Modelling the interaction between policies and international trade flows for liquid biofuels

A case study on the European Union as an export market for biodiesel

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Challenge the future

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Abstract

Biofuels are inextricably bound up with policy. Various drivers can be identified for the production and consumption of biofuels, such as environmental considerations, energy security and economic development. Therefore, biofuels may be an appealing option to policy makers. Biofuels are in general more expensive to produce than their fossil counterparts. Therefore, (support) policy is necessary to increase the competitiveness of biofuels. Policy makers can implement various measures to realize the potential benefits of biofuels, such as import- and export tariffs, imposing trade embargoes, offering subsidies, mandating blending targets and creating tax exemptions.

The biofuel market is an international affair, because demand and supply of feedstock and biofuel are unequally distributed around the globe. In the past it appeared that domestic biofuel policies could have major unforeseen and unintended effects on the international bioenergy markets. In turn, this had negative consequences for the biofuel industry of certain countries and the realization of their underlying policy objectives. Hereto, the "splash-and-dash" practice is an illustrating example. In short, this practice refers to a tax policy deployed by the government of the USA which affected international trade flows of biodiesel. The emerging trade flows harmed the European biodiesel industry, because biodiesel entered the European market at very competitive prices.

The influence of policy measures on the global bioenergy markets is not extensively investigated. Lamers et al. [2011] found that trade volumes were largely influenced by import duties, whereas trade routes were mainly driven by tariff preferences. In other words, it is found that there is some interaction between policies and patterns of international trade flows (in terms of volumes and routes) of biofuels and feedstock. However, the study performed by Lamers et al. [2011] did not explain the underlying mechanism. The aim of this research is to fill this knowledge gap. With this knowledge, decision making by policy makers may become better informed and aforementioned effects of policies may be reduced or even prevented.

The main research question addressed in this research is: *Which mechanism can explain the effect of policies on emerging patterns in the international trade flows of liquid biofuels and feedstock?* To answer this question, an agent-based model (ABM) of the international liquid biofuel markets is developed. If literature on international trade flows for bioenergy is reviewed, it appears that the models applied are usually general- or partial equilibrium models. Contrary to equilibrium models, ABM allows for heterogeneous actors with bounded rationality, the ability to learn and intrinsic behavioural traits. Above that, geographical aspects can be incorporated. It is hypothesized that these factors play an important role in international bioenergy trade. Therefore, this approach could be of added value to the current strand of literature in which equilibrium models are applied.

To limit the scope of this research, a case study is performed. In this case study a number of key players in the international biodiesel market are considered: the European Union, Indonesia and Malaysia. Since the take-off of the biodiesel industry (around the year 2000), the European Union has been one of the largest producers and consumers of biodiesel in the world. In addition, the European biodiesel market has been targeted as an export market for biodiesel and feedstock (palm oil) by Indonesia and Malaysia. In view of the case study, the focus of this research is on first-generation liquid biofuels. The answer to the main research question is twofold and formulated as follows:

- For the case study two (historical) time series of trade flows are considered. Firstly, the import of biodiesel by the European Union originating from Indonesia and Malaysia. Secondly, the import of palm oil for biodiesel purposes by the European Union, also originating from Indonesia and Malaysia. It is found that the proposed mechanism succeeds in reproducing these patterns simultaneously in the correct order of magnitude and with the same general dynamics. The corresponding normalized mean square error amounted to 58.3%. This result provides confidence in the realism and accuracy of the model.

- The model results show that the import of palm oil is dampened as the import tariff on palm oil increases (and vice versa). It is also shown that the import of biodiesel decreases as the import tariff on biodiesel increases. This means that the model confirms the pattern described by Lamers et al. [2011] and thus can explain the underlying mechanism.

With these results, the model can be used to explore characteristics of the biofuel supply chain, such as the emergence of international trade flows under different policies and scenarios. Therefore, in this research a policy exploration is performed. To be more specific, the aim of the policy exploration is to gain insight into the expected influence of different policy combinations until year 2030 on the international trade flows of palm oil and biodiesel originating from Indonesia and Malaysia and directed towards EU-28. Based on this exploration, a number of policy recommendations are formulated. It is emphasized that model outcomes may not be representative as realizations of the exogenous model parameters fall outside the considered scenarios or model assumptions turn out to not hold true.

In the exploration, two policies are varied: the import tariff on biodiesel and the import tariff on palm oil, both imposed by the European Union. Furthermore, nine different scenarios are evaluated. These scenarios contain different combinations of price development of fossil diesel and palm oil. The scenarios consider normal (as expected), high (+20%) and low (-20%) price developments.

In the policy exploration it is found that a change in palm oil price produces a larger effect with respect to biodiesel import than a same proportional change in fossil diesel price. Similarly, it is found that a change in palm oil price produces a larger effect with respect to palm oil import than a same proportional change in fossil diesel price. It is also found that relative more financial pressure must be exerted to reduce the import of palm oil to the same level as for biodiesel. Therefore, it is concluded that the effect of changing the import tariff on biodiesel is greater than the effect of changing the import tariff on palm oil.

If the current-day situation of policy measures are maintained in the future, the import of biodiesel is expected to grow significantly to around $15*10^6$ ton in 2030 (upper limit: $15.8*10^6$ ton, lower limit: $12.5*10^6$ ton). This would be sufficient to realize a blending mandate of around 8.2% (upper limit: 8.6%, lower limit: 6.8%). Considering the (expected) 10% blending mandate, this would mean that almost the entire blending mandate is fulfilled with foreign biodiesel. At the same time, the import of palm oil is expected to fluctuate between 1-$3*10^6$ ton (upper limit: $3.7*10^6$ ton, lower limit: $0.5*10^6$ ton). This could represent an additional 1.1% point (upper limit: 1.4%, lower limit: 0.7%) for the blending mandate. Therefore, under these conditions palm oil is expected to be less dominant in the European biodiesel market in comparison with imported biodiesel from Indonesia and Malaysia. Taking all these aspects into account, around 0.7% point (upper limit: 2.5%, lower limit: 0%) of the blending mandate would remain for the biodiesel industry in the European Union using rapeseed as feedstock.

Based on the simulation outcomes, the concerns expressed by the European biodiesel industry seem legitimate. Following the results, the current setup of policy measures of the European Union does not seem sufficient to prevent collapse of the European biodiesel industry due to imports from Indonesia/Malaysia. To curb these international trade flows, a raise in import tariffs would be required. It is expected that a raise of import tariff on biodiesel to 40% would be sufficient to maintain the import of biodiesel at a low level. In a worst case scenario, the import of biodiesel would be around $4*10^6$ ton in 2030. In case the growing import of palm oil is also considered undesired, this import tariff on biodiesel should be complemented with a raise of the import tariff on palm oil for biodiesel purposes. However, it is important to take into account that raising the import tariff on palm oil may negatively affect productivity of biodiesel plants situated in the European Union, because rapeseed appears hardly able to replace palm oil as feedstock for biodiesel production.

1
Introduction

In this chapter an introduction to this research is given. After a brief opening statement, a literature review is given in section 1.2. The purpose of this literature review is to provide the reader with the fundamentals of the world of bioenergy and biofuels. Subsequently, the problem statement and objective of research are given in section 1.3 and 1.4 respectively. This chapter is concluded with an outline of this thesis.

1.1. Introduction

The Paris Climate Conference of the United Nations in 2015 (COP21) resulted in a much-debated agreement to address global warming. At this conference, many countries and organizations submitted plans on how they will contribute to realization of this goal. Two members of the G20 (a forum of the largest economies in the world) indicated that bioenergy will fulfil an important role in their contribution towards realization of climate objectives. On the one hand, Brazil indicated that it strives for increasing the share of biofuels in the Brazilian energy consumption to around 18% by 2030 [Federative Republic of Brazil, 2015]. On the other hand, India indicated that it sets up a National Policy on Biofuels that aims for a share of 20% for biofuels in the energy consumption of the transport sector [Republic of India, 2015].

Various drivers can be identified for the production and consumption of biofuels [Nuffield Council on Bioethics, 2011], such as environmental considerations, energy security and economic development. Therefore, biofuels may be an appealing option to policy makers. Biofuels are in general more expensive to produce than their fossil counterparts [Jolly and Woods, 2004], [Demirbas, 2009], [Peters and Thielmann, 2008]. For example, Yusuf et al. [2011] estimates that biodiesel production cost is 1.5 to 3 times higher than fossil diesel production cost in developed countries. Therefore, (support) policy is necessary to increase the competitiveness of biofuels. Policy makers can implement various measures to realize the potential benefits of biofuels, such as import- and export tariffs, imposing trade embargoes, offering subsidies, mandating blending targets and creating tax exemptions.

Since domestic biofuel policies are mainly focused on realization of national objectives, the intended objectives and the actual outcome of the biofuel policies do not always match [Lamers et al., 2011]. Due to a lack of attention for the consequences on a global level, policy measures may result in unforeseen and unintended effects. These side-effects are associated with negative consequences for the biofuel industry itself (e.g. in view of profitability and stability, see section 1.3) and the realization of the underlying policy objectives (like alleviation of climate change, energy security and economic development, see section 1.2.3). To reduce or even prevent these effects, decision making by policy makers needs to be better informed.

1.2. Literature review

In this section the results of the performed literature review are presented. Prior to presenting this, the applied search method is discussed. Subsequently three sections are devoted to introducing different aspects of biofuels. Firstly, in section 1.2.2 biofuel types, production and consumption is treated. Secondly, in section 1.2.3 different drivers for producing and using biofuels are clarified. Lastly, in section 1.2.4 different forms of biofuel support policy are discussed.

1.2.1. Search method

For this introductory chapter a literature review is conducted. This literature review aims for identifying a knowledge gap between existing knowledge and the problem statement. This allows us to recognize the importance of the research and to formulate research questions. The literature is retrieved by making use of the following search engines: Google Scholar, Scopus, ScienceDirect and the online library of the TU Delft.

1.2.2. BIOFUEL TYPES, PRODUCTION AND CONSUMPTION

Renewable energy may originate from a wide range of different sources, such as solar power, wind power, geothermal power and bioenergy. Bioenergy is energy derived from biomass. Biomass is any organic matter derived from plants or animals available on a renewable basis, such as agricultural crops and wood [IEA, 2016b]. Bioenergy provides around 10% of the world primary energy supply [IEA, 2016a]. With this contribution, bioenergy currently is the largest contributor to the energy supply from renewable energy sources. Biofuels are liquid and gaseous fuels produced from biomass [IEA, 2016b]. Globally, three types of biofuels can be distinguished based on the type of feedstock [Dahiya, 2014]:

- First-generation biofuels: produced from the oils, sugars and starches contained in food crops, such as sugar cane, corn, rapeseed and soybeans.
- Second-generation biofuels: also known as advanced biofuels [Dahiya, 2014], produced from non-food crops containing cellulosic material, such as wood and grass.
- Third-generation biofuels: produced from lipid production by algae.

One type of feedstock that can be used to produce biofuel are oilseeds. Oilseeds are the seeds from agricultural crops that have a relative high oil content, such as rapeseed and soybeans. By processing these seeds, seed oil can be obtained. After harvesting (see Figure 1.1), the feedstock usually does not exist in a form that can be converted directly into energy without some form of pre-processing [Dahiya, 2014]. Therefore, the biomass usually is pre-processed. During processing, the moisture content may be reduced, contaminants may be removed or stability may be improved [Holm-Nielsen and Ehimen, 2016]. By reducing the water content, the energy density is improved and associated transport cost are reduced.

Various types of methods can be used to perform this pre-processing, such as a screw press, roller press or a pelletizer [Tumuluru et al., 2010]. Besides mechanical treatment, thermal and chemical treatment at a biorefinery may also be necessary. A biorefinery is a facility that integrates (chemical) conversion processes and equipment to produce biofuels and other chemicals from biomass [Holm-Nielsen and Ehimen, 2016]. Biodiesel may be produced through transesterification of vegetable oils (originating from oilseeds for example) and fats, while bioethanol may be derived from crops with a high content of sugar, starch and cellulose through the process of fermentation [Naik et al., 2010]. The final step in the biofuel supply chain is the distribution of the biofuel among the end-users.

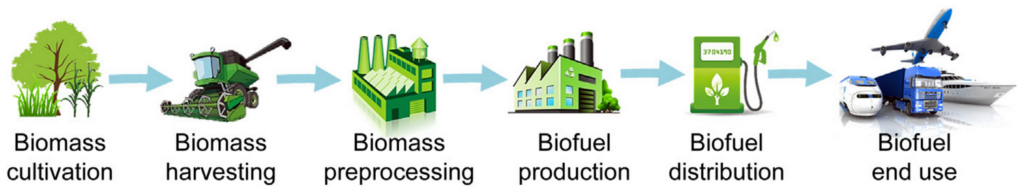

Figure 1.1: General structure biomass and biofuel supply chain [Holm-Nielsen and Ehimen, 2016]

Many countries have implemented and planned initiatives to increase production and consumption of biofuels [Taheripour and Tyner, 2010]. Consequently, the global biofuel production and trade has grown exponentially in the last decade (from less than 30 PJ to 572 PJ for biodiesel and from 340 PJ to over 1540 PJ for bioethanol in the period 2000-2009) [Lamers et al., 2011]. Above that, it is expected that the consumption of biofuels will triple in the period 2011 to 2035 [Holm-Nielsen and Ehimen, 2016]. The applications of biofuels are widespread. Biofuels are also applied for generating electricity and heat. Hereto, biofuels can be co-fired with coal in existing coal-fired power plants for example. Biofuels may also be used to create replacements of fossil fuels used in the transport sector. For instance, biodiesel, bioethanol and biomethanol can be used to create substitutes for diesel, gasoline and natural gas respectively. The two main types of liquid biofuels today (biodiesel and bioethanol) are almost solely consumed by the transport sector [Rajagopal and Zilberman, 2007].

1.2.3. DRIVERS FOR BIOFUELS

As already indicated in section 1.1, various drivers can be identified for the production and consumption of biofuels [Nuffield Council on Bioethics, 2011]. Each of these three drivers is clarified in this section. First of all, it is considered a viable approach to alleviate climate change. Biofuels are considered (close to) carbon neutral. This means that the amount of carbon dioxide emitted during production and conversion of the biofuel into mechanical or thermal energy offsets the amount of carbon dioxide captured during growth of the biomass. Since carbon dioxide is a greenhouse gas, biofuels might dampen the growth of the concentration of greenhouse gasses in the atmosphere and thus attenuate the associated effects in terms of climate change. Taking this into account, biofuels may also become of interest to companies to fulfil a role in their corporate social responsibility (CSR) programs. CSR is the responsibility of companies towards stakeholders and to society that extends beyond meeting the law and serving shareholders' interests [Van de Poel and Royakkers, 2011].

Secondly, biofuels address the issue of energy security. Energy security plays an important role for countries with a society that is mainly driven by fossil fuels and do not possess fossil fuel reserves. Therefore, these countries are dependent on the import of fossil fuels. This imposes short- and long-term threats, such as insecurity of energy supply and volatility of energy prices. By producing biomass in domestic regions, disadvantages of these dependence relationships can be reduced [Demirbas, 2009]. Energy security is also important to companies. This especially holds true for those companies with a business model that heavily relies on fossil fuels, such as oil- and gas companies and transport companies (e.g. airlines and shipping companies). These companies can, for example, use bioenergy as part of a diversification (hedging) strategy by creating a portfolio of fossil fuels and bioenergy to reduce their exposure to price volatility [Ghoddusi, 2015]. To summarize, drivers for production and consumption of biofuels may also contain a strategic component.

Thirdly, biofuels are seen as an opportunity to enhance economic development in both developed and developing countries. For example, it allows farmers to grow lucrative crops for the production of biofuels. Above that, it has been found that oil companies and governments deployed large investments in biofuel R&D programmes and the construction of bio refineries [Sims et al., 2010]. In other words, biofuels might generate jobs and income. In addition, the potential benefits of biofuels in terms of energy security are of course closely related to economic development. However, these potential advantages of the production and consumption of biofuels are not undisputed. For example, Borenstein [2012] argues that the reasoning underlying government policy (such as job creation, industry building and energy security) generally lacks evidence and may in some cases be based on faulty economic reasoning.

1.2.4. BIOFUEL SUPPORT POLICY

To realize the potential advantages of biofuels, policy makers can impose various measures to stimulate the production and consumption of biofuels, such as imposing import- and export tariffs, trade embargoes, direct government funding, offering subsidies, mandating blending targets and creating tax exemptions. For example, the European renewable energy directive prescribes that renewable sources (like biofuels) must account for at least 10% (on energy content basis) of all transport gasoline and diesel for all member states as of 2020 [EU, 2009]. This is realized by offering a blend of conventional diesel and biodiesel at gas stations, for example.

In literature different categorizations of biofuel support policies can be found. In this section three different classifications are discussed. Firstly, Mabee [2007] gives a basic classification by classifying these support policies in "top-down" and "bottom-up" approaches. On the one hand, top-down policies affect large groups or even all companies and consumers. An example of a top-down policy is the creation of tax exemptions. This may result in cost reduction for the production and consumption of biofuels, which makes biofuels more attractive to industry and consumers. On the other hand, bottom-up policies target only particular companies or consumer groups involved in biofuels. An example of a bottom-up policy is the offering a public tender for a biofuel related project. Top-down and bottom-up policies can be combined, as long as they together create a favourable environment for the development of biofuels.

Lamers et al. [2011] proposes a triad for the categorization of biofuel support policies, which each may contain measures to push (e.g. blending mandates) and pull biofuels (e.g. tax exemption) into the market. The first group contains policy that promotes domestic consumption of biofuels. The second group consists of policy measures that promote domestic production of biofuels. The last group consists of trade related measures, by either protecting domestic production or hindering export of feedstock and biofuels.

