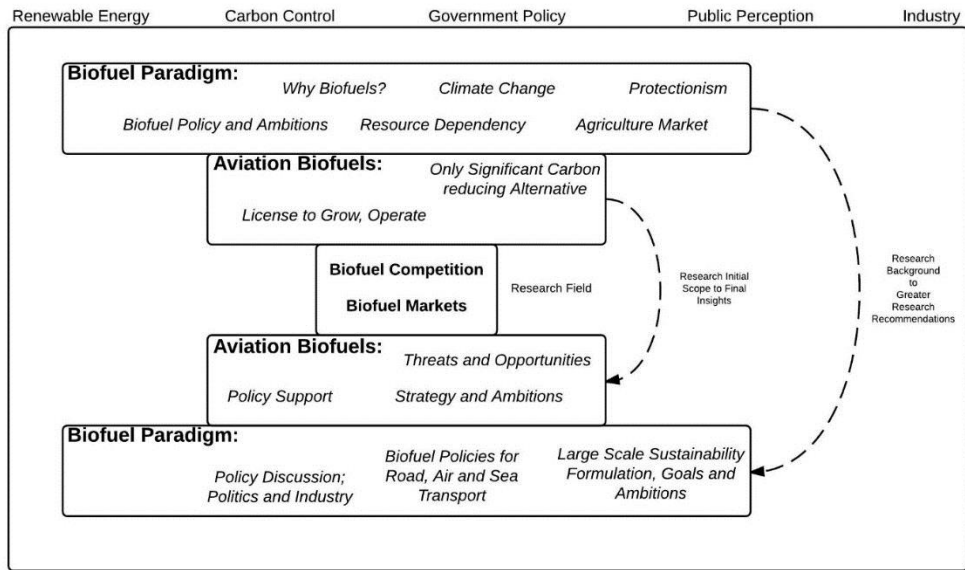


Figure 82: Perspective Change on the Biofuel Fields Before and After the Conducted Research

Recommendations within the TPM faculty research fields

The recommendations on the research regarding the use of ABM and the exploration of the biofuel policy environment are both ideally suited within the research fields of the faculty of TPM (TU Delft). Considering, that this research has identified a much larger field which up until now is under-represented at the faculty, an explicit recommendation for a set of research topics and the relationship that these research topics may have with one another is given and shown in Figure 83.

The faculty is comprised of three research departments; these are the following (TPM TU Delft, 2014);

1. Department of Engineering Systems and Services

Core activity: “understanding and predicting emerging technological innovations and user service patterns, and using these insights for improved design, regulation and operation of engineering systems and services in the domains of Energy, Mobility and ICT. “

2. Department of Multi-Actor Systems

Core activity: “design of new ‘smart’ governance principles, adaptive policies and decision making strategies, supported by new ways of modelling that combine formal models with large-scale gaming and simulation techniques, and increasingly, real time big data. “

3. Department of Values, Technology and Innovation

Core activity: “Developing useful frameworks for responsible innovation and value sensitive design, through critical evaluation of technological advancements on the basis of fundamental values such as ethics and safety and frugality. In this field applied philosophy, safety sciences and economics of technology & innovation are integrated. “

The themes of all departments fit in well with the proposed research topics, naturally there is often an overlap between the research themes as was the case in this particular thesis (ABM and Multi-Actor Policy). A further explanation and reasoning is made clear in Figure 83. It is important to note that this a suggestion for specific further research fields based on the observation made of a relative lack of in-depth knowledge in order to fully and confidently derive more quantitative conclusions and recommendations regarding the (European) biofuel market in terms of market pricing and effects of government policies and industry initiatives such as is the case with the implementation of biofuels for aviation.

Following directly from this thesis, it is recommended to build further on the introduction into the biofuel (biomass) market paradigms in order to fully facilitate an understanding of these markets in an academic sense, but also to be able to provide worthwhile contributions to the industry and government sectors which are related to this field. The possible practical contributions of these research topics are heavily dependent on the level of cooperation and information sharing which is made possible between the academic research, industry knowledge and government policy design. The lack of this information sharing has been an area of difficulty in the scope of this thesis as has been documented already.

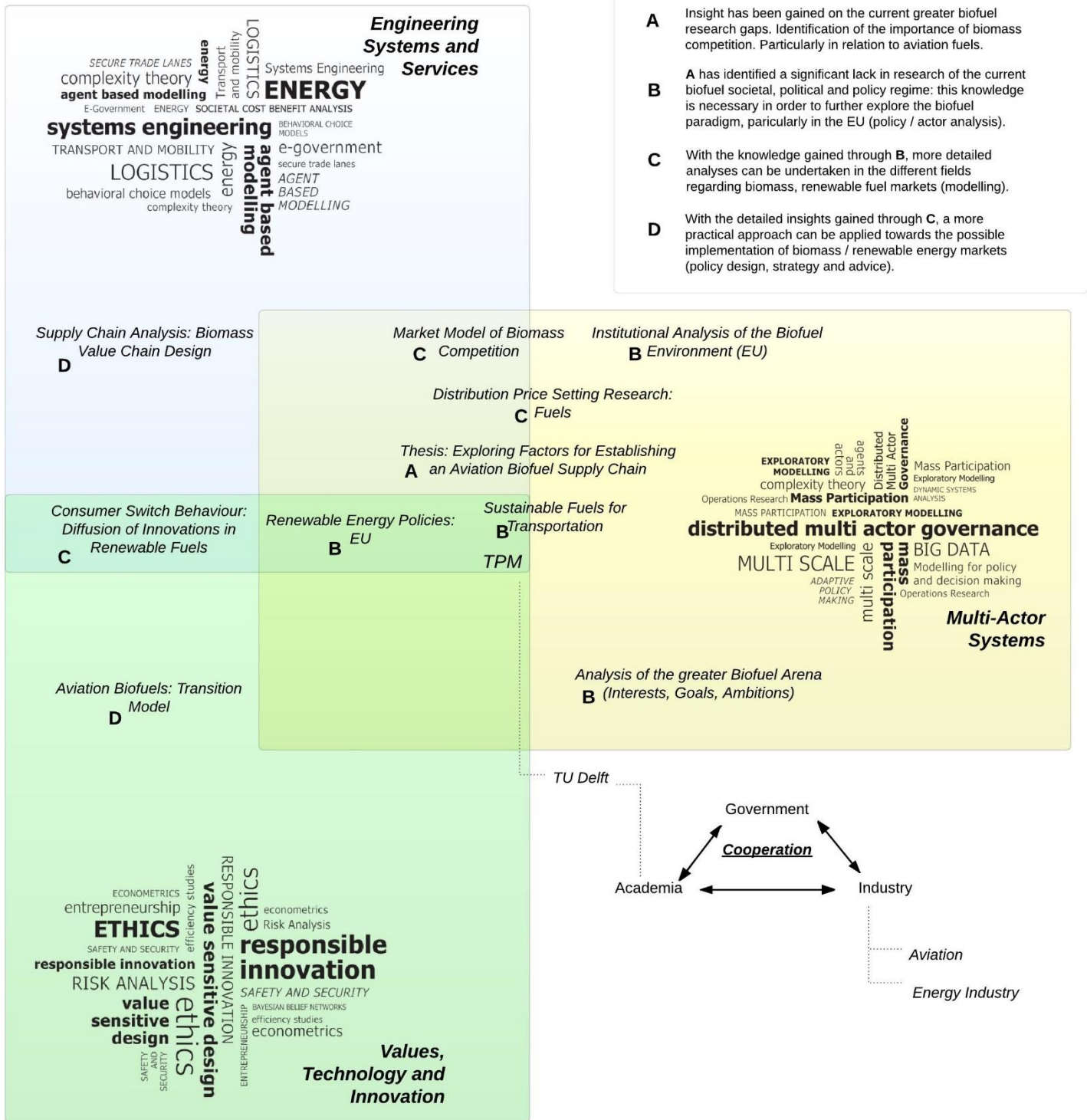


Figure 83: Map of the TPM Research Fields and Potential Future Research Topics

9.3 Recommendations from an Industry Perspective

A substantial part of the research is the understanding of how biofuel markets operate and how the aviation sector can achieve its goals in terms of biofuel use. From this research it is clear how a lot of the focus is on the sustainability of feedstock, and the technical developments of different production pathways. However, substantial research into biokerosene policies is strongly lacking; given the results of the BioJet model, this presents as a significant problem. Actors in the biofuel sector acknowledge the need for government policies and a level playing field, however a substantial theoretical basis and design for these policies is lacking. Therefore, considering the previously mentioned aspects and the results of this research in terms of the *level playing field*, it is recommended to explicitly explore how actors can implement a policy drive (policy design) towards biofuels for aviation as the results of this research indicate that this aspect is essential considering biofuel market competition with uneven direct and indirect government support.

The concept of a “level playing field” is used frequently by the aviation industry; this is due to the very strong competition between airlines on a global scale. Furthermore, the service that is provided by airlines has become a commodity, that is the degree of product differentiation towards the flying consumer has become smaller and smaller and the act of flying can be regarded as a good; consumers want the lowest price for a good. A distinction can be made when referring to the level playing field; there is the competition between the aviation industry as a whole versus other transport sectors and there is the competition between airlines amongst themselves. The biofuel implementation requires a different perspective when placed in the context of either of these two elements.

Competition within the Aviation Sector

The aviation industry is a global market; therefore any geographic distortions in terms of the regulation system (country or region specific) can have a profound impact on the business of the individual airlines. It is for this reason, that any policies or changes in the regulatory system which do not equally affect all aviation competitors are undesired. In the case of biofuel implementation, any mandate or carbon offsetting rules will need to apply across the industry; this is very unlikely considering the resistance towards these implementations from both the industry itself and the respective governments. Furthermore, market prices for jet fuel are institutionally liberal (no tax or subsidy whatsoever) throughout the world and they have been since 1944 (ICAO, 1944).

Competition between the Aviation Sector and Other Sectors

As the product that aviation provides is in effect, a good (travel from A to B), and there are also alternative sectors which can deliver this good (rail, ship, road), the aviation industry is also in competition as a sector with these other industries. A significant issue which is present however is that particularly the rail and road transportation sectors are much more locally (within a region or country) based compared to aviation and therefore the regulatory environment can be managed much more easily and directly by the respective government on institutions. This can be well observed in matters

regarding the taxation or subsidizing of energy for these modes of transport; the market price of energy for these modes is directly impacted by the institutional environment and in the case of biofuels, the road sector has an unfair advantage in terms of the guaranteed scale of the biofuel market in relation to the biokerosene market (which clearly is not guaranteed at all). This presents itself as an uneven playing field from the perspective of airlines in general, but particularly from airlines which are based in countries with a heavily regulated transportation market such as the U.S. and the E.U.

License to Operate and License to Grow

Closely related to the level playing field which is mentioned by aviation players is the concept of the “license to operate” and the “license to grow”. This entails the organizational legitimacy which actors in the aviation industry (which is a highly visible industry) seek from the direct consumers, wider public and the government environment. A main issue in this field is the carbon emissions which are associated with flying and which are relatively difficult for the industry as a whole to significantly manage (at the moment only through biofuels). From the perspective of the industry, the implementation of biofuels is expected to maintain the industries’ licenses to operate and grow in the future. Potentially, the acknowledgement by the government in the fact that biofuels for aviation are institutionally too challenging (due to these governments own policies) may also be an outcome which enables the industry to maintain these licenses.

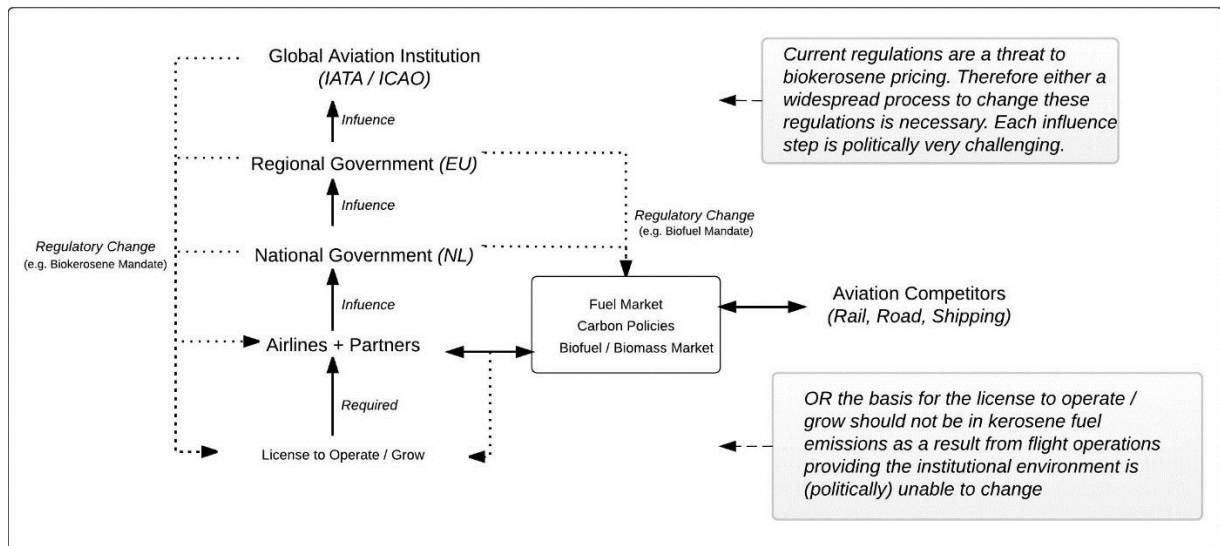


Figure 84: Aviation Steps Towards a Biokerosene Level Playing Field

9.4 A Reflection on the Thesis

To finish this report I would like to add a personal note on how I have experienced the progression of the research; from the gathering of background information right until the finalisation of the thesis report.

The Beginning

I have always had an affinity with aviation, through being a user of the aviation product and through my background in Aerospace Engineering (Bachelor program TU Delft). In parallel with this, I have had a sincere interest in the general energy paradigm. This spans from fossil fuels to renewable, sustainable green energy technologies. The (renewable) energy paradigm has been more and more intertwined within a multi-actor, complex environment. It is a subject of utmost relevance to society, politics, business and more recently it has become a central topic within the sustainability field (climate and scarcity of resources). Through my Master program background in Technology and Policy Management this embeddedness of the energy field within such a diverse environment has triggered also an academic interest towards energy. By chance the opportunity presented itself to carry out my master thesis at Schiphol Airport in the field of biofuels for aviation; a combination of my energy and aviation interest fields; naturally this appealed strongly to me and I have been very fortunate that this opportunity presented itself. My personal interest in the topic of this thesis explains why I have in this report at times extensively elaborated on relatively broad concepts within the aviation biofuel environment, it also explains the added attention paid towards the practical implications of the Agent Based Model relative to the actual model from a technical perspective.

Initializing the Project

The starting of the project was characterized by an extensive background research into biofuels, Brazilian sugarcane and the Agent Based Modelling paradigm. As I was previously unacquainted with both biofuels and ABM, the initial phases of the thesis project progressed much more slowly than anticipated. However, the more I got into both subjects, the more interested I became, which resulted me into overly researching both topics. However, the large amount of background information I had acquired has paid off in the long run through the ability to put this research into perspective in a larger picture.

Once the research proposal had been approved, I started with the decomposition of the Brazilian sugarcane market and further systematic breakdown of this system into clear and understandable elements. This step, in hindsight is perhaps also the most important step of the entire research as here the core element of the biomass market competition behaviour is exposed; which has led to the overall conclusion on biokerosene pricing versus regular biofuels and fossil fuels. However, without the actual model being ready yet these insights did not occur to me at the time.

The Agent Based Model

The core of the thesis has been the software implementation, tweaking (very time consuming) and testing of the actual model in NetLogo. Particularly, the having to repeatedly implement a new model section, running the model to see if it worked as planned and then adapting the section based on insights gained through the simulation runs took me much more time than anticipated, even taking into account the fact that I was initially very much aware of the high chance for time delays in this phase.

NetLogo was chosen as the software environment for simplicity reasons; it is a relatively easy software tool to understand for anybody with only minor experience in programming. This simplicity did show a large drawback in the implementation of the model in this thesis as the debugging process was much more intensive than with other programming tools; the simplicity of the software also means that for large models, the user is given no detailed information on problems in the programming implementation. In hindsight, I would certainly recommend when using large models (more than a couple of pages of coding) to use a more extensive programming tool such (such as Python for instance).

Model Testing and Analysis of the Results

When I was satisfied that I had come up with a working model of the sugarcane market and also with the implementation of the biokerosene element within this model, the testing of what actually happens in the model was underway. The interesting aspect of this testing was how it quite quickly became clear that from a larger perspective the focus of the tests need not be to determine how to decrease the price of biokerosene relative to regular kerosene, but how to decrease the price of biokerosene relative to regular biofuel for the road transport market (hydrous and anhydrous ethanol in this case). This realisation has further dominated the end results of this research work as has been extensively explained already in this report. Personally, I find that this latter realisation is a prime example of the added value of the *modelling* of a complex system; the user needs to be able to “play” with the carefully decomposed system elements in an iterative setting.

With the extensive background research I had done on biofuels for aviation, it was quite simple to put the results of the simulations into perspective; the results show the importance of the biofuel institutional environment for the possible market price of biokerosene. This latter aspect has already widely been acknowledged and identified throughout the industry, but it has surprised me that there are no concrete studies available which show what and how precisely this environment is important (as this research has done). This is particularly surprising given the amount of attention which is given to aviation biofuels and the importance with which this subject has been *publicly* treated with from both the airline, fuel and public sectors.

Thesis Round-up

Finally, regarding the finishing of the research, the most rewarding aspect has been the writing of this report in that sense that I have been able to apply and document a structured and scientific methodology towards a real-world problem, I have generated results using this methodology and I have been able to put these results into a real-world perspective. If I would look back on this thesis and how it has progressed there are not many things I would have done structurally differently; of course some issues may have worked out better, however the difficulties which have arisen (particularly in modelling) have also helped me significantly in understanding the bigger picture of what I have been studying. The cliché in modelling is very true however, and this cannot be overstated; it is extremely important to strictly define the scope of your model, to identify when you really must let go of concepts which do not seem to work out in the model and to zoom out of your model every now and then. This is a well-known piece of advice, but I myself have learned this the hard way nevertheless.

I hope that the reader of this report has developed a clearer understanding of the challenges which are present in biofuels for aviation from a market perspective and I hope that the results of this thesis can trigger further (academic, industry and public) interest in the perspective from which I have written this report. Ideally, I hope this thesis can contribute towards a more structured discussion and thinking on what needs to be done in this field from a policy making perspective; and ultimately make some impact on making aviation a bit more sustainable.

Apart from the satisfaction that I have gained from completely immersing myself in Agent Based Modelling, aviation biofuels and the Brazilian ethanol market, I have also learned many things during this thesis which I hope will serve me well in the future; wherever this may be.

Bibliography

Adhitya, A., Behdani, B., Lukszo, Z. & Srnivasan, R. (2010). *Performance Analysis of a Multi-Plant Specialty Chemical Manufacturing Enterprise Using an Agent-Based Model*. Computers and Chemical Engineering, Vol. 34, p. 793-801.

ANFAVEA. (2013). *Brazilian Automotive Industry Yearbook*.
<http://www.virapagina.com.br/anfavea2013>
Visited May, 2014.

Armbrust Aviation Group. (2014). *New Fuels Report*.
<http://www.armbrustaviation.com/>
Visited July, 2014.

ATAG. (2009). *Beginner's Guide to Aviation Biofuels*.
<http://www.atag.org/our-activities/sustainable-aviation-biofuels.html>
Visited May, 2014.

Augusdinata, D., Lee, S., Zhao, F. & Thissen, W. (2014). *Simulation Modeling Framework for Uncovering Behaviours in the Biofuels Supply Chain Network*. Simulation: Transactions of the Society for Modeling and Simulation International, Vol. 90, Issue 9, p. 1103-1116.

Bankes, S. (1993). *Exploratory Modelling for Policy Analysis*. Operations Research, Vol. 41, Issue 3, p. 435-449.

Bankes, S. & Gilbert, N. (2002). *Platforms and Methods for Agent Based Modeling*. National Academy of Sciences, Vol. 99, Issue 10, p. 7197-7198.

Banse, M., Kemfert, C. & Sorda, G. (2010). *An Overview of Biofuel Policies across the World*. Energy Policy, Vol. 18, Issue 11, p. 6977-6988.

Bas, G., Van der Linden, D., Vannieuwenhuysse, B., Oudshoorn, M. & Van der Lei, T. *When Big is No Longer Beautiful. Exploring the Competitiveness of Factories in Containers Using an Agent-Based Simulation Model of a Global Supply Chain*. Working Paper, TPM TU Delft, 2014.

BioEnergy Consult. (2014). *Powering Clean Energy Future*.
<http://www.bioenergyconsult.com>
Visited September, 2014

BioPort Holland. (2013). *BioPort for Jet Fuels in the Netherlands*.
<https://klmtakescare.com/en/content/bioport-for-jet-fuels-in-the-netherlands>
Visited May, 2014.

- BNDES & CGEE. (2008). *Sugarcane Based Bioethanol: Energy for Sustainable Development*.
Rio de Janeiro, Brazil: BNDES.
- Boeing, Embraer, FAPESP & UNICAMP. (2013). *Flightpath to Aviation Biofuels in Brazil: Action Plan*.
<http://www.fapesp.br/publicacoes/flightpath-to-aviation-biofuels-in-brazil-action-plan.pdf>
Visited May, 2014.
- Borshchev, A. & Filippov, A. (2004). *From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools*.
<http://www2.econ.iastate.edu/tesfatsi/systemdyndiscreteeventabmcompared.borshchevfilippo v04.pdf>
Visited May, 2014.
- Brailsford, S., Churilov, L. & Dangerfield, B. (2014). *Discrete-Event Simulation and System Dynamics for Management Decisions Making*.
West Sussex, United Kingdom: John Wiley & Sons.
- Buxton, D., Garnett, J., Macal, C., Pidd, M. & Siebers, P. (2010). *Discrete-Event Simulation is Dead, Long Live Agent-Based Simulation!*
Journal of Simulation, Vol. 4, p. 201-210.
- Carley, K., Carrol, G., Harrison, J. & Lin, Z. (2007). *Simulation Modeling in Organizational and Management Research*.
The Academy of Management Review, Vol. 32, Issue 4, p. 1229-1245.
- Carriquiry, M., Du, X. & Timilsina, G. (2011). *Second Generation Biofuels: Economics and Policies*.
Energy Policy, Vol. 39. p. 4222-4234.
- Charlita de Freitas, L & Kaneko, S. (2011). *Ethanol Demand under the Flex-Fuel Technology Regime in Brazil*.
Energy Economics, Vol. 33, Issue 6, p. 1146-1154.
- Cheze, B., Gastineau, P. & Chevallier, J. (2011). *Forecasting World and Regional Aviation Jet Fuel Demands to the Mid-term (2025)*.
Energy Policy, Vol. 39. Issue 9, p. 5147-5158.
- Chiong Meza, C. (2012). *Understanding Socio-technical Change. A System-Network-Agent-Approach*.
Dissertation, Delft University of Technology, the Netherlands.
- Climate-KIC. (2014). *Fuel Supply Chain Development and Flight Operations (RENEWABLE JET)*.
<http://www.climate-kic.org>
Visited May, 2014.

Cortez, L & Rosillo-Calle, F. (1998). *Towards ProAlcool II: A Review of the Brazilian Bioethanol Programme*
Biomass and Bioenergy, Vol. 14, Issue 2, p. 115-124.

Crutchfield, J. (1994). *Is Anything Ever New? Considering Emergence*.
Santa Fe Institute Studies in the Sciences of Complexity XIX, MAL Addison-Wesley

De Bruijn, H. & Ten Heuvelhof, E. (2008). *Management in Networks. On Multi-Actor Decision Making*.
London, United Kingdom: Routledge.

Defensie. (2014). *Defensie Pijpleiding Organisatie; DPO Pijpleidingnetwerk*.
<http://magazines.defensie.nl/materieelgezien/2014/02/pijpleiding>
Visited, September, 2014.

De Gorter, H., Drabik, D., Kliaugas, E. & Timilsina, G. (2013). *An Economic Model of Brazil's Ethanol-Sugar Markets and Impacts of Fuel Policies*.
Policy Research Working Paper, The World Bank, Environment and Energy.

EC. (2013). *2 Million Tons per Year: A Performing Biofuels Supply Chain for EU Aviation. (August 2013 Update)*.
http://ec.europa.eu/energy/renewables/biofuels/doc/20130911_a_performing_biofuels_supply_chain.pdf
Visited May, 2014.

Emirates. (2014). *Position Paper: Airlines and Subsidy*.
http://www.emirates.com/english/images/Airlines%20and%20subsidy%20-%20our%20position%20new_tcm233-845771.pdf
Visited October, 2014.

Energy Charter Secretariat. (2007). *Putting a Price on Energy: International Pricing Mechanisms for Oil and Gas*.
http://www.encharter.org/fileadmin/user_upload/document/Oil_and_Gas_Pricing_2007_ENG.pdf
Visited September, 2014.

Ferreira, L. & Borenstein, D. (2011). *Normative Agent-Based Simulation for Supply Chain Planning*.
Journal of the Operational Research Society, Vol. 62, p. 501-514.

Gardner, E. (1985). *Exponential Smoothing: The State of the Art*.
Journal of Forecasting, Vol. 4, Issue 1, p. 1-28.

Gordon, G. (1961). *A General Purpose Systems Simulation Program*.
McMillan NY, Proceedings of EJCC, Washington D.C., U.S.A., p. 87-104.

HLPE. (2013). *Biofuels and Food Security. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*.
Rome, Italy: CFS.

- Holland, J. (1992). *Complex Adaptive Systems*.
Journal of the American Academy of Arts and Sciences, Vol. 121, Issue 1, p. 17-30.
- ICAO. (1944). *Convention on International Civil Aviation done at Chicago on the 7th Day of December, 1944*.
http://www.icao.int/publications/Documents/7300_orig.pdf
Visited on September, 2014.
- Jacobsson, S. & Lauber, V. (2004). *The Politics and Policy of Energy System Transformation: Explaining the German Diffusion of Renewable Energy Technology*.
Energy Policy, Vol. 34. p. 256-276.
- Jennings, N. (2000). *On Agent-Based Software Engineering*.
Artificial Intelligence, Vol. 117, p. 227-296.
- Junginger, M., Lako, P., Lensink, S., van Sark, W. & Weiss, M. (2008). *Climate Change Scientific Assessment and Policy Analysis: Technological Learning in the Energy Sector*.
Bilthoven, the Netherlands: NEAA.
- Junginger, M., Faaij, A., Poot, T., Van den Wall Bake, J.D. & Walter, A. (2009). *Explaining the Experience Curve: Cost Reductions of Brazilian Ethanol from Sugarcane*.
Biomass and Bioenergy, Vol. 33, Issue 33, p. 644-658.
- IATA Fuel. (2014). *Fact Sheet: Fuel*.
http://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fuel-fact-sheet.pdf
Visited May, 2014.
- IATA. (2013). *IATA 2013 Report on Alternative Fuels*.
<http://www.iata.org/publications/Documents/2013-report-alternative-fuels.pdf>
Visited May, 2014.
- Kostova & Zaheer. (1999). *Organizational Legitimacy under Conditions of Complexity: The Case of the Multinational Enterprise*.
The Academy of Management Review, Vol. 24, Issue 1, p. 64-81.
- Lempert, R. (2002). *Agent-Based Modeling as Organizational and Public Policy Simulators*.
National Academy of Sciences, Vol. 99, Issue 10, p. 7195-7196.
- Louie, M. & Carley, K. (2008). *Balancing the Criticisms: Validating Multi-Agent Models of Social Systems*.
Simulation Modelling Practice and Theory, 16(2), p. 242-256
- Lufthansa Group. (2014). *Lufthansa Conducts first European Scheduled Flight on Sugar-based Biofuel*.
<http://www.lufthansagroup.com/en/press/news-releases/singleview/archive/2014/september/15/article/3215.html>
Visited September, 2014.