Lastly, Rajcaniova et al. [2013] points out that policies can either directly or indirectly affect the biofuel market. Direct policies directly affect biofuel production or consumption. An example of a direct policy is biofuel production subsidy. Indirect policies indirectly affect biofuel production or consumption. An example of an indirect policy is a feedstock production subsidy, which for example may affect the oilseed market. Besides these categorizations, overviews with specifications of biofuel support policy applied around the world can be found in scientific literature, e.g. [Sorda et al., 2010], [Kumar et al., 2013] and [Wiesenthal et al., 2009].

1.3. PROBLEM STATEMENT

In the last decade the biofuel market has been driven by governmental policies [Sorda et al., 2010]. As indicated in section 1.2.3, various drivers can be identified for the production and consumption of biofuels. In section 1.2.4 various biofuel support policies are discussed, which are used by policy makers to stimulate the production and consumption of biofuels. In line with Sorda et al. [2010], Junginger et al. [2011] found that support policy is one of the main drivers for the development of international bioenergy trade, but at the same time they found that support policy forms one of the major barriers towards this development. In other words, policy makers play a positive and negative role in the development of the global biofuel trade and production.

To elaborate on this negative role, Lamers et al. [2011] points out that domestic policies are mainly focused on realization of national objectives. However, the biofuel market is an international affair, because many countries (e.g. Japan, South Korea, the United States, and some countries in Europe) do not have the domestic capacity to realize their objectives and therefore are dependent on the import of feedstock and biofuel from other countries [Dufey, 2007]. The lack of attention for the consequences on a global level may result in unforeseen and unintended effects with respect to trade flows (in terms of routes and volumes) of biofuels and feedstock.

A striking example to illustrate these effects is provided by Lamers et al. [2014]. In 2004 the government of the USA established the Volumetric Excise Tax Credit (VETC). This policy subsidized the blending of fossil diesel with biodiesel. However, VETC was not limited to domestic production or consumption and thus was also available for importers and exporters. This freedom resulted in the so-called "splash-and-dash" practice. This practice is organised is as follows. Biodiesel is shipped to the USA. Subsequently, the biodiesel is blended with a very small fraction of fossil diesel (0.1%) ("splashing"). This type of blending met the requirements of VETC and thus allowed for making use of the tax advantage. After claiming the tax credit, the blended diesel is exported again ("dashing"), in particular to Europe.

Carriquiry and Babcock [2015] describe some consequences of the splash-and-dash practice. Firstly, the tax credit allowed for exporting biodiesel to the EU at very competitive prices compared to EU produced biodiesel. In turn, the European biodiesel industry argued that this was a form of unfair trade practices, which harmed production of biodiesel within the EU. This resulted in a formal complaint addressed at the European Commission, which started an investigation. Eventually, in July 2009 the EU established import duties for biodiesel originating from the USA to counter the VETC subsidies. This significantly reduced export of biodiesel from the U.S to the EU and biodiesel was again shipped directly from the country of origin (e.g. Argentina, Malaysia and Indonesia) to the EU [Lamers et al., 2014]. Carriquiry and Babcock [2015] also point towards another negative consequence. Of course, the USA did not intend to subsidize the European biofuel market. Therefore, the USA faces misuse of a domestic biofuels program that undermined the realization of national objectives. Lastly, when VETC was adjusted, this also had negative consequences for biofuel producing countries. Since then, Argentina and other biofuel producing countries cannot benefit from VETC and are not able any more to compete with USA producers (who still qualify for the biodiesel subsidy) and production and exports of biodiesel have fallen [Tomei and Upham, 2009].

This example illustrates some major unforeseen and unintended effects on a global level that may follow from domestic biofuel support policy. These side-effects are associated with negative consequences for the biofuel industry itself and the realization of the underlying policy objectives. To reduce or even prevent these effects, decision making by policy makers needs to be better informed. Governments take into account the potential impact of national policy measures on a global level. However, the influence of domestic biofuel policy measures on the global bioenergy markets is not extensively investigated. This knowledge gap is confirmed by Lamers et al. [2011], who state that additional scientific research is required to provide further insights into the complex and interwoven links of the international biofuel market. This also shows that this problem statement is relevant from a scientific point of view.

1.4. OBJECTIVE OF RESEARCH

As introduced in section 1.3, the influence of domestic biofuel policy measures on the global bioenergy markets is not extensively investigated. Lamers et al. [2011] found that trade volumes were largely influenced by import duties, whereas trade routes were mainly driven by tariff preferences. In other words, it is found that there is some interaction between policies and patterns of international trade flows (in terms of volumes and routes) of biofuels and feedstock (as depicted in Figure 1.2). However, the study performed by Lamers et al. [2011] did not explain the underlying mechanism. The aim of this research is to fill this knowledge gap.

Figure 1.2: Hypothesized relationship between biofuel police and international trade flows of liquid biofuels and feedstock

By developing a model of the international liquid biofuel markets, the interaction between policies and patterns of trade flows can be investigated. Subsequently, the retrieved insights can be used to fill the current knowledge gap with respect to how policies affect the international biofuel markets. This can contribute to reduce or even prevent unintended effects and associated negative consequences for the biofuel industry itself and the realisation of underlying policy objectives.

To limit the scope of this research, a case study is performed. In this case study a number of key players in the international biodiesel market are considered: the European Union, Indonesia and Malaysia. The European Union is selected, because since the take-off of the biodiesel industry (around the year 2000), the EU-28 has been one of the largest producers and consumers of biodiesel in the world. Above that, in the past the European biodiesel market has been targeted as an export market for biodiesel and feedstock by various countries.

Data shows that the production of biodiesel in the European Union has grown over the years. It appears that this growth is mainly covered by using palm oil as a feedstock. However, it is not possible to grow oil palm in the European Union, because oil palm is a tropical tree crop. Therefore, if palm oil is demanded in the European Union it must be imported. Global palm oil production is dominated by Indonesia and Malaysia. However, not all palm oil is (directly) exported by these countries. Like the European Union, Indonesia and Malaysia accommodate a large scale biodiesel industry. In recent years the export of biodiesel from Indonesia and Malaysia is mainly directed to the European Union. Considering these trade flows, Indonesia and Malaysia are also incorporated in the case study. This case study implies that the focus of this research is on first-generation liquid biofuels. This section concludes with the formulation of the research questions. The main research question is stated as follows:

> *Which mechanism can explain the effect of policies on emerging patterns in the international trade flows of liquid biofuels and feedstock?*

To answer the main research question, the following sub questions are addressed in this research:

1. Which actors are involved in the biofuel supply chain and which role do they fulfil?
2. Which governance structures and market institutions are applied for organising transactions in the biofuel supply chain?
3. To which extent are biomass and biofuels traded internationally?
4. How do actors involved in the biofuel supply chain make decisions while fulfilling their role?
5. What is the expected influence of different policies on future international trade flows of liquid biofuels and feedstock under different scenarios?
6. Which recommendations can be formulated for governments with respect to policy for liquid biofuels?

1.5. OUTLINE OF THESIS

In this section the outline of this thesis is discussed. Chapter 2 presents the applied research method. In this chapter different modelling paradigms are described. Based on the presented information a choice for agent-based modelling (ABM) is made. The chapter is concluded with an introduction to ABM.

In chapters 3 to 6 the proposed research questions are addressed. An overview of the research questions addressed in this thesis per chapter is given in Table 1.1. The sub research questions can be divided into two parts. The questions number one up and to number four directly feed the main research question. Each of these questions attempt to unravel a part of the internal structure of the (international) biofuel supply chain.

In chapter 3 a literature review is presented. In this literature review the feedstock used for global production of biodiesel and bioethanol is considered. Furthermore, data on international trade of biomass and biofuel is analysed. Subsequently, market institutions in the biofuel supply chain are examined. This allows us to answer research questions number one, two and three. In chapter 4 the conceptual model is put forward. In this chapter the modelling approach, model elements and their properties and/or behaviour will be given. The chapter is concluded with a quantification of the model parameters. Since this model builds on the ideas presented in previous research, there is no strict line between the literature review (chapter 3) and the modelling part (chapter 4). In the modelling part question number four is addressed.

As already indicated, in this research a case study is performed. Research questions four up and to six are only considered in detail from the perspective of the case study. The latter two research questions can be answered by means of the developed model. Hereto, the mechanism proposed in chapter 4 are implemented in an ABM. The model is then used to perform computer-based simulations in chapter 5. With these simulations it is examined whether the proposed mechanism are able to reproduce observed patterns in the international trade flows. This allows us to answer research question number five.The computer model can be used to explore characteristics of the biofuel supply chain, such as the emergence of international trade flows under different policies. Based on this exploration, a number of policy recommendations are formulated. Hereby the latter research question is fulfilled. As stated earlier on, these insights can contribute to reduce or even prevent unintended effects and associated negative consequences for the biofuel industry itself and the realisation of underlying policy objectives.

The thesis is concluded in chapter 6. In this chapter the findings of chapter 2 up and to 5 are summarized and the answers to the research questions are recapitulated. Above that, recommendations for future research are formulated.

Table 1.1: Overview of research questions addressed in thesis per chapter

Chapter	Title	Research question						
		main	1	2	3	4	5	6
1	Introduction							
2	Methods							
3	Literature review		•	•	•			
4	Modelling					•		
5	Simulation runs	•					•	•
6	Conclusions and future research	•	•	•	•	•	•	•

2
METHODS

The objective of this chapter is to clarify the methods applied in this research. Firstly, an introduction to socio-technical systems is given in section 2.1. As indicated in chapter 1, in this research use will be made of ABM. This choice will be substantiated in section 2.2. Above that, the basics of ABM will be described.

2.1. SOCIO-TECHNICAL SYSTEM

In this section it will be discussed what defines a socio-technical system and what the socio-technical system is in the context of this research. Hereto, some aspects of the conceptual model (as will be presented in section 4.3) are already revealed. However, for the details of the conceptual model the reader is referred to the corresponding section. The concept of socio-technical systems is introduced, because it is an useful way to present the system examined and the model formulated in this research. Above that, in section 2.2 the concept will be used for defining the research approach.

According to De Bruijn and Herder [2009], a socio-technical system refers to a system that involves both complex physical-technical systems and networks of interdependent actors. A socio-technical system is assumed to consist of two (linked) systems: a technical system and a social system. The technical system contains components like transport networks, equipment and goods. For a technical system the components and the connections among those components need to be specified. The social system contains components like humans and governments/institutions. For a social system the components, the connections among those components and the behaviour of the components need to be specified. This third aspect underlies the distinction between the social system and the technical system. For technical systems the specification of the components and the connections among those components is sufficient, because the rest is taken care of by the laws of nature. However, this does not hold true for social systems. For example, consider an imposed regulation by an government specifying how two actors should behave with respect to each other. This regulation is not necessarily obeyed. That is to say, humans cannot be programmed to strictly follow a predefined set of rules. Therefore, social systems and technical systems are different.

This research, in fact, considers biofuel supply chains in an international context. In section 1.2.2 an introduction to this topic is given. The biofuel supply chain is a network in which feedstock and biofuels flow. For this network the two systems of a socio-technical system, as introduced above, are pointed out. The technical system consists of, for example, the facilities for production of biofuel and feedstock. These components are connected, for example by roads and rivers. Commodities (like biofuel and feedstock) flow through these connections. The social system consists of components like farmers, biofuel producers, distributors, retailers, consumers and governments. These different actors interact with each other, have different behaviours and possess different technical elements. In addition, governments impose biofuel related policies. Concluding, a biofuel supply chain can be considered as a socio-technical system.

Governments are actors which impose policies on other actors and may influence how actors behave. In the model developed for this research, governments will not be included as an actor. Although a model could be developed for these actors, this is considered too complex for the available time for this research. Instead of modelling the governments as an actor, only their established policies (like import- and export tariffs and blending mandates) are present in the model.

2.2. RESEARCH METHOD

This section proposes a research method for answering the research questions as formulated in section 1.4. In section 2.2.1 a research approach is formulated, in terms of how the research is performed. Please note that in this chapter the noun "state" is used. Since this research considers an international context, this word may be confusing. Only in this chapter, the noun "state" refers to a condition or situation. In all other chapters it refers to a nation or country.

2.2.1. RESEARCH APPROACH

In chapter 1 the knowledge gap considered in this research is described. To fill the knowledge gap a quantitative approach is chosen, because this research builds on previous research (like Lamers et al. [2011]) and thus is not purely exploratory, there is no ambiguity about the to-be measured concept (routes and associated volumes of feedstock and biofuels) and differences for this concept are quantifiable.

In this research use will be made of computer-based simulation. It is hard to define computer-based simulation, but Winsberg [2015] provides the following two useful descriptions. In a more narrow sense, a computer simulation is a program that is run on a computer and uses step-by-step methods to explore the approximate behaviour of a mathematical (calculation) model. The algorithm takes a specification of the system's state (defining all of its variables) at some time t as input, then based on this calculates the system's state at time $t+1$, then continues in the same way for subsequent time steps. Eventually, the algorithm constructs a numerical picture of the development of the system's state. In a more broad sense, one can think of computer simulation as a comprehensive method for studying systems. In this case, computer simulation refers to the entire process of developing a model, realizing implementation of that model so the model can be run on a computer, calculating output of the algorithm and lastly visualizing and studying the resultant data.

In this research, in fact, biofuel supply chains in an international context are considered. In section 2.1 it is clarified that a biofuel supply chain can be viewed as a socio-technical system. Behdani [2012] distinguishes three main paradigms for the simulation of socio-technical systems: System Dynamics (SD), Discrete-Event Simulation (DES) and Agent-Based Modelling (ABM). According to Behdani [2012], the three simulation paradigms for modelling socio-technical systems have different building blocks and key assumptions to describe the world. The main characteristics of the three simulation paradigms are summarized in Table 2.1. First we consider the characteristics of the entities. In view of modelling feedstock and biofuel markets, SD faces a problem. The actors in the biofuel supply chain have different characteristics in terms of decision-making rules and attributes. For example, farmers may differentiate with respect to the size of arable land and biofuel producers with respect to production capacity. Therefore, the simulation paradigm should be able to model heterogeneous entities. Contrary to SD, DES and ABM are able to model heterogeneous entities.

In Table 2.1 also a description of the micro-level entities is given. The micro-level entities are the building blocks of the system. DES is equipped with passive objects, which have no intelligence or decision making capability and move through a system in a pre-specified process. On the other hand, ABM features active entities, which can make sense of the environment, can interact with other entities and make autonomous decisions. These latter characteristics are considered more suitable for modelling the liquid biofuel and feedstock trade flows. For example, if the domestic demand for biofuel increases, the affected actors may decide to increase production of feedstock or to import more biofuel. In other words, the behaviour of the actors is adapted to the prevailing situation. This behaviour requires a form of intelligence of the entities and thus makes ABM more suitable than DES.

Taking into account the above consideration, ABM succeeds best in capturing the characteristics of the feedstock and biofuel markets. Therefore, it is chosen to apply ABM as a computer-based simulation paradigms. In the subsequent section the corresponding modelling approach is discussed.

Table 2.1: Main characteristics of three simulation paradigms, adapted from Behdani [2012]

System Dynamics (SD)	Discrete-Event Simulation (DES)	Agent-Based Modelling (ABM)
System-oriented: focus on modelling the system observables	Process-oriented: focus on modelling the system in detail	Individual-oriented: focus on modelling the entities and interactions between them
Homogenized entities: all entities are assumed have similar characteristics	Heterogeneous entities: entities may have different characteristics	Heterogeneous entities: entities may have different characteristics
No representation of micro-level entities	Micro-level entities are passive "objects" (with no intelligence or decision making capability) that move through a system in a pre-specified process	Micro-level entities are active entities (agent) that can make sense of the environment, interact with others and make autonomous decisions
Driver for dynamic behaviour of system is "feedback loops"	Driver for dynamic behaviour of system is "event occurrence"	Driver for dynamic behaviour of system is "agents" decisions and interactions"
Mathematical formalization of system is in “Stock and Flow”	Mathematical formalization of system is with “Event, Activity and Process”	Mathematical formalization of system is by “Agent and Environment”
Handling of time is continuous (and discrete)	Handling of time is discrete	Handling of time is discrete
Research by changing the system structure	Research by changing the process structure	Research by changing the agent rules and system structure
System structure is fixed	The process is fixed	The system structure is not fixed

AGENT-BASED MODELLING

The purpose of this section is to give an introduction to ABM in a nutshell. This introduction is given by making use of a schematic overview of an ABM depicted in Figure 2.1. From this figure it can be seen that in essence an ABM consists of an environment and agents in that environment. Both elements will be discussed by means of the descriptions formulated by Van Dam et al. [2012]:

- The agent is the smallest element of an ABM. An agent is able to receive inputs from the environment and other agents and is able to perform (reactive, proactive, flexible and autonomous) actions on itself and other agents to meet its design objectives. An agent consists of states and rules. The actions of agents are the actual activities that agents perform by application of rules. The actions may affect the agent itself, other agents and the environment. The behaviour of an agent refers to the overall observable sum of the actions of an agent and state changes.
  - The state of an agent is a collection of (current) parameters that defines an agent [Wooldridge and Jennings, 1995]. For example, in view of this research a biofuel producer could have a certain production capacity. The state of an agent may be affected by input from other agents or the environment.
  - The rules of an agent define the decision rules by which states are translated to actions. These could for example be "if-then" statements or multi-criteria decision rules by weighing different alternatives.
- The environment of an agent is the domain in which agents live. It contains all information (external to the agent) that is used in the decision making processes of agents and provide a context for agent interaction. As already indicated in Table 2.1, ABM makes use of discrete time. In ABM jargon, the smallest unit of time is referred to as a "tick".