- Maani, K. & Cavana, R. (2000). *Systems Thinking and Modelling: Understanding Change and Complexity*. Auckland: Prentice-Hall.
- Mabee, W., Saddler, J., Sims, R. & Taylor, M. (2008). *From 1st- to 2nd- Generation Biofuel Technologies: An Overview of Current Industry and RD&D Activities*.
- Morin, E. (1999). *Organization and Complexity*. Annals of the New York Academy of Sciences, Vol. 879, p. 115-121.
- Neiro, S. & Pinto, J. (2004). *A General Modeling Framework for the Operational Planning of Petroleum Supply Chains*. Computers and Chemical Engineering, Vol. 28, p. 871-896.
- Northwestern University NetLogo. (2014). *NetLogo User Community Models*. <http://ccl.northwestern.edu/netlogo/index.shtml>
Visited May, 2014.
- Pacina, H. & Silveira, S. (2011). *Consumer Choice between Ethanol and Gasoline: Lessons from Brazil and Sweden*. Energy Policy, Vol. 39, Issue 11, p. 6936-6942.
- Petrobras. (2014). *Experience in Brazilian Ethanol: Distribution Logistics*. <http://www.petrobras.com>
Visited October, 2014.
- Poet-DSM. (2014). *Project Liberty: Advanced Biofuels*. <http://poet-dsm.com/>
Visited September, 2014.
- Purvin & Gertz. (2008). *Study on Oil Refining and Oil Markets: Prepared for the European Commission*. http://ec.europa.eu/energy/observatory/oil/doc/refining/2008_01_study_oil_refining_oil_markets.pdf
Visited September, 2014.
- Qantas. (2013). *A Feasibility Study of Australian Feedstock and Production Capacity to Produce Sustainable Aviation Fuel. (Public Report)*. <http://www.qantas.com.au/infodetail/about/environment/aviation-biofuel-report.pdf>
Visited May, 2014.
- R (2014). *R-Project Statistical Computing and Graphics*. <http://www.r-project.org/index.html>
Visited May, 2014.
- Robertson, D. (2005). *Agent-Based Modeling Toolkits Netlogo, RePast and Swarm*. Academy of Management Learning & Education, Vol. 4, Issue 4, p. 525-527.
- Robinson, S. (2003). *Simulation: The Practice of Model Development and Use*. West Sussex, United Kingdom: John Wiley & Sons.

Rosillo, C., Teelucksingh, S., Thraen, D. & Seiffert, M. (2012). *The Potential and Role of Biofuels in Commercial Air Transport – Biojetfuel*.

Ruijgrok, G. (2009). *Elements of Airplane Performance*.
Delft, the Netherlands: VSSD.

Simulation TBM. (2014). *Exploratory Modelling and Analysis (EMA) Workbench*.
<http://simulation.tbm.tudelft.nl/ema-workbench/contents.html>
Visited, November, 2014.

Sargent, R. (1998). *Verification and Validation of Simulation Models*.
Proceedings of the 30th conference simulation, Washington D.C., U.S.A

SkyNRG. (2014). *White Paper on Sustainable Jet Fuel*.
<http://skynrg.com/wp-content/uploads/2013/11/White-paper-on-sustainable-jet-fuel-June-2012-Faaij-van-Dijk-copy.pdf>
Visited, October, 2014.

Shell Aviation. (2014). *People, Prices and Places – Our Prices*.
<http://www.shell.com/global/products-services/solutions-for-businesses/aviation/ppp/prices.html>
Visited, October, 2014.

TPM TU Delft. (2014). *Faculty of Technology, Policy and Management: Research Portfolio*.
<http://www.tbm.tudelft.nl/en/research/research-portfolio/>
Visited, November, 2014.

Sterman, D. (2002). *System Dynamics: Systems Thinking and Modeling for a Complex World*.
Working paper series, ESD International Symposium, MIT.
<http://esd.mit.edu/WPS/internal-symposium/esd-wp-2003-01.13.pdf>
Visited May, 2014.

Van Dam, K., Nikolic, N. & Lukszo, Z. (2013). *Agent Based Modelling of Socio-Technical Systems*.
Dordrecht, the Netherlands: Springer.

Wilensky, U. (2004). *NetLogo: A Simple Environment for Modeling Complexity*.
Proceedings at the International Conference on Complex Systems, Boston, U.S.A

UNICA (2014). *Brazilian Sugarcane Industry Association Data*.
<http://www.unicadata.com.br/?idioma=2>
Visited May, 2014.

US Department of Defense (2014). *Defense Production Act Title III*.
<http://www.dpatitle3.com/>
Visited, August, 2014

Ziolkowska, J. (2013). *Evaluating Sustainability of Biofuel Feedstocks: A Multi-Objective Framework for Supporting Decision Making*.
Biomass and Bioenergy, Vol. 59, p. 425-440.



APPENDICES

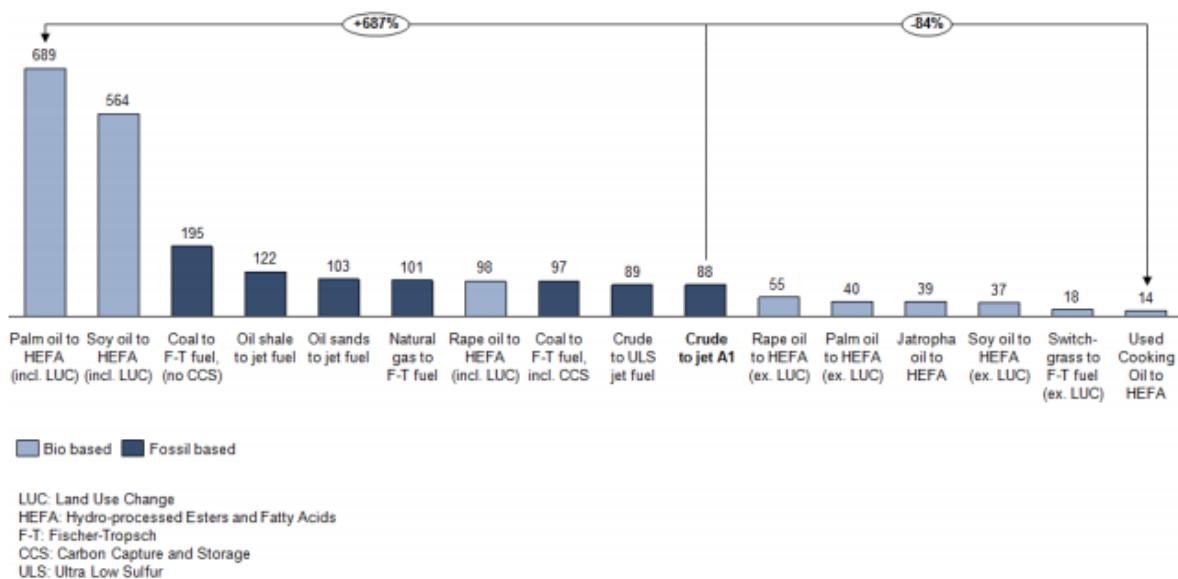
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Appendix A: Short Review of the Sustainability of Jet Biofuels

The sustainability of biofuel use as considered by the aviation industry is composed of three defining aspects. The first of which is related to the total amount of carbon dioxide through the biofuel lifecycle that is emitted by the production and the use of the biofuel. A full overview of the different lifecycle emissions for different fuel production pathways and feedstock use which is given below. The goal of aviation biofuels is to reduce the emissions of greenhouse gasses and as such hard criteria for airlines in the suitability of fuel is the fact that the carbon emissions must be as low as possible.

Well to Wing emissions different jet fuel production pathways (gCO₂/MJ), including renewable options (SkyNRG, 2012):

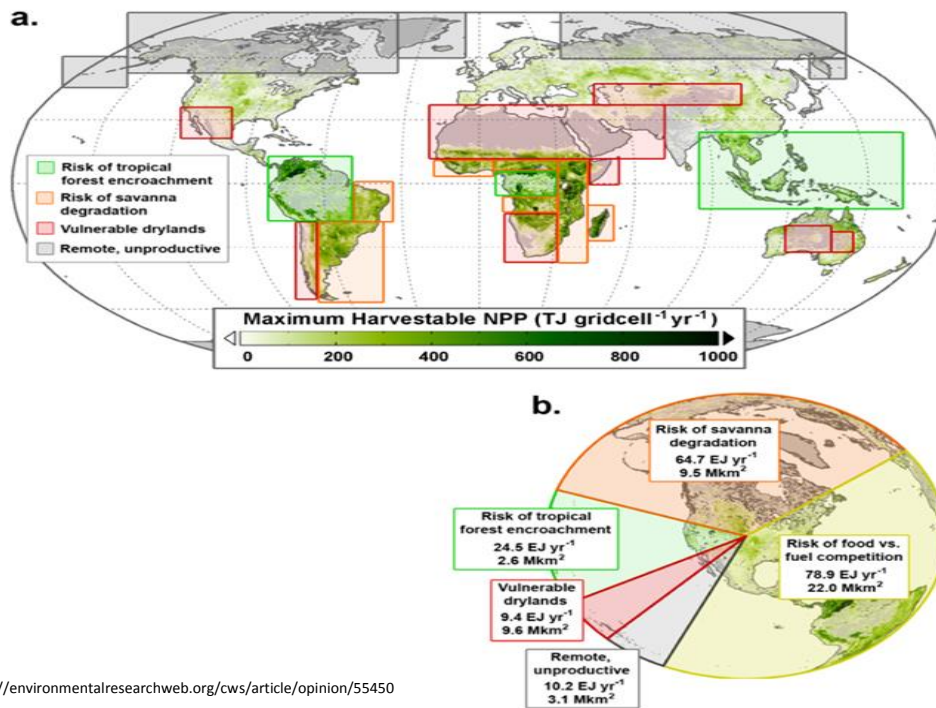


Source: SkyNRG, 2012: <http://skynrg.com/wp-content/uploads/2013/11/White-paper-on-sustainable-jet-fuel-June-2012-Faaij-van-Dijk-copy.pdf>

The second sustainability criteria for jet biofuels is related to the land use of the feedstock production. Critics of biofuels note that a significant increase in the demand for biofuels and the corresponding increase in feedstock production will lead to substantial pressures in the field of agriculture. Particularly in developing countries it has been shown that forests are cleared in favour of biofuel production; a prime example being the production of palm oil in South East Asia. In reaction to these fears, the aviation industry and its sustainability partners such as the World Nature Fund, only endorse biofuels which are shown not to impact the land use in a region. A further illustration of the geographic areas in the world with an increased risk of land use conflicts arising from biomass production is shown in (Land Use Risks Around the Globe).

The third sustainability criteria is closely related to the land use criteria of different feedstock. The most controversial aspect of biofuels is by far the so-called food versus fuel debate. Critics of biofuels state that the increase in biofuel production drives up the price for food as the agriculture food commodity is put into direct competition with the price of fuel. Extensive discussions, media campaigns and scientific research have been conducted to explore this assumption; all of which have not produced a single definitive answer. Considering the highly visible nature of airlines in the public perception and the high sensitivity airlines have with regards to consumer behaviour, the airline industry is very cautious when it comes to biofuels which are sourced from an edible feedstock. This latter aspect has meant that in the sustainability criteria for jet biofuels, the condition is present that these are not produced from an edible feedstock (so-called second generation biofuels). A full overview of these different categories in biofuels concerning their suitability in respect to the food versus fuel criteria is shown in (overview of next generation biofuel feedstocks).

Land use risks around the globe:



Source: <http://environmentalresearchweb.org/cws/article/opinion/55450>

Overview of next generation biofuel feedstocks:

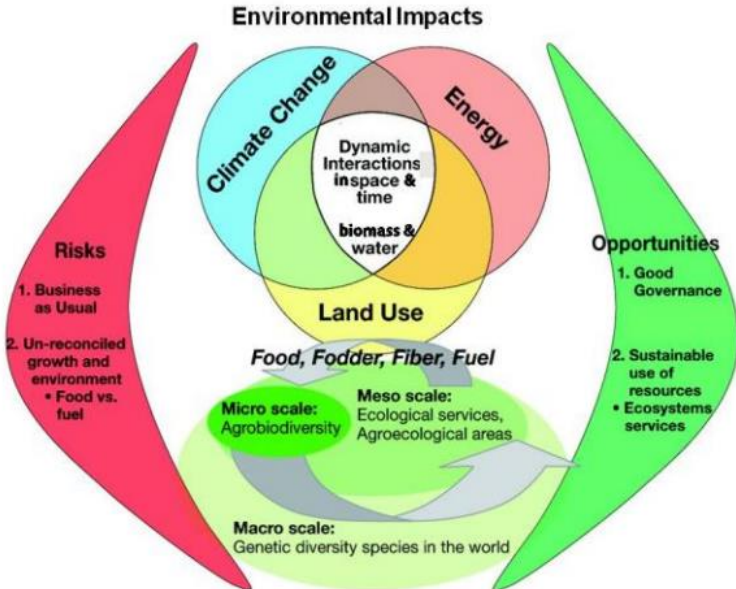
	Biofuels and biomass feedstocks		
	1 st generation	2 nd generation	3 rd generation
Biomass type	Annual crops = food crops. Typical examples are corn, rapeseed, cereals	Lignocellulosic materials, including agricultural and forestry residues, cultivated trees and grasses	Micro & macro algae produced in ponds and bioreactors (in wastewater or seawater)
Land type	Production is limited to arable land and competition with food markets direct	Arable, pasture as well as marginal and degraded lands	Can be produced with limited land use; does not require fertile land
Potential	Constrained	Large	Very large (in principle)
Economics (outlook)	Relatively high feedstock costs, largely determined by food markets	Currently more expensive than 1 st generation, but robust outlook for more competitive production costs on medium term (>2020)	Expectedly long development time is needed; uncertain outlook
Sustainability	Modest GHG and environmental performance. Food versus fuel conflict	Generally (very) good environmental performance and net GHG emission reduction	In principle very sounds, but Certain sustainability aspects less understood
State of the art	Relatively simple and proven conversion technologies	Range of technologies in demonstration phase but not commercial yet	Unproven technology; competitive production is uncertain and requires fundamental breakthroughs

Source: SkyNRG, 2012: <http://skynrg.com/wp-content/uploads/2013/11/White-paper-on-sustainable-jet-fuel-June-2012-Faaij-van-Dijk-copy.pdf>

The choice of biofuels by the aviation sector as a means to mitigate sustainability concerns in the future operations of the sector is in itself from a sustainability view point highly debated. The arguments used in this field are often highly emotional; the information is therefore often conflicted by many actors which surrounds sustainable biofuels use under a great level of public complexity. The stance by the aviation up until now has been to remain very cautious in this regard; all controversial feedstock sources are avoided in order to avoid the biofuels sustainability debate altogether. This stance however does mean that the economic costs of the biofuels will more often than not be higher than when the sustainability criteria are not as big of an issue. Furthermore, avoiding the biofuels debate altogether may present as a future problem for biofuel use as the criteria for biofuels become ever stricter. It remains to be seen how economically feasible truly non-controversial biofuels may be and how the public perception changes once the use of these fuels is up scaled. Furthermore, it is interesting to note how the strict criteria on jet biofuels have so far proven to act as a significant economic barrier towards wide spread biofuel use and indirectly have caused the aviation sector to keep on the “business as usual” path of using fossil fuel kerosene, the fuel which is most controversial of all from a sustainability point of view.

Regarding the sustainability aspects which have been discussed in this section, (Bioenergy dynamic interactions) clearly shows a schematic overview of the different aspects which surround the sustainable biofuel paradigm.

Complex Dynamic Interactions in the Bioenergy Paradigm (SkyNRG, 2012)



Source: SkyNRG, 2012: <http://skynrg.com/wp-content/uploads/2013/11/White-paper-on-sustainable-jet-fuel-June-2012-Faaij-van-Dijk-copy.pdf>

Appendix B: Kerosene Prices around the World and Their Impact on Airline Competition

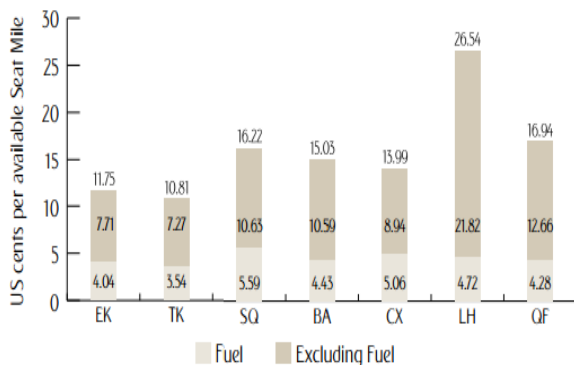
The price of kerosene around the world varies based purely on market conditions; this is due to the fact that kerosene is not taxed around the world. The geographic location of airports with respect to the supply locations of kerosene is an important determinant in the difference in airfield kerosene prices. Unlike what most would expect, the lowest kerosene prices are not specifically only located at oil-rich countries per se; the most important price driver is the availability of a large scale refining centre. Therefore the lowest kerosene prices are found near the Middle East (low oil price) and Singapore locations (low refining price due to largest refining hub in the world). An overview of the distribution of the different kerosene prices (in dollars per liter) is shown in (Overview of Kerosene Airfield Prices Around the World).

Overview of Kerosene Airfield Prices Around the World:



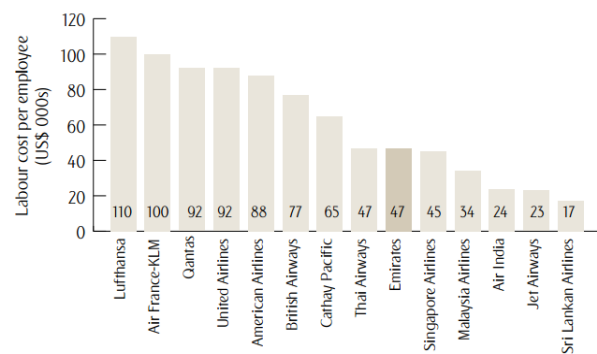
In addition to the geographic distribution of kerosene prices, an overview is shown which shows how, even though the cost of fuel determines for a large part the total operating cost of airlines, another large driver for uneven cost distributions between airlines is the significant difference in the cost of employees. The cost competitive advantage by Middle Eastern airlines is not always related to the cheap cost of fuel (which has been shown to be at parity prices with Asia), but is also very much related to the very high cost of labour in the European setting. This contradicts to the broad view that European airlines are at a cost disadvantage based primarily on the price of fuel; this should be noted in further discussions regarding jet fuel pricing and competitiveness of airlines.

Unit Cost Comparison 2010-2011



Source: Published financial reports

Labour cost per employee, financial year ending 2010



Source: Oxford Economics, airline annual reports

Appendix C: Comparison of Jet Fuel and Typical Gasoline / Biofuel Properties

Jet fuels

Jet fuel is used for commercial (Jet A-1, Jet A, and Jet B) and military (JP-4, JP-5, JP-8...) jet propulsion; aviation gasoline (avgas) is used to power piston-engine aircraft. They are basically mixtures of kerosene and gasoline (half-&-half for JP-4, 99.5% kerosene for JP-5 and JP-8, 100% kerosene for Jet A-1), plus special additives (1..2%): corrosion inhibitor, anti-icing, anti-fouling, and anti-static compounds. Jet A-1 comprises hydrocarbon chains with 9 to 15 carbon atoms. Jet B (also named JP-4, with composition distribution from 5 to 15 carbon chains), is used in very cold weather, and in military aircraft.

Jet A-1 is the international standard jet fuel, with a freezing temperature of $T_f=50$ °C (47 °C as a limit); Jet A (with $T_f=40$ °C) is a low-grade Jet A-1 only and mostly used in USA; and Jet B ($T_f<50$ °C), the commercial name of JP-4, is only used in very cold climates. They all have a lower heating value of 42.8..43.6 MJ/kg. Minimum flash point is 60 °C for JP-5, 38 °C for Jet A-1 and JP-8 (typical value for Jet A-1 is $T_{flash}=50$ °C, with a vapour pressure at this point of 1.5 kPa; 1 kPa at 38 °C), and $T_{flash}=20$ °C for JP-4. Typical density at 15 °C is 810 kg/m³ for Jet A-1, and 760 kg/m³ for Jet B. Jet fuel must withstand 150 °C without fouling (dissolved oxygen in fuel exposed to air reacts with the hydrocarbons to form peroxides and eventually deposits after few hours); further heating leads to thermal cracking.

Jet A-1 specification is $T_{flash}=49.4$ °C at 100 kPa (but it might decrease to $T_{flash}=15$ °C at cruise altitude with 25 kPa). Fuel tank ullage can be inertized with nitrogen-enriched air with $x_{O_2}<12\%$. JP-4 has $T_{flash}=20$ °C. Jet A-1 surrogate is 1-dodecene (C₁₂H₂₄), whereas Jet B (also named JP-4) surrogate is ndecane C₁₀H₂₂. Jet A-1 viscosity at 20 °C is about $8.0 \cdot 10^{-6}$ m²/s.

Price: [Jet A-1 sells](#) at some 0.8 \$/L (about 20 €/GJ in terms of LHV).

Bioethanol and ETBE

Bioethanol is bio-fuel substitute of gasoline; i.e. it is ethanol obtained from biomass (not from fossil fuels), and used as a gasoline blend.

Pure bioethanol (E100-fuel) is by far the most produced biofuel, mainly in Brazil and USA. More widespread practice has been to add up to 20% to gasoline by volume (E20-fuel or gasohol) to avoid the need of engine modifications. Nearly pure bioethanol is used for new 'versatile fuel vehicles' (E80fuel only has 20% gasoline, mainly as a denaturaliser). Anhydrous ethanol (<0.6% water) is required for gasoline mixtures, whereas for use-alone up to 10% water can be accepted. ETBE (ethanol tertiary butyl ether, C₆H₁₄O, =760 kg/m³, LHV=36 MJ/kg), is a better ingredient than bioethanol because it is not so volatile, not so corrosive, and less avid for water. ETBE-15 fuel is a blend of gasoline with 15% in volume of ETBE. ETBE is obtained by catalytic reaction of bioethanol with isobutene (45%/55% in weight): CH₃CH₂OH+(CH₃CH)₂=(CH₃)₃-CO-CH₂CH₃. To note that isobutene comes from petroleum. The other gasoline-substitute ether, MTBE (methanol tertiary butyl ether, (CH₃)₃-CO-CH₃), is a full petroleum derivate (65% isobutene, 35% methanol).

Gasoline

Types: EU: Eurosuper-95, Eurosuper-98 (both lead-free) and USA: Regular (97 RON) and Premium (95 RON).
Density: 750 kg/m³ (from 720 kg/m³ to 760 kg/m³ at 20 °C).
Viscosity: $0.5 \cdot 10^{-6}$ m²/s at 20 °C.
Vapour pressure: 50..90 kPa at 20 °C, typically 70 kPa at 20 °C.
Heating value. Average Eurosuper values are: HHV=45.7 MJ/kg, LHV=42.9 MJ/kg.
Fuel ratio: A=14.5 kg air by kg fuel.

Thermal expansion coefficient= $900 \cdot 10^{-6}$ K⁻¹ (automatic temperature compensation for volume metered fuels is mandatory in some countries). Boiling and solidification points. Not well defined because they are mixtures. (e.g. when heating a previously subcooled sample at constant standard pressure, some 10% in weight of gasoline is in the vapour state at 300 K, and some 90% when at 440 K).

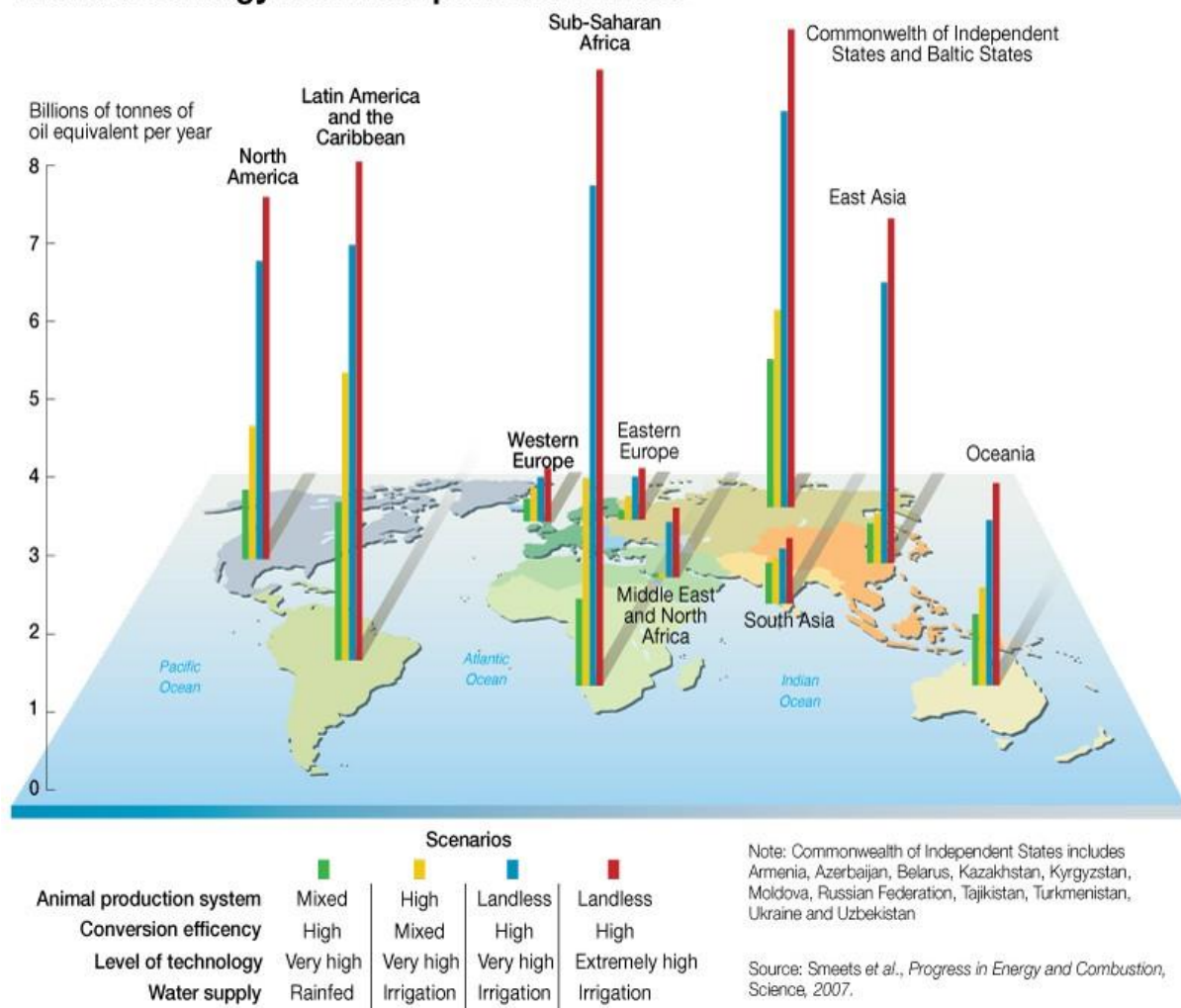
Source: <http://webservice.dmt.upm.es/~isidoro/bk3/c15/Fuel%20properties.pdf>

Appendix D: Biomass Energy Efficiency and Climate Impact

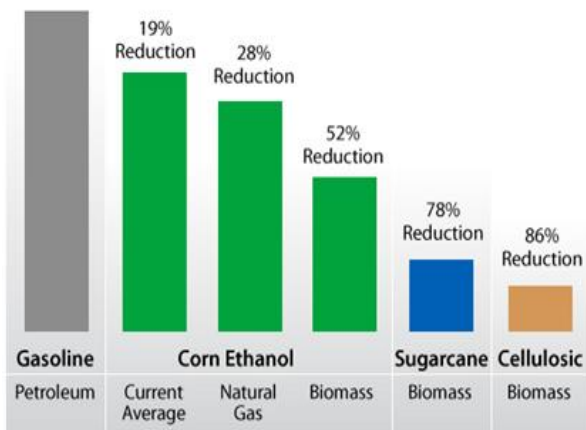
The following graphs show the different energy potential and the corresponding impact on greenhouse gas emissions (energy efficiency of biofuel production directly impacts the greenhouse gas reducing impact) of the different feedstock and the geographic potential of the feedstock in terms of bioenergy generation.

It can be clearly observed that sugarcane based biofuel has the highest potential for reducing carbon emissions and for meeting large scale demand for biofuels. Furthermore, one should note that the European aviation goals of implementing a 20% portfolio demand for biofuels of the total demand for fuel by 2020, would imply the equivalent in biofuel energy volume of the total output of the Brazilian ethanol market. This does not take into account the energy density implications of bio-ethanol; this thus present as an optimistic projection in relation to the volumes necessary to reach such goals.