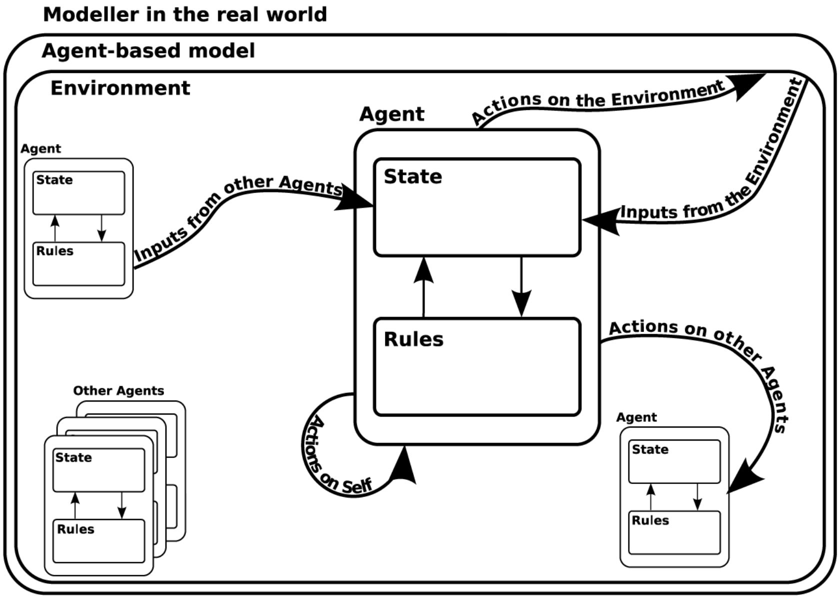

Figure 2.1: General structure of an agent-based model [Van Dam et al., 2012]

If literature on international trade flows for bioenergy is reviewed, it appears that the models applied are usually general- or partial equilibrium models (see e.g. Banse et al. [2008], Birur et al. [2008] and Bouet et al. [2012]). In these kind of models a set of mathematical equations is solved to derive a solution. Equilibrium models are typically equipped with assumptions like perfect information, rational actors (profit maximizers), homogeneous actors, aggregate production/demand functions and geographic aspects do not play a role. With ABM one is able to overcome these assumptions. It allows for heterogeneous actors with bounded rationality, the ability to learn and behavioural traits. Above that, geographical aspects can be incorporated. It is hypothesized that these factors play an important role in international bioenergy trade. Therefore, ABM could be of added value to the current strand of literature in which equilibrium models are applied.

MODELLING APPROACH

The software package used to implement and perform simulation runs is NetLogo (see [Wilensky, 1999]). NetLogo is free and open source software package for ABM. It provides programming language and modelling environment for simulation with multiple agents. Using NetLogo for research purposes is not new. In scientific literature various applications of NetLogo can be found (see e.g. [Filatova et al., 2009], [Kimbrough and Murphy, 2009] and [Earnest, 2008]). More details on the software packages used will be provided in chapter 5.

2.3. SUMMARY

In this chapter it is discussed what defines a socio-technical system and what the socio-technical system is in the context of this research. The concept of socio-technical systems is introduced, because it is an useful way to present the system examined and the model formulated in this research. Above that, it is applied in this chapter for defining the research method (section 2.2). In the corresponding section, three main paradigms for the simulation of socio-technical systems are discussed: system dynamics, discrete-event simulation and agent-based modelling. ABM is chosen, because it allows for modelling heterogeneous entities which can make sense of the environment, can interact with other entities and make autonomous decisions. These characteristics are considered very useful for modelling the liquid biofuel and feedstock trade flows. In addition, if literature on international trade flows for bioenergy is reviewed, it appears that the models applied are usually general- or partial equilibrium models. Contrary to equilibrium models, ABM allows for heterogeneous actors with bounded rationality, the ability to learn and intrinsic behavioural traits. Above that, geographical aspects can be incorporated. It is hypothesized that these factors play an important role in international bioenergy trade. Therefore, this approach could be of added value to the current strand of literature in which equilibrium models are applied.

3

LITERATURE REVIEW

The literature review given in section 1.2 served as a background to clarify the problem statement and the objective of this research. In this chapter a more in depth literature review is conducted. In the first section feedstock used for global production of biodiesel and bioethanol is considered. One of these is vegetable oil. Since vegetable oils play a role in the case study performed in this research, this type of feedstock is examined in more detail. The next two sections focus on a different topic, namely trade in the biofuel supply chain. In section 3.2 actors and governance structures are discussed. This is complemented with a review of international trade of liquid biofuel and feedstock and pricing systems. The last section of this chapter (section 3.3) takes a more theoretical point of view. In this section different types of market institutions for matching buyers and sellers are considered.

3.1. FEEDSTOCK FOR LIQUID BIOFUELS

In this section different types of feedstock for liquid biofuels are discussed. Hereto, a global perspective is taken. One major feedstock is vegetable oil. Since vegetable oils play a role in the case study performed in this research, this type of feedstock is examined in more detail. In section 3.1.2 the processing of oilseeds, processing outputs and applications of vegetable oils are discussed.

3.1.1. FEEDSTOCK COMPOSITION

In section 1.2.2 a classification of biofuels is given based on the type of feedstock used for production. This classification distinguishes between first-, second- and third generation biofuels. In general, there are two main types of liquid biofuel: bioethanol and biodiesel. This section addresses which feedstock is used for these types of biofuels. Firstly, bioethanol production is discussed, followed by biodiesel production.

The composition of feedstock that is used for global bioethanol production is depicted in the left part of Figure 3.1. From this figure it can be seen that maize and sugar cane form the main feedstock used for bioethanol production. Because these correspond to the class of first-generation biofuels, the first-generation biofuels are predominant in the field of bioethanol. The remaining feedstock used for bioethanol production is diverse and for example consists of other food crops and non-food crops, like corn, molasses and switch-grass.

A similar analysis is conducted for biodiesel. The composition of feedstock that is used for global biodiesel production is depicted in the right part of Figure 3.1. This figure shows that vegetable oils form the main feedstock used for biodiesel production. Since this feedstock also corresponds to the class of first-generation biofuels, the first-generation biofuels are as well predominant in the field of biodiesel. The remaining feed-stock used for biodiesel production for example consists of other food crops, non-food crops, animal fats, waste oil and algae. In the next section vegetable oils will be discussed in more detail.

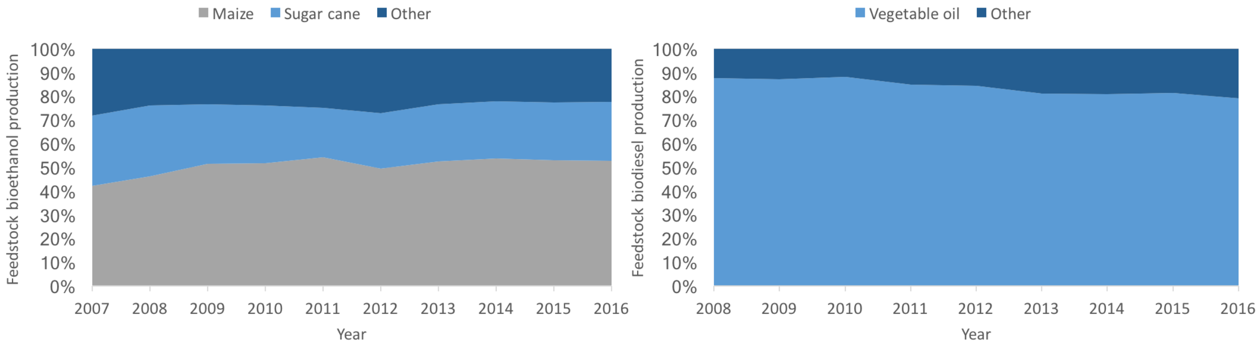

Figure 3.1: Feedstock composition of global bioethanol- (left) and biodiesel (right) production, derived from OECD [2017]

3.1.2. VEGETABLE OILS

In section 3.1.1 it is described that vegetable oils form the main feedstock for biodiesel production. This section is devoted to vegetable oils. Oilseeds are the seeds from agricultural crops that have a relative high oil content, such as rapeseed and soybeans. By processing (e.g. crushing) these seeds, vegetable oil (sometimes called seed oil) can be obtained. So for example, by processing rapeseed and soybeans, rapeseed- and soybean oil respectively can be obtained. As already stated in section 1.2.2, various types of methods can be used to perform processing, such as chemical- and mechanical treatment (e.g. crushing). The aim of this section is to describe different aspects of vegetable oils, such as oilseed processing and applications of vegetable oils.

OILSEED PROCESSING

In this section two aspects of oilseed processing are discussed. The first aspect considers which outputs result from oilseed processing. The second aspect considers to which extent oilseeds are crushed in practice. As background information a schematic overview of processing rapeseed is included in Appendix A.

If oilseeds are processed, this results in different products. For most of the oilseeds, processing result in retrieval of oil, meal and other material. These outputs are retrieved in different proportions, which is amongst others dependent on oilseed type and processing equipment used. In Table 3.1, the outputs for different types of oilseeds are expressed as weight ratios. These numbers are retrieved by analysing sixteen subsequent years (2000-2016) on a global level. For example, if one ton of rapeseed is processed, on average this resulted in 40% rapeseed oil, 58% rapeseed meal and 1.5% other material. The meaning of these three outputs are as follows. Firstly, the oil refers to a liquid (viscous) substance. Secondly, meal refers to the solid residue after processing the oilseeds. Meal has a high protein content and is used predominantly for feeding animals, although is is also used as a fertilizer [Parkhomenko, 2004]. Though at first instance meal may look like an unimportant by-product, it is important to notice that the animal feed market is a billion dollar industry. Fuglie et al. [2011] assessed the market size for manufactured animal feed, i.e. feed derived from meal. The results indicate that global sales of manufactured animal feed accounted for over $220 billion (expressed in constant 2006 U.S. dollars) and 700 billion ton in 2008. Lastly, the remaining material of processing oilseeds is usually considered as waste.

If Table 3.1 is considered, it can be seen that for all oilseeds, after processing less than 50% of the weight remains as oil. For palm kernel, rapeseed and sunflowerseed the highest share of oil is retrieved. If meal content is considered, it appears that processing of soybean results in the highest share of meal. The low variations in oil and meal retrieval indicate a stable global performance throughout the years. This section is finished by addressing the difference between palm oil and palm kernel oil. Palm trees grow palm fruit. Globally, palm fruit consist of two parts: fruit flesh and seeds (sometimes referred to as kernels). In the palm fruit the fruit flesh surrounds the seeds. By crushing the fruit flesh of the palm fruit, palm (fruit) oil is obtained. By crushing the seeds of the palm fruit, palm kernel oil is obtained. So both products originate from palm trees, but from different parts of the palm fruit.

Table 3.1: Weight ratios global outputs of processing of main oilseeds for period 2000-2016 (μ = average, σ = sample standard deviation), derived from USDA-FAS [2017b]

	Oil		Meal		Other	
	μ	μ/σ	μ	μ/σ	μ	μ/σ
Cottonseed	15%	2.2%	46%	0.7%	39%	1.1%
Palm kernel	45%	1.1%	53%	0.9%	2.5%	35%
Peanut	32%	0.0%	40%	1.0%	28%	1.4%
Rapeseed	40%	1.8%	58%	0.4%	1.5%	47%
Soybean	19%	1.8%	79%	0.5%	2.3%	20%
Sunflowerseed	41%	1.7%	46%	1.2%	13%	4.7%

To examine the extent to which oilseeds are crushed, the crush rate is considered. The crush rate is defined as the percentage of oilseeds that is crushed. That is to say, the complement of the crush rate (1-crush rate) corresponds to the fraction of oilseeds that is consumed or stored in an unprocessed condition. In Figure 3.2 the global crush rate is shown for different main types of oilseeds during the period 2000-2016. This figure shows that the crush rate for most of the oilseeds is fairly high, ranging from 75% to almost 100%. The only exception are peanuts. For this commodity less than 50% of the seeds are crushed. However, because peanuts only cover a small fraction of global oilseed consumption, it is concluded that practically almost all oilseeds are crushed.

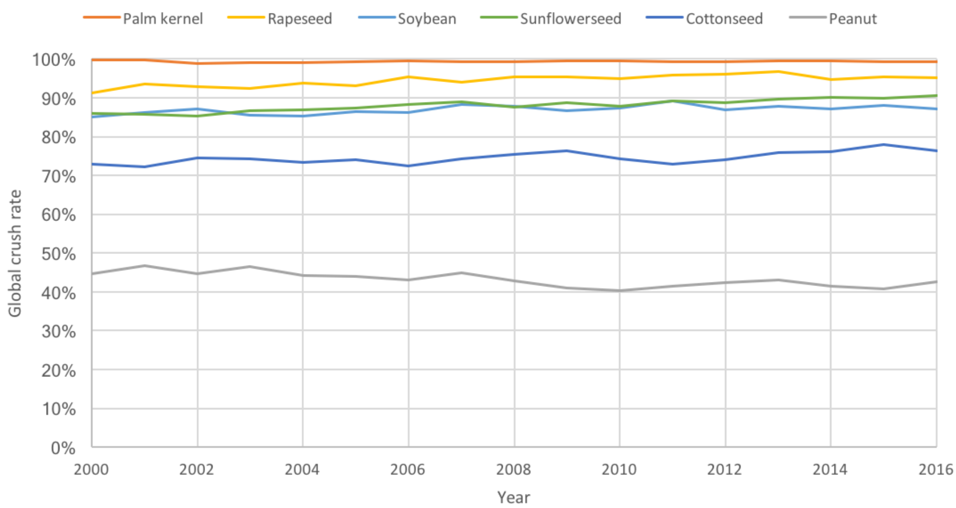

Figure 3.2: Global crush rate for different types of oilseeds, derived from USDA-FAS [2017b]

APPLICATIONS OF VEGETABLE OILS

With respect to the applications of vegetable oils, globally three types can be distinguished. The first application type corresponds to the application of vegetable oils for producing food for human consumption. The second application type is the application of vegetable oils for industrial purposes, like for producing biofuels. The last application type consists of the remaining applications, like the production of animal feed and vegetable oil losses during production.

At the beginning of this section it is shown that the major part of the feedstock used for biodiesel production is vegetable oil. However, it is not shown which types of vegetable oil are used. Hereto, Figure 3.3 is considered. This figure shows that initially rapeseed was the major crop used for biodiesel production. However, later on palm fruit and soybean also came in to play and eventually these crops were responsible for a more or less equal share.

In this section the applications of three vegetable oils (palm-, soybean and rapeseed oil) are considered. These vegetable oils are chosen because Figure 3.3 shows that these vegetable oils are the main feedstock used for biodiesel production. The global consumption of the three vegetable oils for the period 2000-2016 are shown in Figure 3.4 to 3.6. For each of these vegetable oils, the contribution of the three different applications is specified.

Firstly, these plots show that the consumption of vegetable oils has grown steadily in the past years. In addition, it can be seen that the major part of the vegetable oils is consumed for food purposes. In 2000 the corresponding share of vegetable oil consumption accounted for over 80%. In the years afterwards this share slightly decreased. The plots also show that the consumption of vegetable oils for industrial purposes represent a small (< 30%) share. As indicated, among these purposes is the production of biofuels. Rosillo-Calle et al. [2009] and Junginger et al. [2014] made estimations of the share of vegetable oil use for biofuel production. These estimations indicate that less than 1% of vegetable oil consumption was devoted to biofuel production in 2000 and rose to around 12% in 2011. Lastly, the plots indicate that the remaining applications only account for a marginal share.

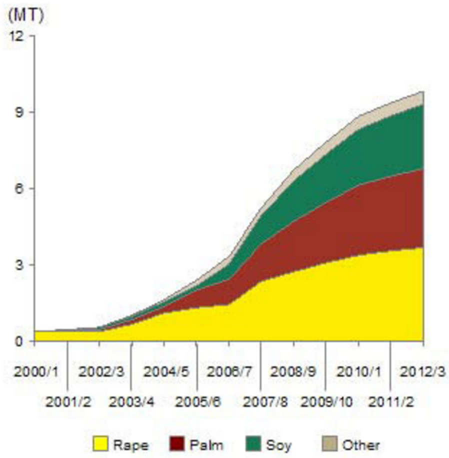

Figure 3.3: Composition vegetable oil used for global biodiesel production [Quispe et al., 2013]

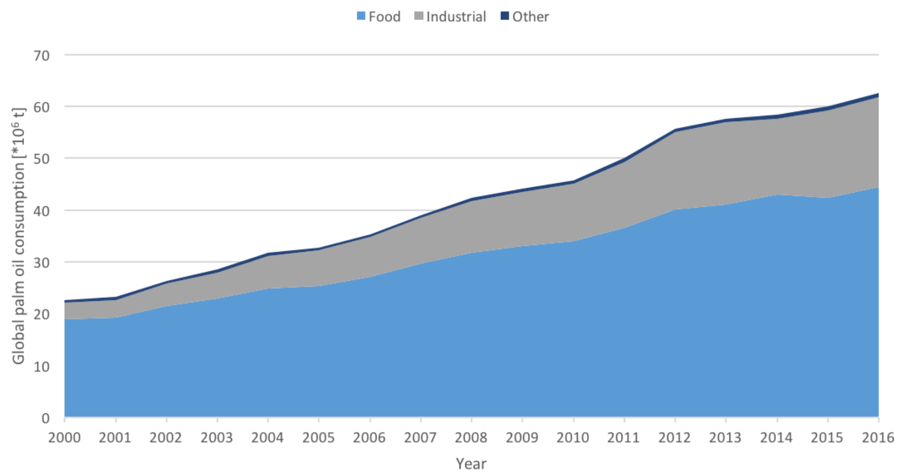

Figure 3.4: Global consumption of palm oil for different applications, derived from USDA-FAS [2017b]

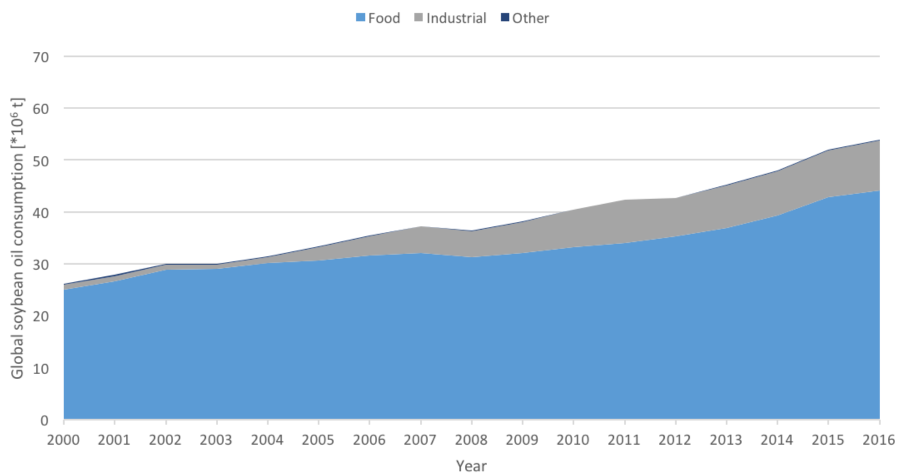

Figure 3.5: Global consumption of soybean oil for different applications, derived from USDA-FAS [2017b]

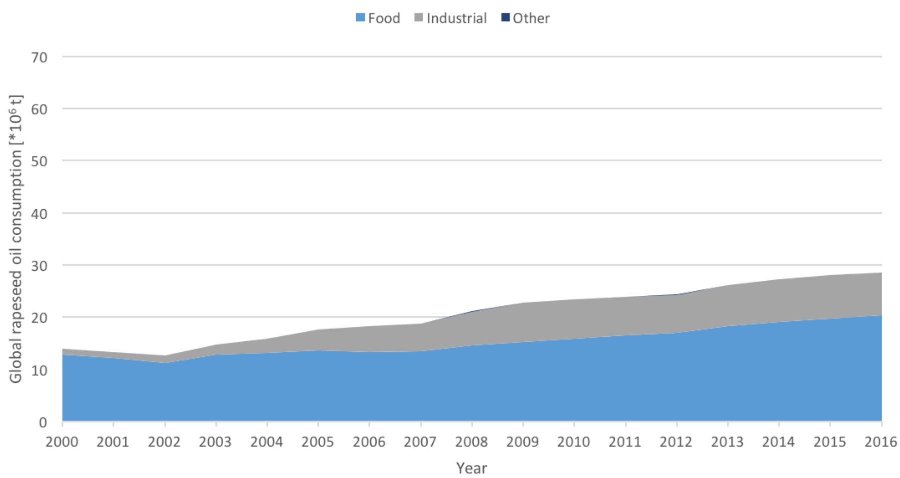

Figure 3.6: Global consumption of rapeseed oil for different applications, derived from USDA-FAS [2017b]

3.2. TRADE IN BIOFUEL SUPPLY CHAIN

In this section trade in the biofuel supply chain is considered. Hereto different aspects are discussed. Firstly, the actors involved in the biofuel supply chain are discussed. Subsequently, governance structures for transferring commodities in the biofuel supply chain are addressed in section 3.2.2. The next two sections (section 3.2.3 and 3.2.4) consider the trade of feedstock and liquid biofuels respectively. The last section considers the pricing system of feedstock and liquid biofuels in more detail.

3.2.1. ACTORS

The actors described in this section are divided in three groups. The first group includes the biomass producers, the second group includes the biofuel producers, distributors and retailers and the third group includes the biofuel consumers.

The first group of actors are the biomass producing companies and contains of farmers. The farmers produce the biomass. Subsequently, the biomass may either be stored or transferred directly to a buyer. This decision may for example be affected by the type of biomass (some agricultural commodities are not suitable for storage) and current and expected prices. After each harvesting cycle farmers decide which type and amount of crop to grow. Farmers may unite, for example, in interest groups, co-operations or associations to gain market power and to protect their interests. Examples are the American Soybean Association and the German Union Union for the Promotion of Oil and Protein Plants (UFOP). But still, biomass is often offered to the market by a relative large number of small companies (so called small holders or small growers), while the demand side for biomass is more consolidated and demand large quantities of biomass [Meeusen et al., 2009]. However, aforementioned author adds to this that this does not hold true for all agricultural commodities. The production of sugar cane and palm oil is performed by large scale plantations and small holders only account for a limited amount of the production.

The second group of actors performs the remaining steps in the biofuel supply chain: the biofuel production, distribution and retail. Though these actors fulfil different functions in the biofuel supply chain, these actors are in this section discussed as one group. The reason is that the actions performed by the actors in the field of biofuel production, distribution and retail are overlapping and mixed and thus cannot easily be separated. One group of actors involved in these activities are the oil companies (like Shell, Petrobras and British Petroleum). These companies can make use of their knowledge, plants and infrastructure in the field of fossil fuels. Another group of actors that is involved in these activities are the agricultural trading companies. These are large multinationals with a leading role in trade, storage and distribution of a large number of agricultural commodities [Meeusen et al., 2009]. As well as being involved in producing and trading of agricultural commodities, the trading companies also play a major role in the production and distribution of biofuels [Murphy et al., 2012]. Examples of trading companies are Archer Daniels Midlands, Bunge, Cargill and Louis Dreyfus Commodities (often referred to as the "ABCD" companies). These companies are the four big trading companies [Murphy et al., 2012]. Similar to the biomass producing companies this group of actors also unite in interest groups, co-operations or associations. Examples are the Association of German Biofuel Producers (VDB), the Dutch Biofuel Industry Association (VNBI) and the European Biodiesel Board (EBB).

The third group of actors includes the biofuel consumers. As indicated in section 1.2.2, the applications of biofuels are widespread, but liquid biofuels are almost solely consumed by the transport sector [Rajagopal and Zilberman, 2007]. Within the transport sector, there is a wide range of customers. Customers from the private sector and public sector consume biofuel. For example, the European renewable energy directive prescribes that renewable sources (like biofuels) must account for at least 10% (on energy content basis) of all transport gasoline and diesel for all member states as of 2020 [EU, 2009]. This is realized by offering a blend of conventional fossil diesel and biodiesel at gas stations, for example. On the other hand, companies also deploy their own initiatives to enhance biofuel consumption. For example, KLM, Schiphol and SkyNRG started an initiative to promote large scale biofuel consumption in the aviation industry [KLM, 2013]. Lastly, governments also belong to the group of biofuel consumers. For example, in Sweden biofuels play an important role in the public transport system. In 2014 the number of kilometres the public bus fleet drove on biofuels rose to 58% [Xylia and Silveira, 2015]. If we take a closer look at the role of different transport modes, it appears that road transport plays an important role in liquid biofuel consumption (see Table 3.2). This table shows that road transport accounts for a major share of both bioethanol and biodiesel consumption.

Table 3.2: Share of road transport in global consumption liquid biofuels

	Bioethanol		Biodiesel		Source
Year	2000	2010	2000	2010	-
Global consumption for road transport [10^6 ton]	10.2	37.8	0.48	16.3	IRENA [2013]
Global consumption [10^6 ton]	13.1	64.3	0.74	18.7	IEA [2017]
Share	78%	59%	65%	88%	-

3.2.2. GOVERNANCE STRUCTURES

As stated in section 3.2.1, the farmers produce the biomass and subsequently the biomass may be sold. While biomass is being traded, transactions are executed. A transaction is defined as the transfer of ownership of goods between different actors. In the supply chain of biofuels multiple transactions may occur. However, the transaction of goods can be organised in different ways. These are called governance structures or institutional arrangements. This section firstly considers different governance structures in the biofuel supply chain in general. Subsequently, the application of these methods for transactions involved in biomass and biofuel trade are considered in particular. In addition, an impression of the quantities of biomass and biofuel traded internationally is given.

According to MacDonald et al. [2004] there are globally three methods for transferring agricultural commodities from farmers to downstream users: spot markets (or cash markets), contracts and vertical integration. These methods are also used for commodities in general (like biofuels). The three methods can be considered to cover a spectrum wherein the spot market forms one extreme, vertical integration forms the other extreme and the contract sits somewhere in-between [Prowse, 2012]. The properties of the three methods are summarized in Table 3.3 and each will be discussed in this section.

MacDonald et al. [2004] describes each of the three methods as follows. From a historical point of view, spot markets are the traditional means of transferring agricultural commodities. Farmers receive payment for their products at the time ownership is transferred to an other actor. Prices are set by an agreement reached between buyer and seller. This agreement is reached just prior to the transaction, but after harvesting. The distinguishing property of a spot market is that goods and money are exchanged immediately ("on the spot"), while using contracts this transaction takes place on a future date.

The second method refers to contracts. Contrary to the spot markets, agreements between buyer and seller are reached prior to harvesting while using contracts. The contract specifies, for example, price, quantity, duration and time of delivery of the goods. Prices can be fixed on a specific level, but can also be specified by means of an equation. Different forms of contracts exist. Examples of contracts are the futures contract and the forward contract. Futures contracts are standardized contracts and are traded on a central futures market. Contrary to futures contracts, forward contracts can be customized and are traded directly between two parties without intervention of an exchange (called traded over-the-counter). After the futures- or forward contract expires, the contracts are exercised via either physical delivery of the commodity (or stock) or cash settlement. According to Du et al. [2013], contract farming has a number of advantages for both the buyer and the seller, in terms of quality control of the commodities, stability of supply of feedstock/income and risk. However, also disadvantages can stick to contracts, in terms of independence and bargaining power of the farmer [Rehber, 1998]. Contract farming is a topic widely discussed in literature. Literature reviews in this field are given by, for example, Bijman [2008], da Silva [2005], Kirsten [2002] and Rehber [1998].

The third method refers to vertical integration. If an organisation gets into business of its suppliers, for example by starting to produce its own supplies or by buying one of its suppliers, the organisation has (backward) vertically integrated. In view of the biofuel supply chain, an example could be that a biorefinery grows its own food crops for biofuel production. Above, we defined a transaction as the transfer of ownership of goods between different actors. In fact, in case of vertical integration we do not speak of transactions any more. Similar to contract farming, vertical integration may offer advantages for the exercising company in terms of quality control of the commodities, stability of supply of feedstock and risk. However, of course, resources are necessary to invest in vertical integration.

In practice the different methods for transferring agricultural commodities to downstream users are applied on different scales. The subsequent two sections elaborate more on the occurrence of the three methods for transferring biomass and biofuel.

Table 3.3: Overview of governance structures for agricultural commodities ('+' means a strength, '-' means a weakness, both in view of the property and for the listed actors)

	Spot markets	Contracts	Vertical integration
Agreement for transaction reached	after production	prior to production	NA
Independence (buyer and seller)	+	-	-
Stability of income (seller)	-	+	(+)
Stability of supply (buyer)	-	+	+
Quality control (buyer)	-	+	+
Investment (risk) (buyer and seller)	+	+	-

3.2.3. BIOMASS TRADE

According to Lamers [2013] contracts between biomass producers and users are the most common form of biomass trade. Historically, the ABCD companies have avoided owning land and production and interact via contracts with biomass producers [Murphy et al., 2012]. Adjemian et al. [2016] states that spot markets represent an increasingly small residual market or are even non-existent for agricultural commodities. The reason given is that the opportunities for farmers to sell their agricultural commodities is often limited to one or a very few potential buyers (so called thin markets). In line with previous mentioned authors, Meeusen et al. [2009] found in multiple case studies that contracts are the most common method of transferring corn and rapeseed in the U.S. and Germany respectively.

In literature also some data can be found on the occurrence of the different governance structures in practice. However, the available data is limited and mainly focuses on the agricultural market of the U.S. For example, MacDonald and Korb [2011] studied the U.S. agricultural market and found that the use of contracts in major field crops has risen sharply in recent years. Additionally, it was found that in 2008 corn, soybean, and wheat producers committed most of their market production to contracts (56, 60 and 62% respectively) and only sold a relative small share (38, 36, 34% respectively) of their production to spot markets or put it into storage. So far in this section, biomass contracts with physical delivery are discussed. In literature no numbers are found on the ratio between the number of biomass contracts that are exercised via physical delivery and the number of contracts that are exercised via cash settlement.

Besides the applied method for transferring biomass, also the actors involved in biomass trade are important. The farmers form the first echelon of the biofuel supply chain. They could sell their commodities directly to the bio refineries. However, according to Meeusen et al. [2009] this direct trading between farmers and end-users is rare and often takes place via one of the large trading companies. Because there are a relative few purchasers of agricultural commodities for international trade (the trading companies), they deal in high volumes and also have significant leverage in terms of setting the purchase price [Murphy et al., 2012].

From a historical point of view, biomass trade between producers and consumers used to have a local and decentralized character [Armbruster and Knutson, 2012]. This means, respectively, that there are biomass markets in which only local actors are involved and these markets operate more or less independently from each other (e.g. with respect to price level). Biomass trade still has a local and decentralized character today. Hereto multiple reasons can be identified. According to Junginger et al. [2014], (not pre-processed) biomass is often not suitable for trading out of its local production area, due to an insufficient level of uniformity in format and chemical content, bulk density, ability to flow and ability to be stored. Junginger et al. [2014] clarifies these barriers as follows. Considering uniformity in format and chemical composition, it is stated in section 1.2.2 that biomass usually does not exist in a form that can be converted directly into energy without some form of pre-processing and therefore biomass usually needs to be pre-processed. This pre-processing introduces variability in formats (shape and size of the particles and bales) and chemical composition of the biomass. This creates challenges to biofuel producers, because their conversion processes are often highly sensitive to format and chemical composition of the feedstock. The quality of biomass demanded by a biorefinery may tie farmers to that specific biorefinery [Peres et al., 2014].

The other barriers all relate to the ability to flow in a long-distance biomass supply chain. A lower bulk density is unfavourable due to the lower energy density and thus relative high transport cost. Above that, there is a lack of technically mature pre-treatment technologies for compacting biomass at low cost to make long-distance transport possible, although this is improving [Faaij, 2006]. The cohesive characteristic of biomass can limit the ability to flow in high-volume handling and storage equipment. Storing biomass may form an additional issue, because the biomass can rot during storage. The rotting results in dry matter loss and further degradation of quality. For example, sugar beets are highly perishable and therefore growers of sugar beets must produce for nearby buyers, which may be limited in number [MacDonald and Korb, 2011]. The same holds true for commodities like sugar cane and oil palm fruit, which also need to be processed quickly after being harvested. Of course, this limits the possibilities for long-distance transport usually required for international trade. These mentioned aspects all clarify the decentralized character of biomass trade.

On the other hand, there are indications that biomass trade may become more global and centralized. For example, various studies have shown that long-distance international transport by vessel is feasible in view of both transport cost and energy use [Faaij, 2006]. Above that, information on prices of commodities exchanged via spot and futures markets is openly accessible, see for example the Chicago Mercantile Exchange (CME, part of CME Group), New York Mercantile Exchange (NYMEX, also part of CME Group) and the National Commodity and Derivatives Exchange (NCDEX). In addition, this market information is becoming more easily accessible and transparent, due to the development of information technologies like the internet. Armbruster and Knutson [2012] state that the internet has become a valuable source of market information for biomass producers and consumers.

An impression of the amounts of biomass that is traded internationally is given in Table 3.4. This table shows the global production (GP), international trade (IT) and share (S=IT/GP) for a number of main feedstock used for biofuel production. In the cells for which no data was available a "-" is displayed. The first thing to be noticed from Table 3.4, is that the share of global production that is traded internationally shows a stable pattern throughout the years. Secondly, it appears that the international trade differs from commodity to commodity. Especially the small amounts of international trade in sugar beets is noteworthy, but agrees with the earlier mentioned perishability of sugar beets. Furthermore, a distinction is made between non-processed biomass commodities and processed biomass commodities (like vegetable oils and syrups). For non-processed biomass this share varies between 0% and 40%. This implies that the major part of these commodities resides within the country of origin, for example for domestic consumption. Multiple reasons to clarify this local character are given in the first part of this section. If a comparison is made between non-processed- and processed biomass, it appears that for most of the processed biomass commodities the share of global production that is traded internationally is not very different from the non-processed biomass. The only exception is palm oil (mainly originating from Indonesia and Malaysia). Considering palm oil, this share grew to nearly 80%. An explanation for this is that since 2000 palm oil has become the major discount oil in comparison to other major oils (due to cheap labour and land and high yields), allowing it to overcome its transport cost disadvantage in supplying markets all over the world [Carter et al., 2007].