World bioenergy technical potential in 2050

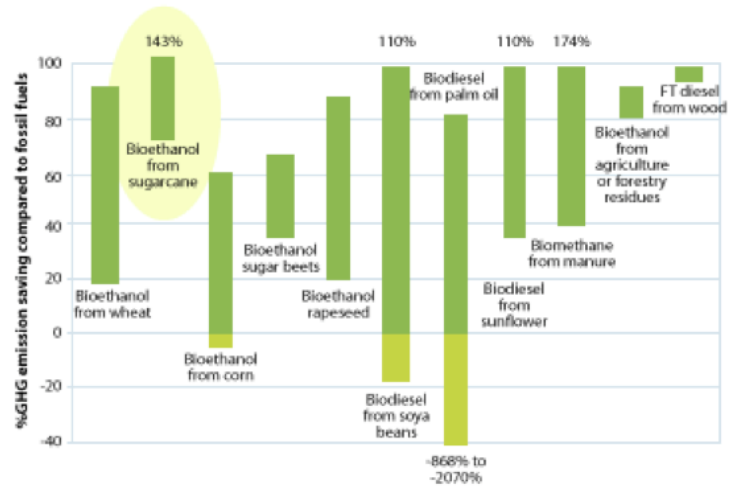


Greenhouse Gas Emissions of Transportation Fuels By Type of Energy Used Processing



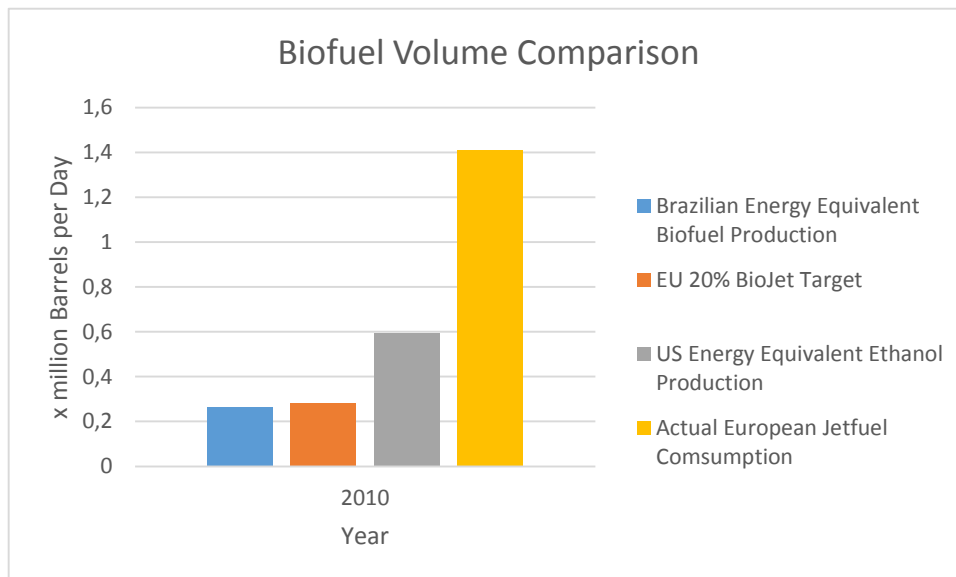
Source: [Life cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types \(2007\)\(PDF\)](#) and [DOE Bioenergy Technologies Office](#)

GREENHOUSE GAS SAVINGS OF BIOFUELS COMPARED TO FOSSIL FUELS



Source: UNEP 2009 based on data from Menichetti/Otto (2008) for bioethanol and biodiesel, IFEU (2007) for sugarcane ethanol, and Liska et al. (2009) for corn ethanol; FRA 2008 for biomethane, bioethanol from residues and FT diesel.

Biofuel Volume Comparison



Source: <http://www.indexmundi.com/>

The above figure shows how the ambitions of the European airline industry with regards to future biofuel implementation are significant when one considers that based on current production volumes of bio-ethanol in Brazil, it would mean that all biofuel produced in Brazil would be destined for biokerosene. Even in this case, one would not meet the 20% biofuel target in 2020. Only the United States would have enough production capacity to meet the demand; however the production of biofuels in the United States does not at all meet the sustainability criteria of the aviation industry as the biofuel used in corn ethanol.

The following shows just how large the kerosene demand is, and how small in comparison the biofuel market still use, even considering the two largest biofuel markets in the world

Sugar Cane vs. Solar Panels Energy Efficiency

- One can harvest 10 tons of sugar per hectare = $10,000 \text{ kg}/10,000 \text{ m}^2 = 1 \text{ kg} / \text{m}^2$.
- This means a square meter of sugar can yields a kilogram of sugar a year.
- As there are 4 calories (or kcal) per gram this gives you 4,000 kcal/ m^2 .
- A square meter of 11% efficient solar panels collects around 550Wh a day in Austin, Texas.
- So for a whole year: $550 * 365 = 200 \text{ kWh}/\text{yr}/ \text{m}^2$.
- $1 \text{ kcal} = 1.16222222 \text{ watt hour}$
- $4,000 \text{ kcals of sugar} = 4.65 \text{ kWh}$.
- That means the 11% efficient solar panel generates $200/4.65 = 50$ times more usable energy a year than the sugar cane does. Nowadays it's even possible to get 22% efficient solar panels that would go up to 100 times.
- Solar panels are therefore 2 magnitudes of order better at creating usable energy per m^2 than sugar cane.

Aside: This is just the usable energy. Plant leaves themselves are closer to 3-6% efficient in capturing sunlight (vs. 10-20% for solar panels).

Only light within the wavelength range of 400 to 700 nm (photosynthetically active radiation, PAR) can be utilized by plants, effectively allowing only 45 % of total solar energy to be utilized for photosynthesis. Furthermore, fixation of one CO₂ molecule during photosynthesis, necessitates a quantum requirement of ten (or more), which results in a maximum utilization of only 25% of the PAR absorbed by the photosynthetic system. On the basis of these limitations, the theoretical maximum efficiency of solar energy conversion is approximately 11%. In practice, however, the magnitude of photosynthetic efficiency observed in the field, is further decreased by factors such as poor absorption of sunlight due to its reflection, respiration requirements of photosynthesis and the need for optimal solar radiation levels. The net result being an overall photosynthetic efficiency of between 3 and 6% of total solar radiation.

Source: <http://fatknowledge.blogspot.nl/2006/03/sugar-cane-vs-solar-panels.html>

Appendix E: Aviation Biofuels Production Pathways and Milestones

Aviation Biofuels Production Pathways and Milestones:

Status	Class	Process	Feedstock
Completed			
Annex A1	FT SPK*	FT derived SPK	Coal, natural gas, biomass
Annex A2	HEFA SPK	Hydroprocessed Fats and Oils derived SPK	Triglyceride oils
In the approval process			
	FT SPK**	FT derived SKA	Coal, natural gas, biomass
	ATJ SPK	Fermentation alcohol, oligomerized and hydrated (ATJ) derived SPK	Sugar, alcohol
In development			
	ATJ SKA	ATJ derived SKA	Sugar, alcohol
	CH SKA	Hydrothermal cracking and cyclization derived SKA	Triglyceride oils
	CRJ SPK	Catalysis, oligomerized and hydrotreated derived SPK	Sugar, alcohol
	DSHC SPK	Direct fermentation to SPK	Sugar
	HEFA SKA	HEFA derived SKA	Triglyceride oils
	HDCJ SKA	Hydroprocessed depolymerized cellulose derived SKA	Lignocellulose
	SAK***	Catalysis to SAK	Sugar, alcohol

Source: IATA, Report on Alternative Fuels, 2012¹³

Notes: * FT SPK Synthetic paraffinic kerosene, ** FT SPK Synthetic kerosene with aromatics, *** SAK Synthetic Aromatics, kerosene boiling range

Appendix F: Model System Parameters

Variable Name	Description [if applicable]	Unit	Baseline	Minimum	Maximum	Source
BASE MODEL						
Energy Density Gasoline	Gasoline Energy density taken as base number	%	100		N/A	N/A
Energy Density Hydrous	Hydrous density in relation to gasoline	%	67		N/A	N/A
Energy Density Anhydrous	Anhydrous density in relation to gasoline	%	67		67	70
Total GEEL demand	Total demand in fuel by users in gasoline energy equivalent terms	L/day	104.8 Million		N/A	N/A
Switch Capacity	Production ratio switch by the refinery per evaluation period	%	10		5	40
Ratio Check Frequency	Frequency of production ratio evaluation	days	28		10	365
Distributor Logistics Factor	Ratio of Logistic Cost over production Cost [distributor to user]	%	0.3 [0.0]		0	0.5
Refinery Logistics Factor	Ratio of Logistic Cost over production Cost [refinery to distributor]	%	0.4 [0.0]		0	0.5
Preferred Level	Distributor storage level benchmark	[-]	0.5		0	1
Sugar Elasticity	Sugar Demand Elasticity	[-]	-2		-3	0
Hydrous Elasticity	Hydrous Demand Elasticity	[-]	-0.68		-1	0
Gasohol Elasticity	Gasohol Demand Elasticity	[-]	-0.23		-1	0
Price Switch Threshold	Price Difference Threshold relative to gasohol price	%	10		0	20
Sugarcane Production	Production Volume of sugarcane in Brazil	Tonnes	1.69 Million		N/A	N/A

Max Hydrous Storage	Maximum Hydrous Storage Capacity	L	N/A		N/A	N/A	N/A
Max Anhydrous Storage	Maximum Anhydrous Storage Capacity	L	N/A		N/A	N/A	N/A
Initial Hydrous Level	Initial Hydrous storage level at distributors	L	N/A		N/A	N/A	N/A
Initial Anhydrous Level	Initial Anhydrous storage level at distributors	L	N/A		N/A	N/A	N/A
Sugar Yield	Yield of sugar per tonne of sugarcane	kg/tonne	133		120	150	UNICA
Hydrous Yield	Yield of hydrous per tonne of sugarcane	L/tonne	75.03		70	90	UNICA
Anhydrous Yield	Yield of anhydrous per tonne of sugarcane	L/tonne	71.74		65	80	UNICA
Hydrous Molasses	Additional hydrous yield through sugar molasse recovery	L/tonne	6.56		0	10	UNICA
Anhydrous Molasses	Additional anhydrous yield through sugar molasse recovery	L/tonne	2.69		0	5	UNICA
Hydrous Processing Cost	Cost of processing a tonne of sugarcane for Hydrous production	\$/tonne	16.01		10	30	De Gorter
Anhydrous Processing Cost	Cost of processing a tonne of sugarcane for anhydrous production	\$/tonne	28.54		20	40	De Gorter
Sugar Processing Cost	Cost of processing a tonne of sugarcane for sugar production	\$/tonne	46.56		40	60	De Gorter
Global Sugar Demand	Consumption [demand] of Brazilian sugar	kg/day	109.58 Million		N/A	N/A	UNICA
Gasoline Price	Price of Gasoline [without blend]	\$/L	1.05		0.5	2	ANP
Sugarcane Price	Price of sugarcane [paid to farmers using the CONSECUNA agreement]	\$/tonne	56.11		30	80	IEA
Global Sugar Price	Global Price for sugar [export price]	\$/kg	1.0		0.3	1	ERS
Gasohol Blend Mandate	Blending mandate for anhydrous fuel with gasoline	%	25		0	40	UNICA

Anhydrous Tax	Imposed Tax on anhydrous ethanol	\$/L	0.05		0	0.1	SINDICOM
Hydrous Tax	Imposed Tax on hydrous ethanol	\$/L	0.26		0	0.4	SINDICOM
Gasoline Tax	Imposed Tax on gasoline	\$/L	1.28		0	2	SINDICOM
Margin Constant	Marketing Margin imposed by distributors	[-]	0.5		0	1	De Gorter
Smoothness Parameter	Forecasting smoothness constant used to predict future storage levels and prices	[-]	0.3		0	1	N/A
	BIOJET MODEL						
Kerosene Price	Global price of kerosene	\$/L	1.0		0.5	1.5	IATA
Biofuel Ratio	Percentage of kerohol fuel and regular kerosene	%	1.0		0	10	KLM
Blend Ratio	Percentage of biokerosene fuel in kerohol fuel (blend with kerosene)	%	25		0	50	KLM
Biokerosene Tax	Imposed Tax on biokerosene	\$/L	0		-1.0	0	IATA
Kerosene Tax	Imposed Tax on kerosene	\$/L	0		0	1.5	N/A
Bio Margin	Ratio kerohol price to kerosene price which aviation is willing to pay	[-]	0		0	3	N/A
Max Bio Storage	Maximum Biokerosene Storage Capacity	L	N/A		N/A	N/A	N/A
Airport Logistics Factor	Ratio of Logistic Cost over production Cost [distributor to airport]	%	0.2		0	0.5	UNICA
Kerosene Airfield Price	Price of kerosene at the airport paid by airlines	\$/L	N/A		N/A	N/A	N/A
Kerohol Airfield Price	Price of kerohol at the airport paid by airlines	\$/L	N/A		N/A	N/A	N/A
Kerosene Demand	Aviation Demand of Kerosene	L/day	N/A		N/A	N/A	N/A
Bio Logistics	Ratio of Logistic Cost over production Cost [Biorefinery to kerosene centre]	[-]	0.4		0	0.7	N/A
Bio Margin Constant	Marketing Margin imposed by kerosene centres	[-]	0.5		0	1	N/A

Biokerosene Yield	Yield of biokerosene per tonne of sugarcane	L/tonne	70		30	90	N/A
Biokerosene Molasses	Additional biokerosene yield through sugar molasse recovery	L/tonne	1.5		0	2	N/A
Min Biokerosene Processing Cost	Lowest achievable ratio of biokerosene proc. Cost over anhydrous costs	[-]	1.5		1	3	N/A
Initial Biokerosene Processing Cost	Processing cost of biokerosene from sugarcane before tech learning effects [of anhydrous]	[-]	5		1.5	10	N/A
Learning Volume	Volume of biokerosene production which affects technology learning	L	N/A		N/A	N/A	N/A
Technology Learning Parameter	Parameter of technology learning [decrease in prod. Price as volume doubles]	[-]	0.3		0	0.4	Junginger
Investment Threshold	Degree by refinery willing to invest into biokerosene facilities	[-]	0.3		N/A	N/A	N/A

Appendix G: Model User Interface

World View of the Model

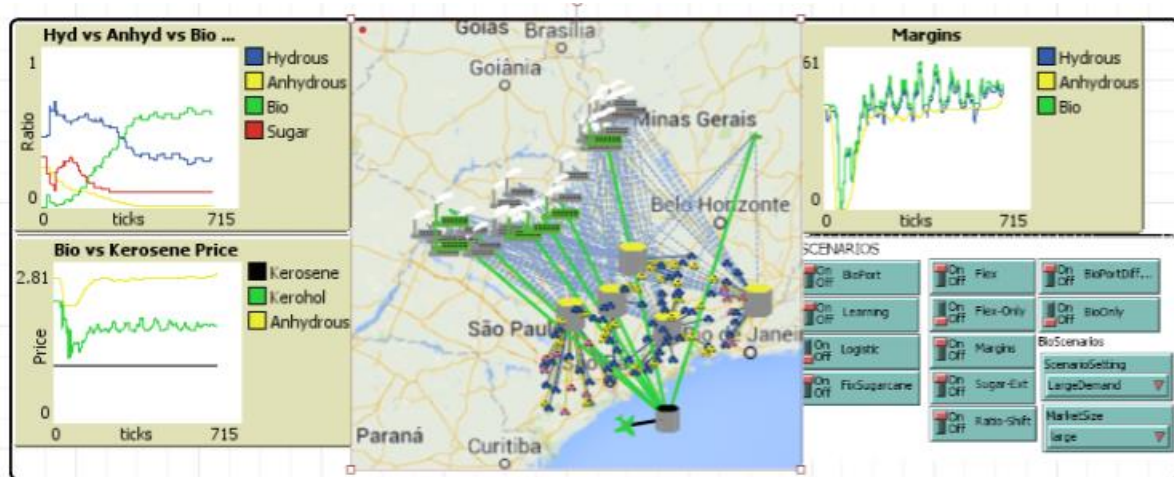
Run Procedure Buttons: Setup and Start the Simulations at the Push of a Button