Table 3.4: Global production (GP), international trade (IT) and share (S=IT/GP) of main feedstock suitable for biofuel production during period 2000-2013, derived from UN-FAO [2017]

		Year [10^6 ton]													
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Sugar cane	GP	1256	1264	1333	1379	1342	1316	1420	1615	1729	1687	1693	1796	1836	1903
	IT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maize	GP	592	616	603	645	729	714	707	790	831	820	851	887	873	1014
	IT	82.2	82.9	87.5	90.2	82.7	89.3	95.7	109	103	100	108	109	119	122
	S	14%	13%	15%	14%	11%	13%	14%	14%	12%	12%	13%	12%	14%	12%
Wheat	GP	585	591	578	558	631	630	600	611	691	686	642	697	673	711
	IT	117	113	121	110	118	120	127	125	130	147	146	148	164	162
	S	20%	19%	21%	20%	19%	19%	21%	20%	19%	21%	23%	21%	24%	23%
Soy-bean	GP	161	178	182	191	206	215	222	220	231	223	265	262	242	278
	IT	47.9	57.2	55.7	65.4	58.0	66.1	67.1	74.4	79.1	81.2	96.7	91.1	97.0	105
	S	30%	32%	31%	34%	28%	31%	30%	34%	34%	36%	36%	35%	40%	38%
Palm fruit	GP	120	129	135	150	163	182	196	193	214	218	225	245	255	266
	IT	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sugar beet	GP	250	230	260	233	252	254	254	247	222	228	229	279	270	248
	IT	0.15	0.11	0.18	0.34	0.32	0.76	0.65	0.36	0.67	0.85	0.96	1.21	0.96	0.70
	S	0.1%	0.0%	0.1%	0.1%	0.1%	0.3%	0.3%	0.1%	0.3%	0.4%	0.4%	0.4%	0.4%	0.3%
Rape-seed	GP	39.5	35.9	34.4	36.8	46.5	50.0	48.0	51.4	57.9	62.6	60.1	62.7	64.6	72.7
	IT	10.1	9.23	7.53	6.91	8.61	8.48	10.6	12.1	16.1	17.8	17.2	17.6	20.0	20.9
	S	26%	26%	22%	19%	18%	17%	22%	24%	28%	28%	29%	28%	31%	29%
Molasses	GP	45.5	46.2	50.8	52.5	50.1	48.3	52.9	59.3	57.1	50.3	54.4	59.7	63.2	63.5
	IT	7.64	8.12	8.39	7.59	8.75	7.23	6.30	6.48	7.18	5.92	5.79	6.30	6.58	6.89
	S	17%	18%	17%	14%	17%	15%	12%	11%	13%	12%	11%	11%	10%	11%
Palm (fruit) oil	GP	22.2	24.8	26.1	28.7	30.1	32.3	39.4	39.8	42.4	43.9	45.8	49.5	52.7	54.4
	IT	13.8	16.2	18.1	20.8	23.5	26.0	29.4	26.7	33.1	35.0	34.8	36.8	39.7	42.8
	S	62%	65%	69%	72%	78%	81%	75%	67%	78%	80%	76%	74%	75%	79%
Soybean oil	GP	25.6	27.7	29.0	30.8	30.7	34.2	35.0	37.5	36.0	36.5	40.7	42.3	42.2	42.8
	IT	7.05	8.35	9.06	9.82	9.73	10.4	11.0	12.3	11.2	9.92	10.4	10.3	9.73	10.0
	S	28%	30%	31%	32%	32%	30%	31%	33%	31%	27%	25%	24%	23%	23%
Rapeseed oil	GP	13.5	12.5	13.1	12.5	15.0	16.8	18.1	18.0	19.3	21.4	22.8	23.1	24.0	24.3
	IT	2.61	2.54	2.66	2.22	2.63	3.09	4.08	4.26	4.46	4.87	5.72	5.98	6.38	6.78
	S	19%	20%	20%	18%	18%	18%	23%	24%	23%	23%	25%	26%	27%	28%

Table 3.5: Global production (GP), international trade (IT) and share (S=IT/GP) of biofuels during period 2000-2009, derived from Lamers et al. [2011]

		Year [10^6 ton]									
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Bioethanol	GP	13	14	16	20	22	26	31	40	51	58
	IT	0.0	0.0	0.0	0-0.1	0.4-0.7	0.7-1.0	2.4-2.6	2.0-2.3	2.8-3.1	1.4-1.8
	S	0.3%	0.3%	0.2%	0.2-0.6%	1.8-3.2%	2.9-3.8%	7.7-8.5%	4.9-5.8%	5.5-6.0%	2.4-3.0%
Biodiesel	GP	0.7	0.9	1.1	1.5	2.0	3.5	6.0	8.5	13	15
	IT	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.9	2.4	2.2
	S	0.0%	0.0%	0.0%	0.2%	0.1%	1.4%	1.7%	10%	18%	14%

3.2.4. BIOFUEL TRADE

In literature little information can be found on the governance structures and actors involved in biofuel trade. Multiple reasons can be identified for this finding. One reason is confidentiality and lack of transparency. The large multinationals involved in biofuel trade stick to a strict confidentiality policy. In addition, according to Kaufman [2008], "back room" deals are especially prevalent in today's biodiesel industry. A similar conclusion is given by van Grinsven et al. [2015]. After an analysis of the role of the Netherlands in the biofuel market, van Grinsven et al. [2015] recommends that transparency of biofuel production and trade needs to be improved. However, there were attempts to overcome this lack of transparency, for example with the rise of online biofuels exchange platforms. In 2005 the Chicago Board of Trade (CBOT, nowadays part of CME Group) started listing bioethanol futures contracts with physical delivery and cash settlement on the CBOT exchange [Liu, 2008]. Similar contracts for bioethanol are traded on the NYMEX.

Another example are the public biodiesel auctions organised in Brazil (one of the largest biodiesel producing countries in the world) by the National Oil Agency (ANP) since 2005. Participation in these auctions is mandatory for producers and importers with a market share larger than 1% [ANP, 2014]. According to Barros and Berk [2016], these auctions are organised on a regular basis (every two months) and physical delivery occurs within one or two months. From the data presented by the author it can be derived that the six auctions that took place during 2015 accounted for a turnover of over 2.6 billion US$. According to Prates et al. [2007] (as cited in Watanabe et al. [2012]), the Brazilian government developed the auction in order to create a transparent market for biodiesel. Like for biomass trade, in literature no numbers are found on the ratio between the number of biomass contracts that are exercised via physical delivery and the number of contracts that are exercised via cash settlement.

A second reason is the relatively recent development of the biofuel markets, in comparison with other commodity markets. This is exemplified by the contracts used in biofuel trade. A clear distinction between international trade in biofuels and trading in other commodities, such as agricultural products and petroleum, is that there are few standard contracts for the physical sale and purchase of biofuels [Feeney, 2009]. What can be said about biofuel trade is that large multinationals like oil companies and agricultural trading companies are involved (as described in section 3.2.1).

In the previous section, it is clarified that biomass trade mainly takes place in a local and decentralized manner. Although in general biomass is difficult and expensive to transport, this is not an issue for liquid biofuels [ICTSD, 2008]. Various characteristics of liquid biofuels are favourable, such as the high bulk density and the ability to flow and to be stored [Junginger et al., 2014]. This creates possibilities for transport of liquid biofuels over long-distances. For example, pipelines exist and are constructed in Brazil for ethanol transport and rail transport is used for fuels in the USA [ICTSD, 2008]. From this information it is concluded that the characteristics of biofuel allow for biofuel trade to take place on a more global level in comparison with biomass trade.

However, if the amounts of biofuel that is traded internationally are considered, it appears that current international trade in biofuels is limited compared with global production of biofuels. An impression of the amounts of bioethanol and biodiesel that is traded internationally is given in Table 3.5. This table shows the global production (GP), international trade (IT) and share (S=IT/GP) for bioethanol and biodiesel. From these tables it can be seen that the international trade in biodiesel and bioethanol is limited during the period 2000-2005. In the period afterwards, the international trade rose significantly. Also the international trade in comparison with global production rose substantially.

On the one hand, if Table 3.4 and 3.5 are compared, it can be seen that the international trading volumes (and global production) for most forms of biomass is substantially larger than for bioethanol and biodiesel. On the other hand, biomass and liquid biofuels have in common that only a small fraction of global production is traded internationally. Based on the described favourable characteristics of biofuel in view of long-distance transport, one would expect (like for processed biomass) that a larger share of biofuel is traded internationally in comparison with non-processed biomass. However, as indicated at the beginning of this section, one should notice that the development of (international) biofuels markets is a relatively recent development. Above that, it is expected that international trade in biofuels will continue to grow substantially in the future due to the divergence between countries with lower production costs and countries with greatest demand for biofuels and due to developing countries that are establishing new infrastructure to serve regional and international biofuels markets [ICTSD, 2008].

Serigati [2013] investigated the integration of international markets of bioethanol. In a literature review performed by aforementioned author, it is found that many researchers (like Elobeid and Tokgoz [2008], Fabiosa et al. [2010], Chen et al. [2011]) explicitly or implicitly assume the existence of a well developed and highly integrated international market, which is able to quickly and cheaply connect the different local markets. However, various forms of anecdotal evidence are presented that refute this assumption. For example, it is indicated that there is no international price of ethanol (contrary to other agricultural, mineral or energy commodities) and distinct drivers influence the local American and Brazilian ethanol markets. By means of a (econometric) cointegration analysis, Serigati [2013] shows that the above described assumption does not hold. Therefore, the assumption of a centralized biofuel market should be considered with care.

3.2.5. PRICING SYSTEMS

In section 3.2.2 different governance structures are discussed, like the spot- and futures market for trading biomass and biofuels. Closely related to the topic of governance structures is the topic of pricing systems. The (transaction) prices of biomass and biofuel depends on, amongst others, prevailing market price, quality premium or discounts, delivery conditions and feedstock price. An important aspect for understanding the pricing system is the relation between spot- and futures prices. Hereto, a few differences between spot and futures markets are highlighted.

Firstly, in a futures market you only pay for the security upon time of delivery. Therefore, the buyer is able to earn interest on the associated amount of money associated while holding the security. Secondly, if the commodity is already harvested, the holder of the futures contract does not need pay for storage cost, deterioration cost etcetera. Thirdly, holding the futures contract does not provide convenience yield. Convenience yield is a rather abstract concept, but captures the value of being able to get your hands on the real thing [Brealey and Myers, 2003]. In other words, a physical inventory of a certain commodity has value, because it provides an insurance to have direct access to the commodity [GARP, 2016]. An example wherein access to a commodity has value is a plant which requires a commodity as a feedstock to keep the plant operational, like a biorefinery. Therefore, convenience yield is only relevant if the commodity is stored. Based on these aspects, the relationship between futures price and spot price can be described by means of Equation 3.1 [Brealey and Myers, 2003]. In this equation r_f denotes the risk-free interest rate and PV denotes the present value. Please note that the (present value of the) convenience yield and storage cost cannot be observed separately, but the difference between them can be derived by determining the difference between the spot price and the discounted futures price.

$$\frac{\text{futures price}}{(1+r_f)^t} = \text{spot price} + \text{PV(storage cost)} - \text{PV(convenience yield)} \tag{3.1}$$

However, this does not fully explain how the pricing system for commodities works. Not all commodities are exchanged via one of the futures exchanges (like CBOT and NYMEX), which are mainly addressed by large buyers and sellers. These goods are also traded on spot markets. Despite the fact the logistics of these transactions make that settlement does not occur immediately (i.e. within 2 days, like for financial securities), and can take up 45 to 60 days [Fattouh, 2011]. However, unlike the futures markets, spot prices for commodities cannot be observed in real time by market participants. In addition, prices in futures contracts are usually based on the method of formula pricing, which links the price to a spot market price [Fattouh, 2011]. Above that, from Equation 3.1 we know that eventually prices in the futures market should converge to the spot prices. But then the question remains how these spot prices come to existence.

Fattouh [2011] investigated this for the (fossil) oil pricing system, which holds many parallels with the pricing system for biofuels. This author describes the following findings. Spot market prices are also referred to as benchmark-, reference-, or assessed prices. These names are derived from the fact that, unlike the futures markets where prices are observable in real time, these prices need to be assessed. The assessments are performed by so-called price reporting agencies (PRAs, such as Platts and Argus). These assessments aim for collecting as much market information as possible, for example by performing surveys among market participants and asking for transaction quantities and prices. Subsequently, based on this information assessed prices are derived, which are used by market participants to settle prices on futures exchanges for contracts and for spot market transactions. Therefore, spot market prices are a central feature of the pricing system. Similar to oil pricing, prices are also assessed for different forms of biofuels. Consequently, spot market prices also form the core in these markets.

3.3. MARKET INSTITUTIONS

In section 3.2.2 different governance structures are discussed for organising the transaction of goods. In that section also the difference between spot- and futures markets is explained. The difference is the moment in time at which goods and money are exchanged. However, in view of how buyers and sellers are matched, also different market institutions exist. In this section two main types of market institutions are discussed: the auction market and the dealer market. This section aims for describing the main market institutions in practice and clarifying how these work.

McAfee and McMillan [1987] (p. 701) define an auction as "a market institution with an explicit set of rules determining resource allocation and prices on the basis of bids from the market participants". In an auction market, market makers (sometimes referred to as specialists) serve customers by matching buyers and sellers. A market maker collects all placed bid- and ask offers in one central location and lists them. If the highest bid-exceeds the lowest ask price, a transaction occurs. In other words, customers buy at the ask price established by a previously placed order of another customer and sell at the bid price established by a previously placed buy order of another customer [Huang and Stoll, 1996]. In an auction market each security (e.g. a commodity or stock) only has one market maker. An example of an market with an auction like structure is the NYSE [Bennouri, 2003].

Globally, the above stated description of auction markets also holds for dealer markets. In a dealer market, market makers (sometimes referred to as dealers) serve customers by buying from and selling to customers on demand. So, contrary to auction markets, market makers trade themselves and provide liquidity to the market. This means that the dealer market is better in comparison to the auction market in terms of liquidity, because if a customer would like to make a transaction at one of the listed bid- or ask offers, the dealer has to honour this request. In case of an auction market, the market maker can only fulfil orders if both bid- and ask-offers of customers are available. Another defining property of dealer markets is the price-setting competition of multiple market makers [Ellis et al., 2002]. That is to say, each commodity (or stock) can have multiple market makers which compete with each other. The market makers compete with each other by each listing a bid- and ask price for a certain security. An example of a market with a dealer like structure is the NASDAQ [Bennouri, 2003].

So far, two differences between auction- and dealer markets are discussed. However, there are two other important differences: the degree of concentration of trading (centralized versus fragmented) and the timing of order submission for liquidity providers (quote and order-driven markets). Bennouri [2003] states that these aspects result in different levels of information availability to the involved actors and explains this as follows. Auction markets are more centralized or concentrated, because orders are collected at one central location and thus executed orders may involve multiple orders from the buy and sell side of the market. Opposed to auction markets, dealer markets are more fragmented. This means that each dealer has its own inventory of customers and transactions occur after pairwise agreements between dealers and traders. The second aspect considers what market information is displayed (i.e. bid- and ask offers, with associated prices, quantities etc.). Auction markets are order-driven, because the orders of the individual buyers and sellers are listed. Contrary to auction markets, dealers markets are quote-driven. This implies that only the bid- and ask offers of the individual dealers are listed. A consequence of the dealer market structure is that the participants have limited information about the transactions occurring at the different dealers. So the auction market structure is better in terms of information supply, because complete order books are available. To summarize, dealer markets are fragmented and quote-driven markets, while auction markets are centralized and order-driven markets.

3.3.1. MARKET ATTRIBUTES

So far in this section, an introduction is given to auction- and dealer markets. Now these markets are discussed in more detail by considering different market attributes. Parsons et al. [2006] performed a literature review and proposed a classification of these markets based on some main attributes. Based on this, an overview of attributes is derived and listed in Table 3.6. In the remainder of this section the proposed classification will be discussed.

Table 3.6: An overview of market attributes

Attribute	Options		
Origin offers	Single-sided	Double-sided	
Trading periods	One (one-shot)	Several (repeated)	
Trade determination	Institutional	Non-institutional	
Price-setting (who)	Institutional	Non-institutional	
Clearing	Discrete (batch)	Continuous (open-outcry)	
Price-setting (how)	Uniform price	Discriminatory prices	
Unmatched offers	Clear	Leave open (persistent shout)	
Information level	Unmatched offers	Bid-ask quote	Price last trade
Offers arrive	Simultaneously	Over time	
Successive offers	Unconstrained	Improvement rule	
Trade unit	Single	Multiple	

The first item of Table 3.6 considers which actors are allowed to make offers. If only buyers or only sellers are allowed to make offers, the market is called single-sided (or one-sided). If both sellers and buyers are allowed to make offers, the market is called double-sided (or two-sided). An example of a one-sided auction market is an art auction wherein an item is sold to the highest bidder. The second attribute considers trading periods. A trading period specifies a time span in which trade can take place in the market. The number of trading periods of a market could be limited to one (called an one-shot market) or there could be various (called a repeated market). In practice, markets usually allow for multiple trading periods. Next, trade determination refers to which actor prescribes whether a transaction has to take place or not. This could be determined by an institution that organises the market or by the traders themselves (non-institutional). The next aspect is who sets the price in case of a transaction. Similarly to trade determination, the price could be set by an institution that organises the market or by the traders themselves (non-institutional).

This latter attribute is closely related to how clearing is performed. The clearing attribute refers to matching buyers and sellers to each other and removing their offers from the order book. For a continuous auction, offers may be submitted and transactions may occur at any moment. In this case, the price is usually determined by the first made offer (of the matched bid- and ask offer). For a discrete (or batch) auction, all bids are collected during a trading period and subsequently cleared at the end of that period. To illustrate this, Figure 3.7 is considered. In this figure two sets of demand- and supply curves are shown. The curves in the left diagram are constructed for the following collected offers. Actors A, B, C, D and E all would like to supply 10 units for a price of of $15, $20, $25, $30, and $35 per unit respectively. Actors F, G, H , I, and J all would like to buy 10 units for a price of $15, $20, $25, $30, and $35 per unit respectively. The price at which the demand- and supply are equal corresponds to the equilibrium price. If this occurs, there are two possibilities: a single (equilibrium) price (see left part of Figure 3.7) or an (equilibrium) price tunnel (a price range, see right part of Figure 3.7). In the first case, if the equilibrium price is used as transaction price, then there is one price for all transactions (called a uniform price). In the latter case, if the equilibrium price is used as transaction price, either a uniform or non-uniform prices for each transaction (called discriminatory prices) could be used. Typically, discrete clearing is associated with a uniform-price, whereby the price is set to the equilibrium.

When clearing is performed the question arises what happens with the unmatched offers. One option is to also remove these from the bid book. The other option is to leave the unmatched offers open. This is referred to as a persistent shout market. An important aspect of trading is the information available. At the beginning of section 3.3 differences in information availability for auction- and dealer markets are discussed.

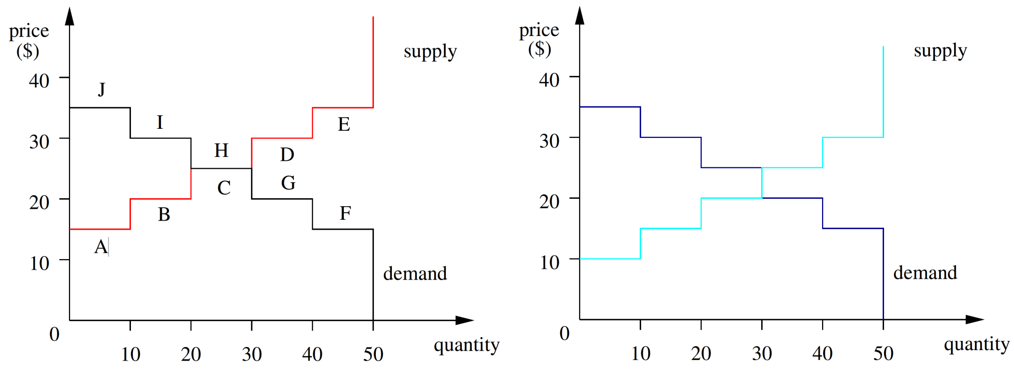

Figure 3.7: Two sets of demand- and supply curves. Left: single price. Right: price tunnel [Parsons et al., 2006]

If information is available, different levels of information availability can be distinguished. This brings us to the next attribute: information level. An option is that information of unmatched bid- and ask offers is available, including prices and quantities. An other option is the availability of the bid-ask quote. This value only specifies the value of the highest bid and the lowest ask. This provides less information to traders than the first option. Information could also be restricted to the price of the last transaction. In that case, information is even more restricted. Related to information availability is offer arrival over time. In case all offers arrive simultaneously, actors are not able to make inferences from offers made by others. However, if offers do arrive over time, this does belong to the possibilities.

Now we turn to the last two attributes listed in Table 3.6. It may occur that during a trading period an actor would like to adjust its offer. This adjustment may be subjected to an improvement rule. This rule states that the actor may only adjust its bid- or ask offer if the unit price is increased. An other option is to put no constraints on successive offers. Lastly, the unit of trade in the market could be single- or multi unit. In a single unit market, traders are only allowed make offers for one unit at a time. In a multi unit market, traders are allowed to make offers for several units at a time.

CONTINUOUS DOUBLE AUCTION

One typical combination of market attributes is already highlighted, namely that discrete clearing is associated with a uniform-price, whereby the price is set to the equilibrium. One other typical combination of market attributes is a continuous double auction (CDA). CDAs are discussed in more detail, because this concept will return later on in the formulation of the conceptual model in section 4.3.

CDAs have been widely used in stock exchange markets and internet auctions [Hu et al., 1999]. As indicated in this section, the market is cleared in a continuous manner and offers may originate from buyers and sellers for this type of auction. This means that in case of non-institutional trade determination, traders can accept offers at any point in time and in case of institutional trade determination, the institution that organises the market attempts to perform clearing every time a new offer is received. In view of these attributes, CDA uses to be associated with discriminatory price-setting.

A well-known work in the field of CDA is performed by Gode and Sunder [1993]. In this study a market is simulated with so-called "zero-intelligence" (ZI) traders. This means that the traders place random bid- and ask offers in the market. This research showed that imposing a constraint on the traders to not make loss making offers, raised the allocation efficiency of the market (i.e. the ratio between realized matched value and maximum possible matched value) to nearly 100%. It is concluded that allocation efficiency of continuous double auctions largely derives from the market structure, instead of traders' motivation, intelligence or learning. In other words, an important part of the dynamics of the market emerge from the trading system itself. In other research it is found that ZI traders in a CDA are a good method for predicting dynamics of the London Stock Exchange (see [Farmer et al., 2005]).

3.4. SUMMARY

This chapter started with a literature review on feedstock for liquid biofuels. If global biodiesel production is reviewed, it appears that vegetable oils form the main feedstock used for biodiesel production. If oilseeds are processed, oil and meal are retrieved. Vegetable oils are used for food- and industrial applications (like biodiesel production). On a global level, rapeseed oil, palm oil and soybean oil are the main vegetable oils used for biodiesel production. However, the major part (>70%) of these oils is consumed for food purposes.

The next two sections focussed on a different topic, namely trade in the biofuel supply chain. Three groups of actors can be distinguished in this chain. The first group includes the biomass producers (farmers), which produce and sell biomass. The second group includes the biofuel producers, distributors and retailers. The actors in this group fulfil different combinations of these functions and thus the roles of these actors show (partial) overlap. The third group includes the biofuel consumers. These consumers originate from the private- and public sector. Liquid biofuels are almost solely consumed for transport purposes (mainly road transport).

Since the biofuel supply chain is a trading network, transactions of commodities are a key element. In this research transactions of biomass and biofuel are examined. Contracts are the most common form of biomass trade. Contrary to biomass trade, little is known about biofuel trade. This originates from a lack of transparency in this sector and the fact that biofuel trade is a relative recent development. For biofuel trade an important role is present for price reporting agencies. These agencies collect market information and provide actors with (assessed) spot market prices. This assists actors in keeping track of market developments outside their field of vision.

In section 3.2 it is also examined to which extent biomass and biofuels are traded internationally. It is found that biomass trade tends to be local and decentralized. The main reason is the relative high transport cost in comparison with the energy density. It appears that the share of biomass that is traded internationally varies between 0% and 40%. Palm oil is an exception: nearly 80% of the palm oil produced is traded internationally. This is related to the low price of palm oil in comparison with similar commodities. In comparison with biomass, biofuels are more suitable for long distance transport. However, if international trade of biodiesel and bioethanol is reviewed, it appears that only a small share (<20%) of global production is traded internationally.

The chapter is concluded with a literature review on market institutions. Hereto, different types of market and their attributes are discussed. Two main types of market institutions are discussed: the auction market and the dealer market. An important type of market is the continuous double auction (CDA). In short, this kind of market is cleared in a continuous manner and offers may originate from buyers and sellers. The concept of CDA will return in the formulation of the conceptual model in section 4.3.

4
MODELLING

In this chapter a description of the model will be given. The first topic addressed in this chapter is pattern oriented modelling. This topic is addressed first, because it forms the guideline for the subsequent steps in model development. Above that, it also assists in understanding the relationship between the model and the objective of research. Subsequently, an introduction to the case study is given in section 4.2. Following on this description, the conceptual model is formulated in section 4.3. This description gives a global overview of the actors and interactions among these actors in the model. The model elements are discussed in more detail in section 4.4 and 4.5. Next, the model input is quantified in section 4.6. This chapter is concluded with a summary of the model. This summary includes a pseudo code, a list of assumptions and a list of model parameters.

4.1. PATTERN ORIENTED MODELLING

In this research a pattern oriented modelling (POM) approach is applied. POM can be described as a general strategy for developing and analysing an ABM. The general idea of POM is to use observed patterns in a real system as indicators of the system's internal organization and subsequently try to reproduce these patterns (simultaneously) with an ABM, in order to decode the internal organization of the real system [Railsback and Grimm, 2011]. Hereby a pattern refers to regularities or so-called "stylized facts". Stylized facts are broad, but not necessarily universal, generalizations of (historical) observations that describe essential characteristics of a phenomenon, which calls for an explanation [Heine et al., 2007]. For example, in case of studying bird flocking, a (qualitative) emerging pattern could be the shape of birds swarms.

As indicated by Railsback and Grimm [2011], these patterns form the guidance in deciding which model elements (like agents and variables) need to be in the model to give it enough realism and complexity to be testable and useful, while avoiding unnecessary complexity. Two important issues in POM are which patterns to select and how many. These issues are subjected to discussion and are to some extent arbitrary. However, what can be said is that for most systems a single pattern is not sufficient and multiple patterns are needed to decode the internal organization of the real system. Simply put, by using more patterns, it becomes less likely that an unrealistic model succeeds in reproducing these patterns. The downside of considering more patterns is, of course, the increase in complexity and required time to reproduce the patterns. Therefore, exploring models tend to start with considering only a single pattern. Besides the number of patterns, the patterns should also be diverse and should characterize a system with respect to the modelling problem [Railsback and Grimm, 2011].

As indicated in the research objective (section 1.4), the influence of domestic biofuel policy measures on the global bioenergy markets is not extensively investigated. Lamers et al. [2011] performed a study on international bioenergy trade, with a focus on liquid biofuels. In this research two patterns are found:

- Pattern 1: Import duties are key influencing factors on trade volumes.
- Pattern 2: Trade routes are mainly driven by tariff preferences.

In other words, it is found that there is some interaction between policies and patterns of international trade flows (in terms of volumes and routes) of biofuels and feedstock. However, the study performed by Lamers et al. [2011] did not explain the underlying mechanism. The aim of this research is to fill this knowledge gap. The patterns listed above are deemed suitable to realize this, because they are believed to be caused by the same mechanism that underlies the effect of policies on emerging patterns in the international trade flows of liquid biofuels and feedstock. A disadvantage of including pattern 2 is that the model design must allow for multiple trade routes to emerge from the model. This requires multiple countries to be taken into account into the model. Since it is expected to be more time consuming to realize this, this research is limited to pattern 1.

4.2. INTRODUCTION TO CASE STUDY

In the previous section the strategy for developing the ABM is discussed. In this section the scope of the model is set by defining a case study. To set the model scope, various data is presented to clarify why this model scope is deemed to be suitable. Firstly, one of the regions considered in the model is the European Union (referred to as EU-28). The EU-28 is selected, because since the take-off of biodiesel (around the year 2000), the EU-28 has been one of the largest producers and consumers of biodiesel in the world. Above that, as will be clarified later on in this section, in the past the European biodiesel market has been targeted as an export market for biodiesel and feedstock by various countries. In other words, the EU-28 biodiesel market is subjected to international trade flows.

Secondly, to narrow down the scope, the feedstock composition for biodiesel production in EU-28 is considered. Hereto data presented presented in Figure 4.1 is used. This figure shows that during the period 2009-2016 the major feedstock used for the production of first-generation biodiesel in EU-28 is rapeseed oil. In addition, this feedstock represented a stable contribution. However, the total production of biodiesel production has grown over the years. The figure shows that this growth is mainly covered by (imported) palm oil. While in 2009 palm oil accounted for only 6.9% of the feedstock consumed for biodiesel production, in 2016 palm oil covered over 25%. In absolute numbers this corresponds to a significant growth of over 400%. Lastly, the figure shows that the contribution of soybean oil declined and sunflower oil only represented a marginal contribution. If the data presented in Figure 4.1 is compared with data presented by Transport Environment [2016], it appears that these numbers are in line. To limit the scope of the model, only two types of feedstock are modelled: rapeseed and palm oil. In this way the major feedstock used for biodiesel production is present and the model allows for international trade of feedstock for biodiesel production.

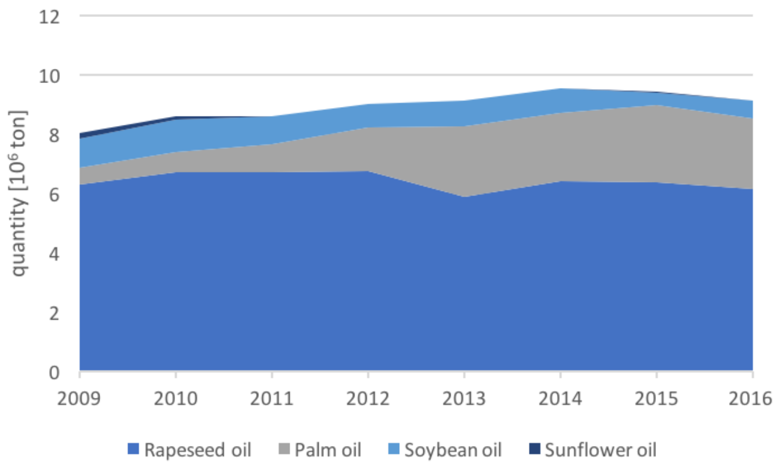

Figure 4.1: Feedstock composition first-generation biodiesel produced in EU-28 [USDA-FAS, 2016a]

Since rapeseed is included in the model, the origin of rapeseed is briefly examined. In Appendix B the trade balances for rapeseed and rapeseed oil for EU-28 are shown. The trade balance for rapeseed shows that rapeseed mainly originates from domestic production. Subsequently, this rapeseed is predominantly crushed. If we take a look at the trade balance for rapeseed oil, one can see that rapeseed oil mainly originates from domestic production. This means that the incorporation of this feedstock does not require the inclusion of additional countries in the model.

However, farmers in EU-28 are not limited to growing rapeseed. In reality many different types of crops can be grown. In the model farmers in EU-28 are also allowed to grow wheat. Wheat is chosen as a second crop for farmers in EU-28, because wheat is the largest commodity in EU-28 in terms of production, area harvested and turnover (derived from USDA-FAS [2017b] and OECD [2017], considering the period 2000-

2016). In reality, of course, many different other types of crops could be grown. Therefore, wheat could be seen as a proxy for all the other crops in the model.

Following the origin of rapeseed oil for biodiesel production in EU-28, the origin of palm oil is treated. It is not possible to grow oil palm in EU-28, because oil palm is a tropical tree crop. Therefore, if palm oil is demanded in EU-28 it must be imported. Palm oil production is dominated by Indonesia and Malaysia. These countries account for between 80 to 85% of global palm oil production [Rosillo-Calle et al., 2009]. In Table 3.4 it is shown that palm oil is traded internationally on a substantial scale. However, not all palm oil is (directly) exported. Like EU-28, Indonesia/Malaysia accommodates a large scale biodiesel industry. The feedstock used in these countries is almost exclusively palm oil (see Appendix C). The produced biodiesel is consumed in Indonesia/Malaysia itself, but also exported in substantial volumes. Besides being the largest producer of biodiesel in the world, EU-28 is also the largest consumer. The export of biodiesel from Indonesia/Malaysia is mainly directed to EU-28. Taking all these aspects into account, Indonesia/Malaysia is an interesting addition for the model in view of the research objective. Therefore, Indonesia/Malaysia is incorporated in the model as a second region.

This section is concluded with a brief recap of the scope of the model. The model considers two key players in the (international) biodiesel market: EU-28 and Indonesia/Malaysia. Above that, four commodities are introduced: biodiesel, palm oil, rapeseed and wheat. In this scope there are globally three possibilities for biodiesel that is consumed in EU-28 in the model:

- Rapeseed is harvested and converted to biodiesel in EU-28.
- Palm oil is extracted in Indonesia/Malaysia and exported to EU-28, subsequently the palm oil is converted to biodiesel in EU-28.
- Palm oil is extracted and converted to biodiesel in Indonesia/Malaysia, subsequently biodiesel is exported to EU-28.

4.3. CONCEPTUAL MODEL

In this section the conceptual model is discussed. A schematic representation of this model is shown in Figure 4.2. A pair of arrows denotes a two-way interaction, while one arrow denotes an one-way interaction. The dashed line rectangle indicates the system boundary. The elements that are within the system boundary are considered endogenous, while the elements that are outside the system boundary are considered exogenous. Please note that only the major exogenous prices and demands are displayed in Figure 4.2. Later on in this chapter it will be shown that also various other (minor) cost and benefit will be taken into account. In the model two regions are present: EU-28 and Indonesia/Malaysia. Each region consists of multiple actors which participate in the biofuel supply chain. An actor is denoted with a solid line rectangle. To indicate which actors are part of a region, a solid line parallelogram is drawn. Based on the literature review (see section 3.2.1), three types of actors are distinguished in the model: biomass producers, biodiesel producers and distributors/retailers.

A central theme in this research are the domestic biofuel policies (like blending mandates and import duties). These are represented in Figure 4.2 by subjecting the elements within a region to corresponding biofuel policies. The biofuel policies are considered exogenous. This is a simplification with respect to reality, but this is necessary because biofuel policies form the independent variable in this research (see Figure 1.2). Besides domestic biofuel policies, countries are also a central aspect of this research. Please note that countries are not represented in the model as an actor as such, but are present in the form of a collection of actors. This collection of actors has certain things in common, like biofuel demand or biofuel policy. Above that, the biofuel policies originate from countries' governments. Therefore, countries do play an important role in the model.

In Appendix B the consumption of rapeseed oil in EU-28 is shown. In this figure it can be seen that rapeseed oil has two final destinations. One destination is domestic consumption for food. This component shows a stable level over the years. The other destination is domestic consumption for industrial purposes (like biodiesel). This component has grown steadily over the past years. However, contrary to what we have seen in Figure 3.6 (taking a global perspective), the consumption of rapeseed oil for industrial purposes dominates the EU-28 market for rapeseed oil. If one considers the feedstock composition of EU-28 for biodiesel production (e.g. Figure 4.1), it can be seen that in the period 2009-2016 around $6*10^6$ ton rapeseed oil is used for biodiesel production. Appendix B shows that in the same period around $6*10^6$ ton rapeseed oil is used for industrial purposes. Therefore, it is concluded that the consumption of rapeseed oil for industrial purposes, as listed in Appendix B, in fact corresponds to the usage of rapeseed oil for biodiesel production.