Real-Time System Information

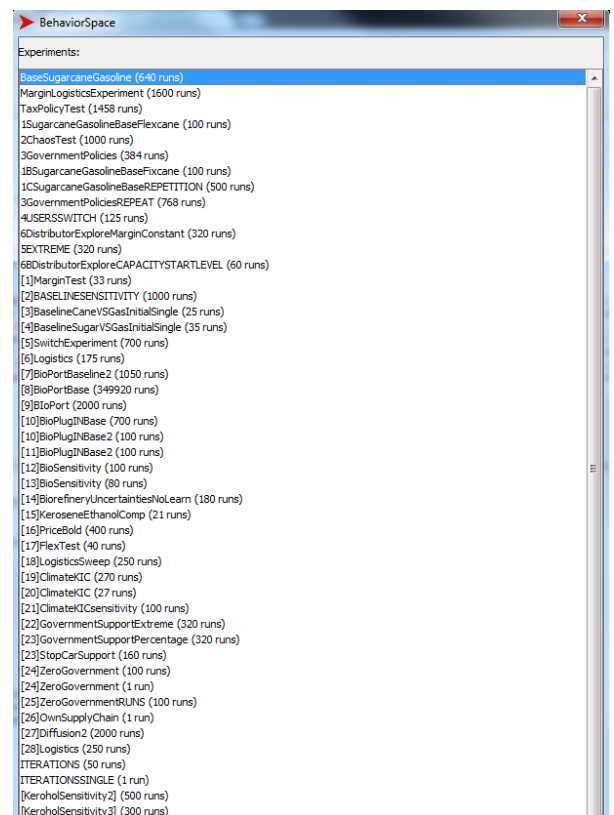
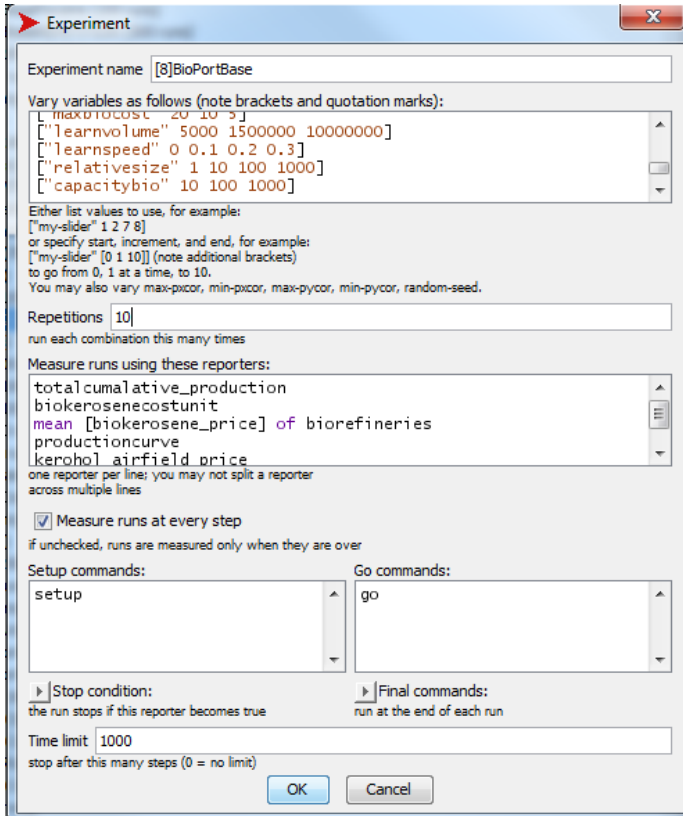
Model Switches; Turn on or Off certain Scenarios

BioJet Demand Scenarios: 747 Volume or Bio-ethanol Market Equivalent BioJet Demand

Parameter Values; User can slide the slider to play with different input variables. This can be done in real-time



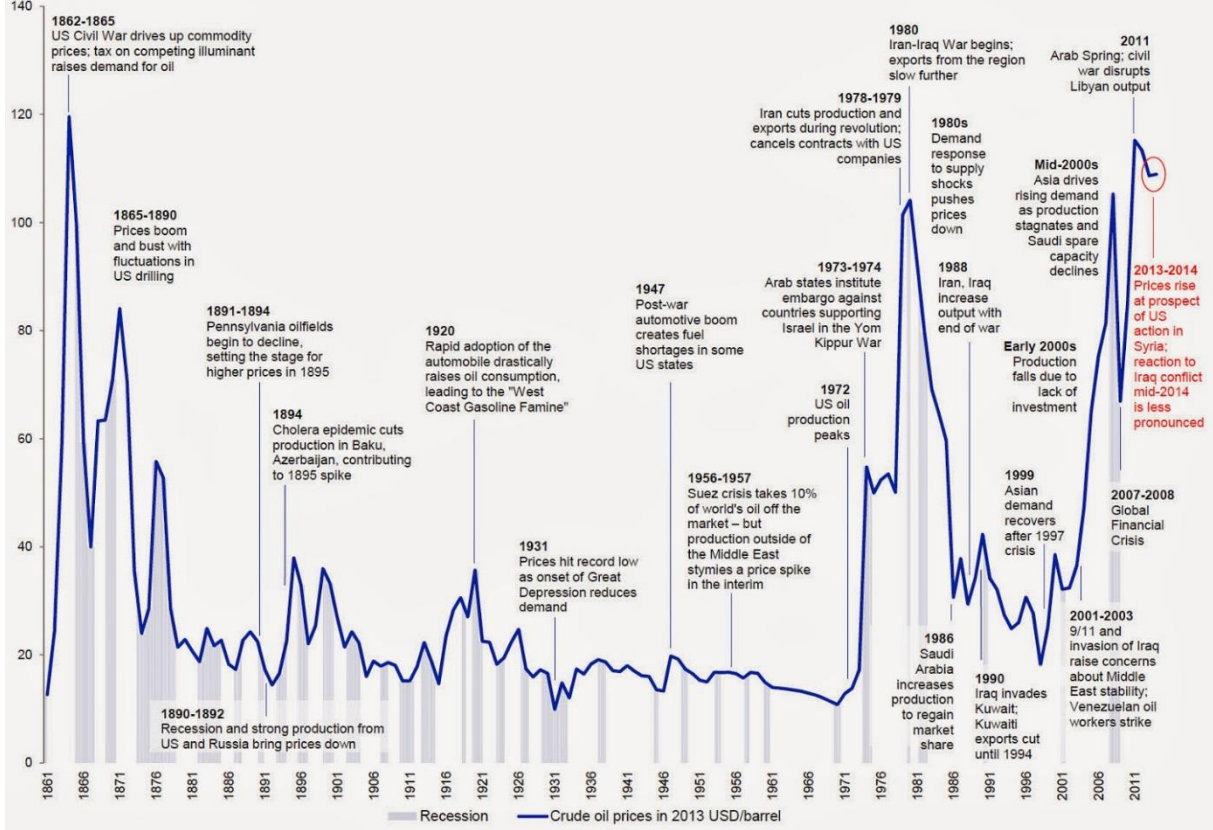
Appendix H: Model Experiments



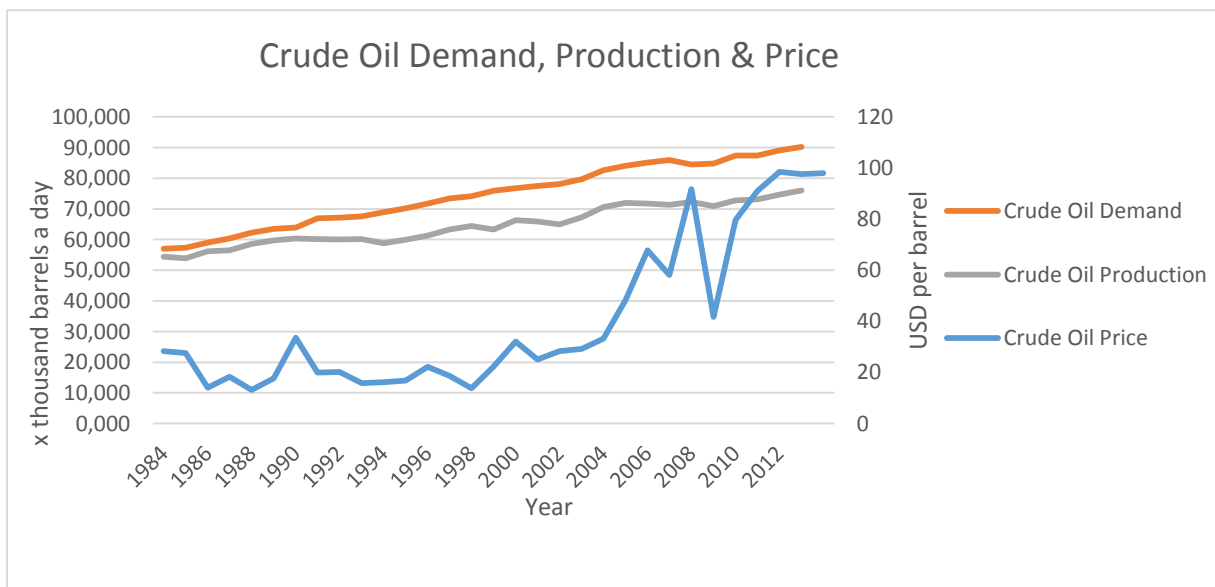
An overview of the use of BehaviorSpace in Netlogo is shown in the screenshots above. The methodology in which the experiments have been carried out is through the setting of a bandwidth in maximum and minimum values for the parameters which are deemed to be able to vary. By setting an increment within these values, a large number of simulations runs is necessary. The addition of multiple parameters values changes during an experiment quickly increases the number of runs required, this can quickly lead to practical issues with regards to run time and data management. The experiments which are carried out in this report, have been primarily based on the testing of a two-dimensional scenario setting; that is to say two parameters are assumed to be able to vary. This setup is satisfactory when one considers the fact that the external prices of commodities are the leading parameters under which the system is under study.

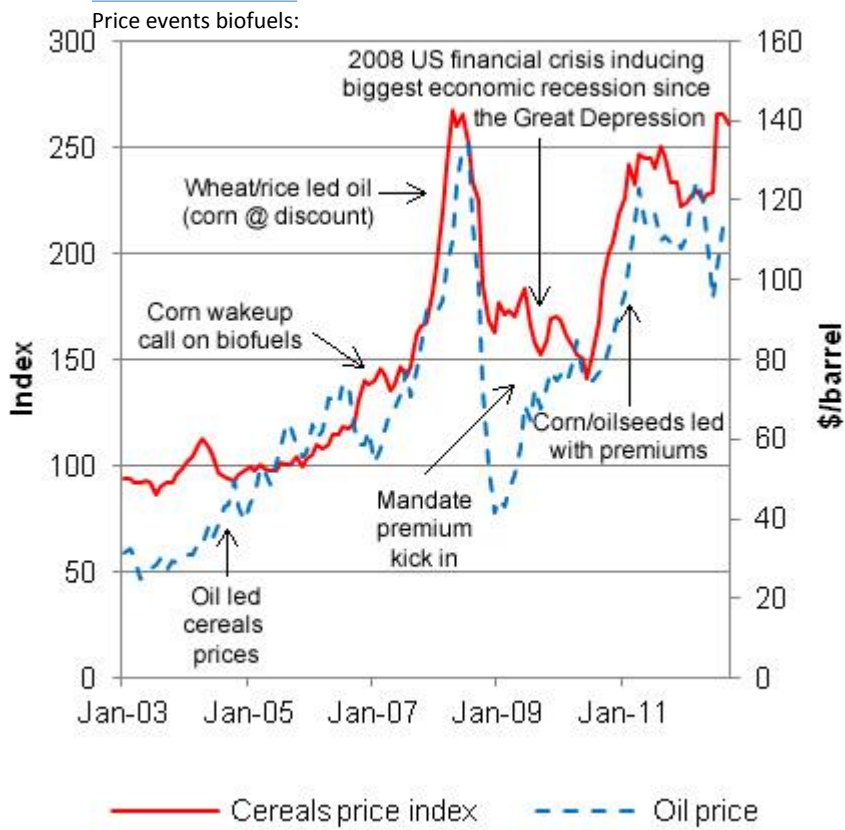
Appendix I: Commodity Prices

Price events crude oil:



Source: <http://ghovexx.blogspot.nl/2014/07/annotated-history-of-world-oil-price.html>



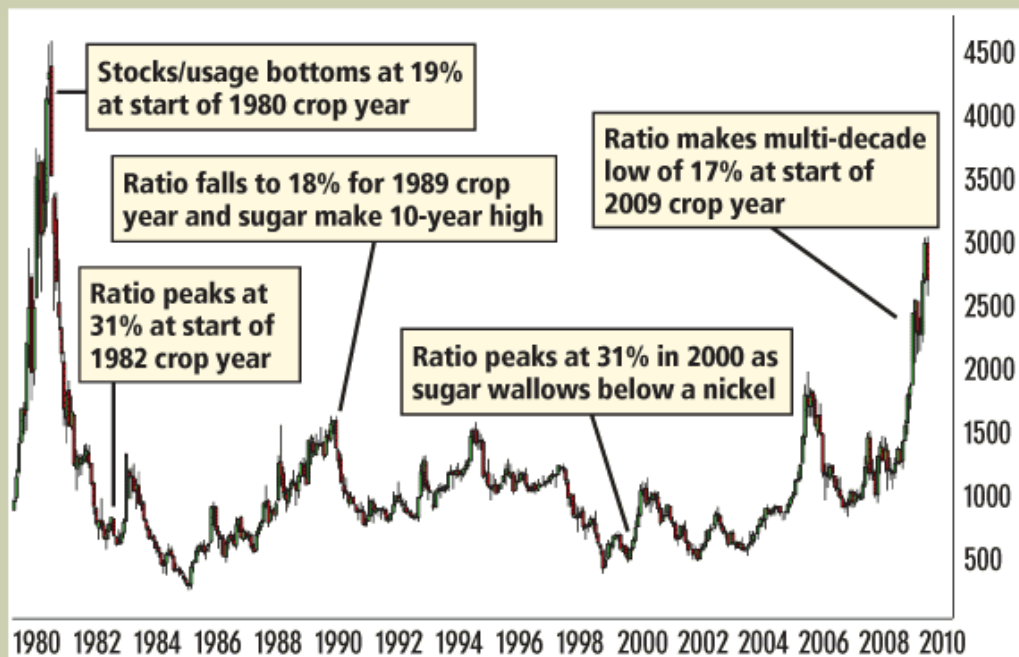


Source: <http://www.agbioforum.org/v16n1/v16n1a01-degorter.htm>

Stocks as a predictor of sugarprice movement:

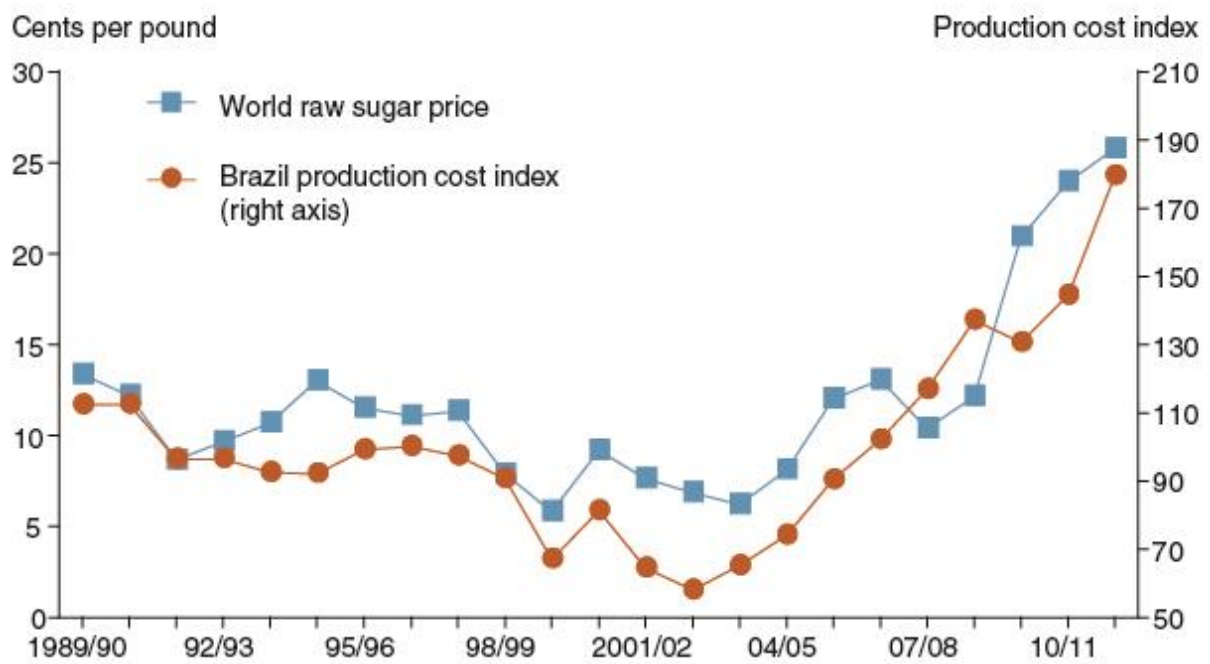
SWEET CORRELATIONS

Stocks to usage ratio in sugar at the beginning of the crop year has tended to be a good predictor of price movement.



Source: eSignal/Hightower Report-USDA

World sugar prices and Brazilian costs of production track closely with each other



Source: USDA, Economic Research Service using data from Intercontinental Exchange, No. 11, NY contract; LMC International.

Appendix J: Data Analysis

R Script Used in Order to Generate Graphs

The prime template of the R Studio Script which is used to generate the plots and graphs is shown. The particular script has been run for many different sets of experiment files.

```
options(stringsAsFactors = FALSE)

library(ggplot2)
library(reshape2) library(sqldf)
library(gridExtra)

setwd("C:/Users/TOM/Desktop/R_Experiments")

myDataFrame = read.table("EXPERIMENTNAME.csv", skip = 6, sep = ",", head=TRUE)

colnames(myDataFrame)[2]="Tick" colnames(myDataFrame)[1]="Run"
colnames(myDataFrame)[3]="GasolineTax"
colnames(myDataFrame)[4]="HydrousTax"
colnames(myDataFrame)[5]="AnhydrousTax"
colnames(myDataFrame)[7]="HydrousProductionPrice"
colnames(myDataFrame)[6]="HydrousPrice"

colnames(myDataFrame)[8]="GasoholPrice" colnames(myDataFrame)[1]="Run"
colnames(myDataFrame)[8]="BiokerosenePrice"
colnames(myDataFrame)[9]="KeroholPrice"
colnames(myDataFrame)[10]="KerosenPrice"
colnames(myDataFrame)[11]="GasolinePrice"
colnames(myDataFrame)[12]="SugarcanePrice"

data2 = data.frame (myDataFrame [1], myDataFrame [3], myDataFrame [5], myDataFrame [11], myDataFrame [8])

data2 = data.frame("GasolineTax", "AnhydrousTax", "GasolinePrice", "Tick") data3 =
melt(data2, id=c("Tick"))

ggplot(data=data3, aes(x=Tick, y=value)) + geom_area(aes(fill=variable))

ggplot(data = data3, aes(x = 1, y = value, fill = variable)) + geom_bar()
+ coord_flip()

ggplot(myDataFrame, aes(color, fill=cut)) + geom_bar() + coord_flip()

colnames(myDataFrame)[9]="HydrousPrice"
colnames(myDataFrame)[10]="GasoholPrice"
colnames(myDataFrame)[11]="TotalProduced"
colnames(myDataFrame)[3]="Users1" colnames(myDataFrame)[4]="Users2"
colnames(myDataFrame)[5]="Users3"
colnames(myDataFrame)[12]="BiokeroseneRatio"
colnames(myDataFrame)[13]="HydrousRatio"
colnames(myDataFrame)[14]="AnhydrousRatio"
colnames(myDataFrame)[15]="SugarRatio"
colnames(myDataFrame)[11]="Totalsugar"

usersdata = melt(myDataFrame, id=c("Run", "Tick", "Totalhydrous", "Totalanhydrous", "KeroholPrice",
"HydrousPrice", "GasoholPrice", "Totalsugar", "HydrousRatio", "AnhydrousRatio", "SugarRatio", "BiokeroseneRatio"))

totalprodratio = melt(myDataFrame, id=c("Run", "Tick", "Users1", "Users2", "Users3", "KeroholPrice",
"HydrousPrice", "GasoholPrice", "HydrousRatio", "AnhydrousRatio", "SugarRatio", "BiokeroseneRatio"))

bioratio = melt(myDataFrame, id=c("Run", "Tick", "Users1", "Users2", "Users3", "KeroholPrice",
"HydrousPrice", "GasoholPrice", "Totalsugar", "Totalhydrous", "Totalanhydrous"))

priceratio = melt(myDataFrame, id=c("Run",
"Tick", "Users1", "Users2", "Users3", "Totalsugar", "Totalhydrous", "Totalanhydrous", "HydrousRatio", "AnhydrousRatio", "SugarRatio", "BiokeroseneRatio"))

ggplot(data=priceratio aes(x=Tick, y=value)) + geom_area(aes(fill=variable))

ggplot(data=data3, aes(x=Tick, y=value)) +
geom_point(aes(colour=variable))+ facet_grid(sugarcane_price ~
sugarcane_price, scales="free_y")

scatterplot = ggplot(data=myDataFrame, aes(x=Tick, y=Price_Difference)) + #use myDataFrame for the data, columns for x and y
geom_point(aes(colour = Run)) + #we want to use points, colored by runNumber xlab("Tick") + #specify x and y labels
ylab("Gasohol Hydrous Price Difference") + ggtitle("Price Difference over time") #give the plot a title print(scatterplot)
#display the scatterplot

ggplot(data=myDataFrame, aes(x=KeroholPrice, y=BiokeroseneRatio)) + stat_density2d(geom="point", aes(size = ..density..),
contour = FALSE)
```

```

scatterplot1 = ggplot (data=myDataFrame, aes(x=Run, y = BiorefineryRatio)) + geom_(aes(colour=Run))
scatterplot2 = ggplot (data=myDataFrame, aes(x=Tick, y =BiokerosenePrice)) + geom_point(aes(colour=Run))
scatterplot = ggplot (data=myDataFrame, aes(x=Tick, y =BiokerosenePrice)) + geom_point(aes(colour=Run))

scatterplot = ggplot() + geom_boxplot(data = myDataFrame, aes(x = Tick, y =
BiokerosenePrice, color = "red")) + geom_boxplot(data = myDataFrame, aes(x = Tick, y =
KeroholPrice, color = "blue"))

print(scatterplot1)

grid.arrange(scatterplot1, scatterplot2)

print(scatterplot)

boxplot = ggplot(data=myDataFrame, aes(x=Tick, y=KeroholPrice)) + #use myDataFrame for the data, columns for x and y
geom_boxplot() + #we want to use points xlab("Tick") + #specify x and y labels ylab("KeroholPrice") +
ggtitle("KeroholPrice over time") #give the plot a title print(boxplot) #display the scatterplot

simpleHeatMapOfScatterPlot = ggplot(data=myDataFrame, aes(x=Run, y=BiorefineryRatio)) + stat_density2d(geom="tile",
aes(fill = ..density..), contour = FALSE)

print(simpleHeatMapOfScatterPlot)

ggplot(data=data3, aes(x=Tick, y=value)) + #use myDataFrame for the data, columns for x and y
geom_line(aes(colour = variable)) + #we want to use points, colored by runNumber xlab("Tick") +
#specify x and y labels ylab("Ratio") + ggtitle("Ratio over time") #give the plot a title

ggplot(data=myDataFrame, aes(x=Tick, y=count_biorefineries)) + stat_density2d(geom="point", aes(size = ..density..), contour =
FALSE)

ggplot(data=data2, aes(x=sugarcane_price, y=value)) + stat_density2d(geom="point", aes(size = ..density..), contour = FALSE)

scatterplot = ggplot(data=myDataFrame, aes(x=Tick, y=KeroholPrice)) + #use myDataFrame for the data, columns for x and y
geom_point(aes(colour = Run)) + #we want to use points, colored by runNumber xlab("Tick") + #specify x and y labels
ylab("KeroholPrice") + ggtitle("KeroholPrice over time") #give the plot a title print(scatterplot) #display the scatterplot

boxplot = ggplot(data=myDataFrame, aes(x=Tick, y=HydrousPrice, group=round(Tick/25))) + geom_boxplot()

print(boxplot)

scatterplot = ggplot(data=data2, aes(x=Tick, y=BiokeroseneRatio)) + #use myDataFrame for the data, columns for x and y
geom_area(aes(fill = variable)) print(scatterplot) #display the scatterplot

ggplot ()

ggplot(data=data3, aes(x=Tick, y=value)) +
geom_point(colour= variable) +
facet_wrap(~Run)

ggplot(data=data3, aes(x=Tick, y=value, group=sugarcane_price)) + geom_line()
+ facet_grid(DistrLogistic-blending_mandate, scales="free_y")

```

Appendix K: Source Code


```

]
users-own
[GBEL_demand
  user_type
  anyhydrous_demand
  realanyhydrous_demand
  hydrous_demand
  realhydrous_demand
  realgasohol_demand
  gasohol_demand
  realgasohol_demand
  gasohol_cost
  hydrous_cost
  local_gasohol_price
  evaluation_frequency
  local_hydrous_price
  switch_inclination
  GBELhydrous_price
  GBELgasohol_price
  switch_change
  preference
  user_distance
  users_logistics]
externals-own
[sugar_supply
  sugar_gap
  sugar_margin
  oldsugar_price
  oldsugar_demand
  sugar_demand
  max_sugar_stock
  anyhydrous_ratio
  hydrous_revenue
  anyhydrous_revenue
  sugar_revenue
  internal_sugar_price
  internal_hydrous_price
  internal_anyhydrous_price
  oldnext_sugar_profit
  hydrous_profit
  anyhydrous_profit
  sugar_production_cost
  anyhydrous_production_cost
  sugar_production_cost
  anyhydrous_production_cost
  next_hydrous_profit
  start_date
  hydrous_smoothness
  oldnext_hydrous_profit
  next_sugar_profit
  next_anyhydrous_profit
  investment_threshold
]
distributors-own
[constant_hydrous
  constant_gasohol
  gasohol_price
  hydrous_consumer_price
  E100_profit_margin
  E85_blend_profit_margin
  hydrous_required
  anyhydrous_required
  hydrous_supplied
  anyhydrous_supplied
  sugar_stock_level
  sugar_stock_history
  oldsugar_level
  oldsugar_supplied
  sugar_required
  sugar_demand_change
  sugar_price
  sugar_level_change
  sugar_level
  sugar_price_change
  oldnext_sugar_level
  sugar_oversupply
  sugar_undersupply
  sugar_price_change
  new_sugar_demand
]
airports-own
[REBEL_demand
  airports_distance
  airports_logistics
  local_bioterosene_price
]
kerosene-centres-own [
  economies_of_scale
  kerosene_required
  biokerosene_required
  kerohol_required
  hydrous_price
  anyhydrous_price
  biokerosene_price
  kerosene_distance
]

```

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anyhydrous_ratio
hydrous_revenue
anyhydrous_revenue
sugar_revenue
internal_sugar_price
internal_hydrous_price
internal_anyhydrous_price
oldnext_sugar_profit
hydrous_profit
anyhydrous_profit
sugar_production_cost
anyhydrous_production_cost
sugar_production_cost
anyhydrous_production_cost
next_hydrous_profit
start_date
hydrous_smoothness
oldnext_hydrous_profit
next_sugar_profit
next_anyhydrous_profit
investment_threshold
]
distributors-own
[constant_hydrous
  constant_gasohol
  gasohol_price
  hydrous_consumer_price
  E100_profit_margin
  E85_blend_profit_margin
  hydrous_required
  anyhydrous_required
  hydrous_supplied
  anyhydrous_supplied
  sugar_stock_level
  sugar_stock_history
  oldsugar_level
  oldsugar_supplied
  sugar_required
  sugar_demand_change
  sugar_price
  sugar_level_change
  sugar_level
  sugar_price_change
  oldnext_sugar_level
  sugar_oversupply
  sugar_undersupply
  sugar_price_change
  new_sugar_demand
]
airports-own
[REBEL_demand
  airports_distance
  airports_logistics
  local_bioterosene_price
]
kerosene-centres-own [
  economies_of_scale
  kerosene_required
  biokerosene_required
  kerohol_required
  hydrous_price
  anyhydrous_price
  biokerosene_price
  kerosene_distance
]

```

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```

hydrous_price
anyhydrous_price
hydrous_gap
anyhydrous_gap
hydrous_level
oldhydrous_level
oldhydrous_required
oldanyhydrous_required
anyhydrous_level
refineries_distance
refineries_logistics
refineries_capacity
max_hydrous_stock
max_anyhydrous_stock
hydrous_stock
anyhydrous_stock
oldhydrous_stock
oldanyhydrous_stock
anyhydrous_stock_change
oldanyhydrous_stock
hydrous_stock_history
anyhydrous_stock_history
oldhydrous_level
oldanyhydrous_level
hydrous_level_change
anyhydrous_level_change
hydrous_percentage
anyhydrous_percentage
anyhydrous_margin
hydrous_oversupply
hydrous_undersupply
anyhydrous_oversupply
anyhydrous_undersupply
next_hydrous_level
oldnext_hydrous_level
next_anyhydrous_level
oldnext_anyhydrous_level