Based on this information, it can be concluded from Appendix B that the rapeseed oil market is dominated by consumption for biodiesel production. Therefore, it is chosen to model the rapeseed market from a biodiesel perspective. That is to say, the emphasis of the model is on the interaction of EU-28 biomass producers with biofuel producers. As will be shown later (see section 4.5.1), the food market for rapeseed is present in the model, but in a different role. This interaction between the EU-28 biomass producers and the biofuel producers takes place via (bilateral) contracts. This governance structure is chosen, because in the literature review (see section 3.2.3) it is found that contracts are the most occurring method of transferring biomass from biomass producers to the users. These contracts are annual contracts and specify the amount biomass and the price. In line with what is found in literature (see section 3.2.3), agreements for contracts for rapeseed are reached in a local and decentralized manner. This means that there are rapeseed markets in which only actors participate that are geographically situated close to each other. This market represents a face-to-face interaction between biomass producers and biodiesel producers and may result in different prices among the rapeseed markets. This market structure is chosen, because in general biomass (like rapeseed) is difficult and expensive to transport (see section 3.2.4). The terms of the contracts are negotiated in a futures market. This futures market is represented by means of a continuous double auction (CDA, see section 3.3.1). This implies that both buyers and sellers can make their offer at any point in time (within a certain time span). If there is a match between a buyer and seller (highest bid exceeds lowest ask), a transaction will occur. The properties of the CDA implemented in the model are summarized in Table 4.1.

Table 4.1: Overview of attributes markets in model (for explanation of attributes see section 3.3.1)

Attribute	CDA	One shot auction
Origin offers	Double-sided	Double-sided
Trading periods	Several (repeated)	One (one-shot)
Trade determination	Institutional	Institutional
Price-setting (who)	Institutional	Institutional
Clearing	Continuous (open-outcry)	Discrete (batch)
Price-setting (how)	Discriminatory prices	Uniform price
Unmatched offers	Clear	Clear
Information level	None	None
Offers arrive	Over time	Simultaneously
Successive offers	Unconstrained	NA
Trade unit	Multiple	Multiple

The commodity rapeseed is subjected to competition from two other commodities. The first commodity (directly) competing with rapeseed is wheat. Farmers take into account the prices of both rapeseed and wheat in making their land allocation decision. This topic will be discussed in detail in section 4.5.1. The price of wheat is considered exogenous. This assumption is considered suitable, because EU-28 is only responsible for around 20% of the global wheat production [USDA-FAS, 2017b]. Besides wheat, rapeseed is also subjected to (indirect) competition from palm oil originating Indonesia/Malaysia. In Table 3.4 it is shown that palm oil is traded internationally on a substantial scale for many years. In other words, biodiesel producers in EU-28 have two options for their feedstock for biodiesel production: rapeseed from local farmers or import palm oil from Indonesia/Malaysia. In the conceptual model, the price of palm oil does not originate from interaction between actors, but is considered exogenous. The price of palm oil is chosen to be exogenous, because the market for palm oil is considered too complex to model within the available time frame of this research.

The biodiesel producers interact with the distributors/retailers via two separate spot markets for biodiesel. One spot market involving domestic producers and the distributors/retailers and one spot market involving foreign producers and the distributors/retailers. The governance structure in form of a spot market is chosen, because in section 3.2.5 it is described that spot market prices are a central feature of biofuel markets. Please recall that in essence the futures markets mentioned earlier and the spot market are very similar, because both are related (also see section 3.2.5).

As described in section 3.2.4, compared to biomass, biofuel is not difficult and expensive to transport. This allows for biofuels to be traded internationally and in a central manner. For example, according to Lamers [2011], the imports of biodiesel by EU-28 varied between 14 to 24% in the period 2007-2010. In addition, Indonesia is one of the key exporting nations of biodiesel to EU-28 [Junginger et al., 2014]. Taking these factors into account, the choice of (two) centralized biodiesel markets is justified. The centrality of these markets is reflected by creating one-shot auctions (see section 3.3.1). In this market all offers arrive simultaneously and there is one uniform market-clearing price (or equilibrium price) for all the participating actors, which is set by an external institution. The properties of the one-shot auctions implemented in the model are summarized in Table 4.1. Lastly, it is chosen to create two separate spot markets for biodiesel originating from EU-28 and from Indonesia/Malaysia, because as described at the end of section 3.2.4, various forms of evidence show that the assumption of a well developed and highly integrated international market for biofuel does not hold.

The bottom part of Figure 4.2 indicates the interaction between the distributors/retailers and the consumers. The distributors/retailers are modelled as one actor, because limited information is available on this group of actors. This restricts well founded modelling decisions. The lack of information can be clarified by the prevailing high confidentiality standards in this sector. With respect to the consumers, the demand for fuel in general and diesel in particular, is dependent on many factors, like gross domestic product (GDP) and price. However, for simplicity the demand for (either fossil- or bio-) diesel is considered exogenous. This means that consumers are not modelled as an actor as such, but are represented by their demand for diesel. Likewise, the (producer) price of fossil diesel is considered exogenous. This assumption is considered suitable, because the blending mandate active in EU-28 only amounts to 5.75%. In addition, EU-28 is only responsible for a small share of the global diesel consumption. Therefore, the (producer) price of fossil diesel will hardly be affected by biodiesel production in EU-28.

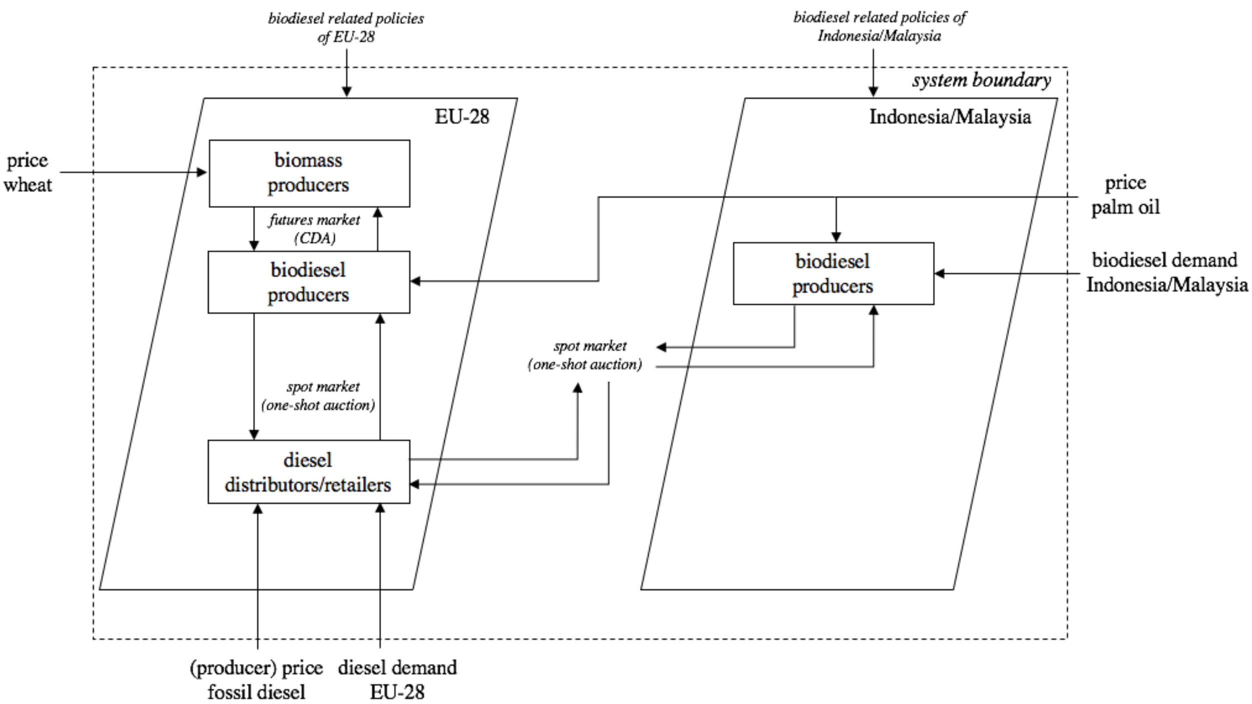

Figure 4.2: Schematic representation of conceptual model

4.4. GENERIC MODEL ELEMENTS

4.4.1. CLUSTERS

In section 4.3 it is clarified that in the model contracts for rapeseed are reached in a local and decentralized manner. This means that there are rapeseed markets in which only actors participate that are geographically situated close to each other. Therefore, in the model so-called "clusters" are formed. Clusters are groups of actors (farmers and biorefineries) that are geographically situated close to each other. Each cluster represents a local market for a crop (in this research rapeseed). Differences in trading volumes and prices may arise among the clusters.

The creation of clusters demands the specification of a cluster size. In the model it is assumed that clusters are circular. In this case, a cluster radius has to be specified. The question which then arises is which cluster radius is still economically feasible. In literature some indications can be found with respect to the cluster radius. For example, in a study by Firrisa [2011] it is found that transport distance between farmer and market (i.e. the biorefinery) covers around 72 km for rapeseed in EU-28. In other studies, similar numbers are found (e.g. Shastri et al. [2011]). However, this number cannot be directly be applied in the model, because in the model it is assumed that all biodiesel plants are integrated plants (see page 49, paragraph on by-product credit from meal). This means that vegetable oil production and biodiesel production always take place at the same location. However, in reality this assumption does not hold true. Since vegetable oils are more favourable in terms of transport cost, this assumption is likely to underestimate the reach of the biorefineries. This could hamper the ability of biorefineries to operate at maximum capacity.

To overcome this issue, a different approach is taken. Instead of applying a predefined cluster radius, the cluster radius is tailored to the situation of each biorefinery. Hereto, the location of a biorefinery is taken as a starting point. Before each simulation run, a biorefinery determines which farmers are situated within the range of the initial cluster radius (5 kilometre). By means of the size of the arable land and rapeseed yield, it is assessed whether this number of farmers is sufficient to cover at least 90% of the maximum production capacity of the biorefinery. If this not is the case, the cluster radius is increased with 5 kilometre. This process is repeated until the desired production capacity is fulfilled.

To give an impression of the result, an example of the NetLogo world is shown in Figure 4.3. This figure show four clusters in the eastern part of EU-28. The picture depicts four clusters (each with a different colour). Three of these clusters consist of one biorefinery (depicted in green) and a number of farmers (depicted in blue/white). One can see that the biorefinery in the blue cluster required a larger cluster radius than the biorefinery in the green cluster, for example. The remaining cluster consist of four biorefineries and a number of farmers. In this case, the cluster areas of the individual biorefineries overlap and therefore are merged into one cluster. This means that these bioefineries are subjected to competition of other biorefineries.

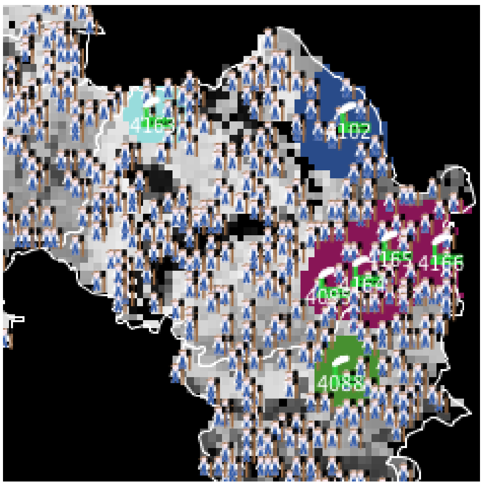

Figure 4.3: Example of clusters in model

4.4.2. ECONOMIES OF SCALE

Economies of scale refer to the principle that companies may achieve a cost advantage in comparison with their smaller counterparts by realizing higher production volumes. This advantage results from the possibility to distribute fixed cost over a larger production volume. As will be described in this section, strong economies of scale are also present in the biofuel industry. Therefore, economies of scale are also incorporated in the model.

A widely applied method to quantify the strength of economies of scale is to make use of a scale factor (sometimes also called scale exponent). This approach is based on the power law specified in Equation 4.1. In this equation, c_i denotes the cost per unit of output at production output o_i and α denotes the scale factor ($\alpha > 0$). This relationship states that if $\alpha < 1$, the production cost per unit of output decreases as output increases. In this equation, c_2 and o_2 refer to (known) base values.

$$\frac{c_1}{c_2} = \left\{ \frac{o_1}{o_2} \right\}^{\alpha} \tag{4.1}$$

Economies of scale are present in production agriculture. Almost every study has found that average cost of agriculture production decrease over a certain size range [Duffy, 2009]. For example, Watanabe et al. [2012] states that there are substantial economies of scale involved in the cultivation of soybeans cultivation.

There are also strong economies of scale present in biofuel production [Khanna et al., 2009], [Junginger et al., 2014], [IRENA, 2013], IEA [2004]. In the latter study it is estimated that the conversion cost (US$/L) of a large scale production facility in Europe using rapeseed oil as feedstock is around four times lower in comparison with a similar but small scale production facility. According to Berghout [2008], which investigated the German biodiesel industry, conversion costs per litre have declined significantly in the period 1991-2004. The main reasons given for this reduction are efficiency gains, due to scale effects, higher plant yields and the shift from batch to continuous processing systems.

However, diseconomies of scale may also be present, because a larger plant requires more feedstock and thus feedstock may need to be transported over larger distances, resulting in larger transport cost. In this way, (a part of) the economies of scale could be cancelled out. Since the scale factors found in literature for the biofuel supply chain are found to be less than 1 (see section 4.6.1), economies of scale are incorporated in the model for biodiesel production and farming.

4.4.3. PRICE OUTLOOK

In the model actors make use of price outlooks of commodities in making their decisions. This is necessary, because at the moment some decisions need to be made, not all desired information is known. For example, in the description of the conceptual model (section 4.3) it is clarified that the interaction between the EU-28 biomass producers and the biofuel producers takes place via (bilateral) contracts. This model choice implies that biorefineries need to make an offer for feedstock, while they do not know what price they will receive by selling the produced biodiesel, since the required feedstock for biodiesel production is handed over later on. This obliges biorefineries to assess what the future price of biodiesel will be (a price outlook) in order to set their maximum price for buying feedstock.

The price outlook in the model consists of two building blocks: exponential smoothing and noise. Firstly exponential smoothing will be discussed, followed by noise. Exponential smoothing is a time series analysis method. With exponential smoothing a weighted average of (historical) observations can be made. Subsequently, this weighted average can be used as a forecast. A formulation of exponential smoothing is shown in Equation 4.2, with $\hat{p}_t$ the smoothed price (outlook) at time step t, β the price damping coefficient ($0 \leq \beta \leq 1$), p_t the price observation at time step t and T the final time step of the simulation. With exponential smoothing, the weight factors fade-out exponentially over time. The rate at which this occurs is dependent on the magnitude of β. The lower β, the more emphasis is put on the current observation and less emphasis is put on previous outlooks, resulting in less damping (i.e. smoothing) of price developments. Similarly, the opposite also holds true. The method exponential smoothing is selected for creating price outlooks, because it is simple method for creating outlooks. Additionally, it also allows us to capture time delay. Time delay refers to the notion that actors may not be able to react immediately upon the information they receive.

$$\hat{p}_t = (1-\beta)p_t + \beta\hat{p}_{t-1} \qquad \text{for } t \in \{1,2,\ldots,T\} \tag{4.2}$$

The second building block of the price outlooks is noise. If a transaction is made in the model, a price for the corresponding commodity is registered. The information actors receive, does not necessarily consist only of the transactions in which they are involved. An actor may also perceive information of the offers made by other actors, for example in the CDA performed by farmers and biorefineries. However, these actors do not necessarily know all details of all transactions made. In other words, the actors do not possess perfect information. Therefore, noise is applied to the actual prices. This is modelled by multiplying the actual prices with a normally distributed random percentage of the actual price while creating a price outlook. The mean of this normal distribution is assumed to be zero, but the standard deviation is considered to be larger than zero. The larger the standard deviation of the noise level, the larger the range of noise is applied to the price realization. In this way, one is able to adjust the accuracy of the price perception of the actors.

4.5. AGENT PROPERTIES AND BEHAVIOUR

In this section the properties and behaviour of the different agents in the model will be discussed. The major part of the values assigned to the different properties will be presented in section 4.6.

4.5.1. FARMERS

The biomass producers grow either rapeseed or wheat and are situated in EU-28. Both rapeseed and wheat are annual crops. The main properties of the biomass producers are:

- location
- arable land [ha]
- yield (for rapeseed and wheat) [ton/ha]
- cluster [#]
- subsidy (for rapeseed and wheat) [US$/ton]
- type of farmer [-]
- adoption threshold rapeseed
- total cost of production [US$/ton]

In the model two types of farmers are distinguished: farmers for the food market and farmers for the energy market. To ensure that food security in EU-28 is respected, a fixed number of farmers is assigned to grow crops for the food market. These farmers allocate their entire land to growing either rapeseed or wheat for the food market. The remaining farmers are allowed to grow crops for either the energy market or the food market. The division between both types of farmers is based on historical data on land allocation, crop supply and crop distribution.The farmers which are not bounded to the food market need to decide each year which crop to grow.