```

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```

if who > 6 [set investmentthreshold RISKSEENERS - random-float 0.2]
]

;SET WORLD POSITION USERS
create-users num-users [
  set xcor (-5 + random-float 29)
  if (xcor > 6) [ set ycor (4 / 14 * xcor) - 21 + random-float 15]
  if (xcor < 6) [ set ycor (5 / 9 * xcor) - 24 + random-float 15]
  set size 1.5
]

;MODEL ASIGNS RANDOMLY WHETHER THE AGENT IS TYPE 1, 2 OR 3
ifelse fix-only = false [set user_type 1 + random 3 if user_type = 1 [set color pink] if user_type = 2 [set color yellow]
blue] [set user_type 3 [set color blue]] [set user_type 2 + random 2 if user_type = 2 [set color yellow] if user_type = 3 [set color
blue]] ;; random initiation of all users type ;; equal chance
set GREEL_demand totalGREEL_demand ;; System GREEL demand is assumed user GREEL demand

;BASED ON WHAT TYPE THE AGENT IS ASSIGNED THE FOLLOWING TYPE UNIQUE PARAMETERS ARE ASSIGNED, ALSO WITH A UNIFORM
DISTRIBUTION BETWEEN AGENTS WITHIN THE SAME TYPE
if user_type = 3 [set switch_inclination (random-float 1.75) + 0.25; the natural willingness to switch; > 1 means very
sensitive, < 1 means insensitive ;; normal distributed with mean 1, dev 0.3
set evaluation_frequency int ((1 / switch_inclination) * 20) ; the natural frequency in which the
consumer does a switch check ;; no time inversely related to switch inclination;; sensitivity to switching means frequent
evaluation ;; with mean 20 ticks
set preference random-float 0.5 + 0.5 ; > 1 means gasoline preferred, < 1 means very
preference. ;; varied by normal distr. mean 1, dev 0.1
if user_type = 2 [set switch_inclination (random-float 1.75) + 0.25; the natural willingness to switch; > 1 means very
sensitive, < 1 means insensitive ;; normal distributed with mean 1, dev 0.3
set evaluation_frequency int ((1 / switch_inclination) * 20) ; the natural frequency in which the
consumer does a switch check ;; assumed inversely related to switch inclination;; sensitivity to switching means frequent
evaluation ;; with mean at every 10 days (ticks)
set preference random-float 0.5 + 1 ; > 1 means gasoline preferred, < 1 means no
preference. ;; varied by normal distr. mean 1, dev 0.1
if user_type = 1 [set switch_inclination random-float 0.3 + 0.5 set evaluation_frequency 30 set preference 1.5] ; user
types 1 are very resistance to switching

]

;SUGAR MARKET "AGENT"
create-externals 1 [
  set xcor -31 set ycor 21
  set size 1
  set color red
  ifelse sugar-ext = true [set new_sugar_demand (4 * (10 ^ 10)) / 365] [set new_sugar_demand (4 * (10 ^ 10)) / 365 + 0.7 /
global_sugar_price]

;IF SUGAR MARKET IS INTERNAL, SAME PARAMETERS AS ETHANOL DISTRIBUTION
set max_sugar_stock new_sugar_demand * CAPACITY
set sugar_stock max_sugar_stock * STARTLEVEL
set oldsugar_level sugar_stock / max_sugar_stock
set oldsugar_price global_sugar_price
]

;IF HUMAN WANTS TO PLAY WITH BLOPER MODEL
if bloport = true [setup-aviation]
if bloport = true [setup-biorefineries]

reset-ticks

;THE MODEL MUST BE INITIALIZED IN ORDER FOR THE SYSTEM TO START CORRECTLY
foreach sort turtles [
  ask users [let nearest-distributor min-one-of distributors (distance myself) ask nearest-distributor (create-downstream-with
myself)]
  ask distributors [create-upstream-with refineries if not any? downstream-neighbors [die]]
  ask refineries [create-extflows-with externals ask my-extflows [hide-link]]
  ask downstreams [logistics]
  ask upstreams [logistics]
  totalsystem
]

;SET WORLD POSITION OF REFINERIES
create-refineries num-refineries [
  set xcor -22 + random-float 30
  if (xcor > 0) [ set ycor (4 / 14 * xcor) + ((random-float 7) + 14)]
  if (xcor < 0) [ set ycor (1 / 3 * xcor) + ((random-float 7) + 5)]
  if (xcor = 0) [ set ycor ((11 / 16 * xcor) + ((random-float 7) + 0))]
  set size 5
  set color grey

;REAL WORLD PARAMETERS WITH A UNIFORM RANDOM DISTRIBUTION BETWEEN AGENTS
set sugar_yield (133 + (-1 + random 2) * random-float 10) ; [kg sugar / tonnes sugarcane] ;; randomly varied by max 20
and min -20
set hydrous_yield (71.03 + (-1 + random 2) * random-float 5) ; [liters hydrous / tonnes sugarcane] ;; randomly varied by
max 10 and -10
set anhydrous_yield (71.74 + (-1 + random 2) * random-float 3) ; [liters anhydrous / tonnes sugarcane] ;; max varied by
max 6 and min -6
by 1 and min -1
set anhydrous_molasses (2.69 + (-1 + random 2) * random-float 0.5) ; [liters anhydrous/ tonnes sugarcane] ;; max varied
and min -2
set hydrous_molasses (6.56 + (-1 + random 2) * random-float 1) ; [liters hydrous / tonnes sugarcane] ;; max varied by 2
set sugar_ratio 0.9 + random-float 0.1 ; range random 20% - 60%
set hydrous_ratio (1 - random-float 0.1) ; dependent setting
set anhydrous_ratio (1 - random-float 0.1) ; range random 50% - 100%
set hydrous_ratio (0.6 + random-float 0.4) ; dependent hydrous setting
set anhydrous_ratio (1 - hydrous_ratio) ;; dependent hydrous setting
set hydrous_production_cost (16.01 + (-1 + random 2) * random-float 2.5) ; ($ / tonnes sugarcane) ;; varied by max 5 and
min -5
set anhydrous_production_cost (28.54 + (-1 + random 2) * random-float 5) ; ($ / tonnes sugarcane) ;; varied by max 10 and
min 10
set sugar_production_cost (46.56 + (-1 + random 2) * random-float 10) ; ($ / tonnes sugarcane) ;; varied by max
set start_date random 28

;UNCERTAIN SYSTEM PARAMETERS
if who = 6 [set investmentthreshold 10] ;;conservative
]

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]

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]

```



```

end

to production-learning :: PRODUCTION COSTS DECREASE AS A FUNCTION OF TECHNOLOGY LEARNING

;COMPLATIVE HISTORY --> AFFECTS THE LEARNING TRAJECTORY
set totalbiobased (sum totalcumulative_production)
if int(totalbiobased / learningvolume) > integercheck {
  if totalbiobased > 0 and productioncurve > 0 {

    let virtualproductioncurve initialproductioncurve - int (totalbiobased / learningvolume) * technology_learning *
    productioncurve
    ifelse virtualproductioncurve > productioncurve {set productioncurve [
      if virtualproductioncurve < 0 [set productioncurve 0]
      if virtualproductioncurve = 0 [set productioncurve 0]
      if virtualproductioncurve > 0 [set productioncurve virtualproductioncurve]
    ]
  }
  set integercheck int (totalbiobased / learningvolume)}

end

; IF HYDROUS IS MORE LUCRATIVE TO THE REFINERY IN THE PAST PERIOD
if nextanhydrous_profit > nextanhydrous_profit and nexthydrous_profit > nextbiokerosene_profit * BIOPREFERENCE {
  set hydrous_ratio hydrous_ratio + ethanol-switch-capacity
  if hydrous_ratio > 0.95 [set hydrous_ratio 0.95]
  if hydrous_ratio < 0.1 [set hydrous_ratio 0.1]
  let ratio 1 - hydrous_ratio
  ifelse ratio > 0 [set anhydrous_ratio hydrous_ratio / (biokerosene_ratio + anhydrous_ratio) * ratio
  set biokerosene_ratio ratio - anhydrous_ratio] [set biokerosene_ratio 0 set anhydrous_ratio 0]
}

; IF ANHYDROUS IS MORE LUCRATIVE TO THE REFINERY IN THE PAST PERIOD
if nextanhydrous_profit > nexthydrous_profit and nextanhydrous_profit > nextbiokerosene_profit * BIOPREFERENCE {
  set anhydrous_ratio anhydrous_ratio + ethanol-switch-capacity
  if anhydrous_ratio > 0.95 [set anhydrous_ratio 0.95]
  if anhydrous_ratio < 0.1 [set anhydrous_ratio 0.1]
  let ratio 1 - anhydrous_ratio
  ifelse ratio > 0 [set hydrous_ratio hydrous_ratio / (biokerosene_ratio + hydrous_ratio) * ratio
  set biokerosene_ratio ratio - hydrous_ratio] [set biokerosene_ratio 0 set hydrous_ratio 0]
}

; IF BIOKEROSENE IS MORE LUCRATIVE TO THE REFINERY IN THE PAST PERIOD
if nextbiokerosene_profit * BIOPREFERENCE > nextanhydrous_profit and nextbiokerosene_profit * BIOPREFERENCE >
nexthydrous_profit {
  biokerosene_ratio biokerosene_ratio + ethanol-switch-capacity
  if biokerosene_ratio > 0.95 [set biokerosene_ratio 0.95]
  if biokerosene_ratio < 0 [set biokerosene_ratio 0]
  let ratio 1 - biokerosene_ratio
  ifelse ratio > 0 [set anhydrous_ratio anhydrous_ratio / (hydrous_ratio + anhydrous_ratio) * ratio
  set hydrous_ratio ratio - anhydrous_ratio] [set hydrous_ratio 0 set anhydrous_ratio 0]
}

; IF SUGAR PROFITS INCREASE SIGNIFICANTLY (OR DECREASE), SUGAR RATIOS WILL BE CHANGED
if nextsugar_profit < nexthydrous_profit * hydrous_ratio + nextanhydrous_profit * anhydrous_ratio + nextbiokerosene_profit
* BIOPREFERENCE * biokerosene_ratio {
  set sugar_ratio sugar_ratio + sugar-switch-capacity
  set ethanol_ratio 1 - sugar_ratio
}

; IF SUGAR PROFITS INCREASE SIGNIFICANTLY (OR DECREASE), SUGAR RATIOS WILL BE CHANGED
if nextsugar_profit < (nexthydrous_profit * hydrous_ratio + nextanhydrous_profit * anhydrous_ratio + nextbiokerosene_profit
* BIOPREFERENCE * biokerosene_ratio) {
  set sugar_ratio sugar_ratio + sugar-switch-capacity
  set ethanol_ratio 1 - sugar_ratio
}

; IF NEXTSUGAR PROFIT < (NEXTHYDROUS PROFIT * HYDROUS_RATIO + NEXTANHYDROUS PROFIT * ANHYDROUS_RATIO + NEXTBIOKEROSENE PROFIT
* BIOPREFERENCE * BIOKEROSENE_RATIO) {
  set sugar_ratio sugar_ratio - sugar-switch-capacity
  if sugar_ratio < 0.1 [set sugar_ratio 0.1]
  set ethanol_ratio 1 - sugar_ratio
}

; IF REFINERY PRODUCES MORE ETHANOL THAN SUGAR, LINK BECOMES ETHANOL DOMINATED AND VICE VERSA, SAME IS TRUE WITHIN ETHANOL
FOR HYDROUS AND ANHYDROUS
ifelse ethanol_ratio > sugar_ratio [ifelse hydrous_ratio > anhydrous_ratio [ask my-upstreams [set color 107]]] [ask my-
upstreams [set color 47]] ask my-extflows [hide-link]] [ask my-extflows [show-link set color 17]]
end

to convert
  if (ticks + start_date) / (ratio-check-frequency * tickinterval) - int ((ticks + start_date) / (ratio-check-frequency *
tickinterval)) = 0 [
    if ticks > 10 {
      if (mean (nextbiokerosene_profit) of biorefineries - investmentthreshold) > nexthydrous_profit and (mean
nextbiokerosene_profit) of biorefineries - investmentthreshold > nextanhydrous_profit) [(set breed biorefineries)
assignbioproperties
create-biobasedflows-with kerosene-centres (ask my-biobasedflows [hide-link])]
    ]
  ]
}

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```

```

end

;COMPLATIVE HISTORY --> AFFECTS THE LEARNING TRAJECTORY
set totalbiobased (sum totalcumulative_production)
if int(totalbiobased / learningvolume) > integercheck {
  if totalbiobased > 0 and productioncurve > 0 {

    let virtualproductioncurve initialproductioncurve - int (totalbiobased / learningvolume) * technology_learning *
    productioncurve
    ifelse virtualproductioncurve > productioncurve {set productioncurve [
      if virtualproductioncurve < 0 [set productioncurve 0]
      if virtualproductioncurve = 0 [set productioncurve 0]
      if virtualproductioncurve > 0 [set productioncurve virtualproductioncurve]
    ]
  }
  set integercheck int (totalbiobased / learningvolume)}

end

; IF BIOPRICES ARE MORE LUCRATIVE TO THE REFINERY IN THE PAST PERIOD
let bioprices mean (biokerosene_prices) ;PER TICK THE PRICE
let revenue totalbiokerosene_production * bioprices ;COST OF BIOKEROSENE PER TICK
set totalbiokerosene_production sum (biokerosene_production) of biorefineries ;ALL BIOKEROSENE PRODUCTION IN THE TICK
set totalbiokerosene_production_costs mean (biokerosene_production_costs) of biorefineries ;COST OF BIOKEROSENE PRODUCTION
IN THE TICK
set totalcumulative_production input (sum (biokerosene_production) of biorefineries) totalcumulative_production ; TOTAL TOTAL
OF BIOKEROSENE PRODUCTION --> LIST
set totalbiokerosene_costlist input revenue totalbiokerosene_costlist ; TOTAL TOTAL COST OF BIOKEROSENE PRODUCTION --> LIST
set totalbiokerosene_cost sum (totalbiokerosene_costlist) ; total total sum of the cost
if totalbiokerosene_production > 0 [set biokerosene_costunit totalbiokerosene_cost / sum (totalcumulative_production)] ;cost
per unit
if totalbiokerosene_production > 0 [set biokerosene_distribution_costs sum (airport_logistics) of airports /
totalbiokerosene_production] ; distribution cost per unit

}

end

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```