One of the objectives of farmers is to maximize profits. In order for energy crops to be adopted by farmers, the economics of these crops must be at least as good as those of traditional crops [Ericsson et al., 2009]. However, maximizing profits is not the only objective of farmers. This can be illustrated by considering the fact that in EU-28 currently the revenue (US$/ha) of wheat is higher and the total cost of production (US$ha) are lower in comparison to rapeseed (see Table 4.7) and support measures for both crops are limited (see section 4.6.5). Nevertheless, currently around 10% of the arable land in EU-28 is devoted to rapeseed and around 35% to wheat [USDA-FAS, 2017b]. Ericsson et al. [2009] states that energy crops are associated with a higher risk because the market for biofuels and biomass is not as well developed as the markets for food and feed. In addition, energy crops are also associated with a higher risk in case a farmers needs to introduce a new production system, which may require new machinery and which they may not be knowledgeable about. Above that, land-use flexibility (the ability to switch between different crop types) may also form an obstacle. These factors are also confirmed by Glithero et al. [2013]. In the corresponding survey the objectives of and rationale behind the decisions of farmers in the UK for growing or not growing certain crops for renewable energy purposes is studied. It is found that besides profitability, reasons like land quality, ease of crop management, commitment of land for a long period of time, moral considerations, knowledge and current farming practice affect decision making.

Unfortunately, the surveys performed on how farmers in EU-28 make these type of decisions is limited in number and scale. Therefore, a more theoretical approach is chosen, as proposed by Berger [2001] and Alexander et al. [2013]. The adoption of rapeseed is considered similar to the adoption of an innovation. Typically, the adoption process over time is approximated with an S-shaped curve in literature (plotting adoption against time, see e.g. Rogers [1995]). In this process, five adopter categories can be distinguished: early adopter to innovators, early adopters, early majority, late majority and laggards. These groups succeed each other in adopting the innovation and not any earlier. Therefore, it can be said that the actors possess adoption thresholds or boundaries to adoption. This means that as long as the adoption threshold of an actor is not met, it will not adopt the corresponding innovation.

In this research also use is made of an adoption threshold. It is assumed that this threshold captures all non-financial considerations of farmers as described earlier on in this section. To determine whether the adoption threshold of an farmer is met, use is made of the approach proposed by Alexander et al. [2013]. This approach considers groups of farmers which are situated close to each other (so-called "neighbourhoods" or "social groups"). It is reasoned that neighbouring farmers affect the decisions of each other, for example by communicating with each other about their experiences with growing a certain type of crop. In this research, growing rapeseed is considered the innovation. Farmers will adopt rapeseed if the following two conditions are both met:

- The local adoption of rapeseed exceeds the adoption threshold of the farmer
- The expected net profit of growing rapeseed coming year is larger than the expected net benefit of growing wheat

Opposite, if both conditions are not met and a farmer previously adopted rapeseed, the farmer will start growing wheat. In the model clusters of farmers and biorefineries are created to address the transport cost associated with transporting biomass. The creation of clusters is discussed in detail in section 4.4.1. The same clusters are used to determine the local adoption of rapeseed. The net profit of both crops is determined by taking into account expected revenues, production cost and subsidies.

Before the remaining behavioural elements of farmers are discussed, a global overview of the decision cycle performed by farmers in EU-28 is given in Figure 4.4. This decision cycle is only applied for those farmers which are not assigned to grow crops for the food market. These farmers will be discussed a the end of this section.

At the start of a new year those farmers firstly evaluate the adoption of rapeseed, as described earlier on in this section. Hereto, a farmer makes use of a price outlook, as described in section 4.4.3. If a farmer does not adopt rapeseed, it will grow wheat. As indicated in section 4.3, the price of wheat is considered exogenous and thus does not require any further modelling. If a farmer did adopt rapeseed, it will firstly participate in the CDA (see section 3.3.1) for rapeseed. In this CDA the farmer interacts with other farmers and biorefineries in its cluster. The initial price offer farmers is a price floor plus a random profit margin (within certain limits, in line with what is usual in this sector). The price floor of the farmers is determined by the sum of the total production cost, transport cost and subsidies. In other words, if a farmer sells its crops at the price floor, the profit margin is 0%.

If a farmer reaches an agreement for a contract, it will higher its price at a certain rate for the next round of the auction if there is rapeseed left to offer, there are buyers remaining and the maximum number of auction rounds has not been reached. If a farmer does not succeed, it will lower its price at a certain rate. However, the price price may not become lower than the price floor (corresponding to a profit margin of 0%). In the model the price change rate is assumed to be 5% per auction round.

If one of the stop conditions of the CDA is met, the market is closed. After the CDA ends, the farmer gets the possibility to agree on contracts on the market for rapeseed for food purposes. However, as indicated at the beginning of this section, rapeseed is unattractive from a pure financial point of view. Above that, this market is an outlet after a failed participation in the CDA, which negatively affects the negotiation position of these farmers. To capture these unattractive elements, the model assumes that the buyers in the food market are price takers, but farmers are only able sell their crops at their price floor. After the rapeseed market for food purposes is closed, the entire process depicted in Figure 4.4 is repeated for the remaining years.

Lastly, it is important to notice that in the model the rapeseed market is separated in a market for food purposes and a market for energy purposes. In this final part of this section this assumption is evaluated. To address food surpluses in Europe, the EU imposed a percentage of arable land to be set aside. This policy is called the set-aside scheme. This policy was part of a reform of the Common Agricultural Policy (CAP, a system of subsidies for European farmers) in 1992. The set-aside scheme allowed to grow crops for non-food purposes (like biodiesel) on the set-aside land, while remaining eligible for subsidies. In Europe, Germany is the main producer of rapeseed. During the years 1990-2000 the German government split the rapeseed market in two separate markets: a rapeseed for food market and and a non-food rapeseed market [Berghout, 2008]. It was forbidden for farmers to sell rapeseed grown on set-aside land on the food market (at the risk of serious penalties).

However, since this period many changes took place with respect to agricultural policy. For example, in 2003 the decoupling of subsidies from agricultural production was started, to let farmers respond more strongly to prevailing market conditions. Hereto, the single payment scheme (SPS) and later on the basic payment scheme (BPS) were introduced. With these reforms arable land instead of production started to play an important role. Above that, the set-aside scheme was abolished in 2008 (with the CAP Health Check). In other words, these (and many other) changes direct the European agricultural markets to a more liberalised condition. To conclude, the modelled strict separation of the rapeseed markets for food- and energy purposes does not hold true anymore. The separation is still incorporated in the model, because it is less demanding to implement. In addition, this assumption is considered suitable, since trading volumes of rapeseed for energy purposes are much larger than the trading volumes of rapeseed for food purposes (see Appendix B). In this perspective, the prices of rapeseed are driven by the buyers and sellers of rapeseed for energy purposes.

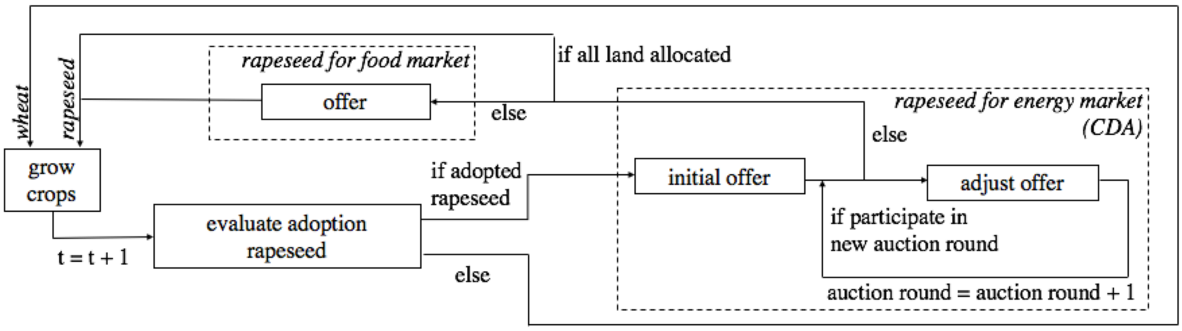

Figure 4.4: Global overview decision cycle farmers in EU-28 (only holds true for those farmers not allocated to food market)

4.5.2. BIODIESEL PRODUCERS

In this section the biodiesel producers (i.e. biorefineries or biodiesel plants) in the model are treated. Firstly, the biodiesel producers in EU-28 are discussed, followed by the biodiesel producers in Indonesia and Malaysia.

EU-28

In this section the biodiesel producers situated in EU-28 are considered. The main properties of the biodiesel producers are (*continued on next page*):

- location
- capacity [$ton_{biodiesel}$ / year]
- plant type [-]
- cluster [#]
- conversion factor rapeseed [$L_{biodiesel}$ / $t_{rapeseed}$]
- conversion factor palm oil [%]
- money received and spend [US$]
- biofuel overproduction [ton]
- oil extraction cost [US$/$L_{biodiesel}$]

- conversion cost [US$/$L_{\text{biodiesel}}$]
- strive capacity utilization [%]
- strive share palm oil [%]

In the model two types of biodiesel producers are distinguished: single-feedstock plants and multi-feedstock plants. The first part of this section will clarify why this is the case. A single-feedstock plant is able to process only one type of feedstock. Contrary, a multi-feedstock plant is able to process multiple types of feedstock. This makes multi-feedstock plants more flexible than single-feedstock plants. For example, multi-feedstock plants are able to switch to the cheapest type of feedstock in case price levels change. However, multi-feedstock plants are more difficult to design and more costly to operate [Sims et al., 2008]. An other important difference is that single-feedstock plants can only process half or fully refined vegetable oils with low free fatty acids contents, while multi-feedstock plants (via additional reactions steps) are able to process feedstock with higher free fatty acids contents (like palm oil, waste oil and animal fats) [Bacovsky et al., 2007].

The distinction between single- and multi-feedstock plants is important, because the model considers two types of feedstock: rapeseed and palm oil (see section 4.2). In addition, at the beginning of the German biodiesel industry (the main biodiesel producer in EU-28), the major part of the biodiesel plants were single-feedstock plants (predominantly processing rapeseed oil), but over time the share of multi-feedstock plants increased [Berghout, 2008]. In other words, not all biodiesel plants in EU-28 are able to process palm oil. Therefore, in the model a distinction is made between single- and multi-feedstock biodiesel plants. Each biodiesel plant is assigned a type. Only the multi-feedstock biodiesel plants are assumed to be able to process palm oil. The share of multi-feedstock plants is assumed to be 43.2% in EU-28 (extrapolated from [Berghout, 2008]).

The objective of the biodiesel producers is to maximize profits. A global overview of the decision cycle performed by the biodiesel producers in EU-28 is given in Figure 4.5. A biodiesel producer can participate in three different markets: two markets for feedstock (rapeseed and palm oil) and one market for biodiesel. Firstly the biomass markets will be discussed, followed by the biodiesel market.

The decision cycle of biodiesel producers starts with an evaluation of the financial performance and a CBA. Firstly the evaluation of the financial performance will be discussed, followed by the CBA. As will be shown in section 4.6.3, there tends to be overcapacity for the production of biodiesel in EU-28. In other words, operating a biodiesel plant at maximum capacity appears to be rather an exception than a rule. This demands modelling the decision of biorefineries to increase, maintain or decrease the desired capacity utilization of their plant. In the model this decision is based on two equations, which are self-made due to the lack of literature on this topic.

Firstly, the overproduction of biodiesel during previous year is considered, see Equation 4.4. In this equation $c_{t,1}$ denotes the capacity utilization to strive for during time step t ($0 \leq c_{t,1} \leq 1$), c_{t-1} the capacity utilization during time step $t-1$ and o_{t-1} the overproduction during time step $t-1$. In other words, the capacity utilization is adjusted for, if any, overproduction. Secondly, the costs and benefits of the operations of previous year are evaluated, see Equation 4.5. In this equation $c_{t,2}$ denotes the capacity utilization to strive for during time step t ($0 \leq c_{t,2} \leq 1$), c_{t-1} the capacity utilization during time step $t-1$, e_{t-1} the total expenditures during time step $t-1$, r_{t-1} the total revenues during time step $t-1$, p the propensity to exploration ($p \geq 0$) and T the final time step of the simulation. In the exponent of Equation 4.5 the ratio of total expenditures and total revenues is incorporated. If the financial result is positive (i.e. $r_{t-1} > e_{t-1}$) this will form a positive incentive to increase capacity utilization and vice versa. The propensity to exploration p captures how strongly a biorefinery reacts to the financial results of past year. If $p > 1$, a biorefinery will react more than proportional to its financial results in adjusting its capacity utilization, if $p < 1$ a biorefinery will react less than proportional. The final capacity utilization to strive for (c_t) is set by taking the minimum of Equation 4.4 and 4.5, as denoted in Equation 4.3.

$$c_t = \min\left\{c_{t,1}, c_{t,2}\right\} \qquad \text{for } t \in \{1,2,\ldots,T\} \tag{4.3}$$

where $c_{t,1}$ and $c_{t,2}$ are defined as

$$c_{t,1} = c_{t-1} - o_{t-1} \tag{4.4}$$

$$c_{t,2} = c_{t-1}^{\left\{\frac{e_{t-1}}{r_{t-1}}\right\}^p} \tag{4.5}$$

Besides an evaluation of the financial performance, a biodiesel producer also performs a CBA at the beginning of the decision cycle. A biodiesel producer in EU-28 has two possibilities for buying feedstock: rapeseed from local farmers (those inside the cluster) or import palm oil from Indonesia/Malaysia. To determine which option is most profitable, each biodiesel producer performs a cost benefit analysis (CBA, not to be confused with CDA). In the CBA all (expected) cost and (expected) benefits are compared. The template used in the model to perform this CBA is given in Table 4.2.

Table 4.2: Template of CBA performed by biorefineries (units: US\$/$L_{biodiesel}$)

	rapeseed	palm oil
benefits		
selling biodiesel		
selling meal		
selling glycerin		
subsidy		
cost		
purchase cost feedstock		
oil extraction cost		
conversion cost		
transport cost feedstock		
transport cost biodiesel		
import tariff feedstock		
net benefit		

From this CBA follows an (expected) net benefit for each type of feedstock. Based on this result, the biodiesel producer sets a strive share of palm oil in their feedstock. Based on the ratio of the expected profit margin while using rapeseed as feedstock and while using palm as feedstock, the strive share of palm oil is set (see Equation 4.6). In this equation $s_{p,t}$ denotes the share of palm oil at time step t ($0 \leq s_{p,t} \leq 1$), p_r the expected profit margin while using rapeseed as feedstock, p_p the expected profit margin while using palm oil as feedstock, p the propensity to exploration ($p \geq 0$) and T the final time step of the simulation. Similarly, the propensity to exploration p captures how strongly a biorefinery reacts to the expected financial results. If $p > 1$, a biorefinery will react more than proportional to the expected financial results in adjusting the strive share of palm oil, if $p < 1$ a biorefinery will react less than proportional. Please note that p is assumed to take the same value as for determining the strive capacity utilization (see Equation 4.5). Also note that for a single-feedstock plant this share will always be 0%. The share of rapeseed oil as feedstock is given by $1 - s_{p,t}$.

$$s_{p,t} = s_{p,t-1}^{\left\{\frac{p_r}{p_p}\right\}^p} \qquad \text{for } t \in \{1,2,\ldots,T\} \tag{4.6}$$

After the evaluation of the financial performance and the CBA are finished, the biodiesel producer starts participating in the commodity markets. The rapeseed market is modelled as a CDA. In the CDA the biodiesel producer interacts with other biodiesel producers and farmers in its cluster. The procedure for a biodiesel producer in participating in a CDA is the same as for a farmer. For a description of this procedure, the reader is referred to section 4.5.1. As indicated in section 4.3, the price of palm oil is considered exogenous. Therefore, no further actions are required by the biodiesel producers for buying palm oil.

Now the feedstock is retrieved, a biorefinery turns over to producing biodiesel. All the feedstock in possession of a biorefinery is converted to biodiesel. Next, the biorefinery starts interacting with the distributors/retailers. As clarified and described in section 4.3, this interaction is modelled as an one-shot auction. In this market all offers arrive simultaneously and there is one uniform market-clearing price (or equilibrium price) for all the participating actors, which is set by an external institution.

The offer of a biorefinery is formulated as follows. The quantity offered by a biorefinery contains of all biodiesel produced. In the model no storage facilities are present. That is to say, if any biodiesel is remaining after the market is closed, it is considered lost. The price of the offer is a price floor plus a random profit margin (within certain limits, in line with what is usual in this sector). The price floor of the biorefineries is determined by the sum of the total (expected) benefits and cost, in a similar way as the CBA is performed. In other words, if a biorefinery would sell its biodiesel at the price floor, the profit margin is 0%. For the subsequent year, this entire process described in this section is repeated.

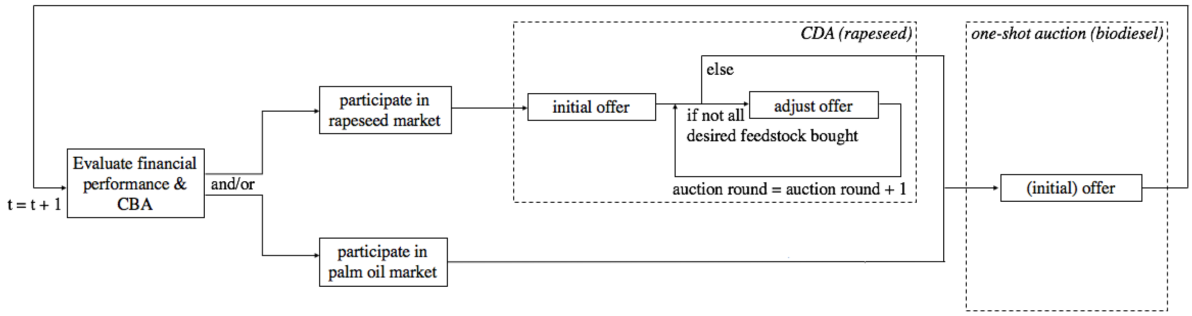

Figure 4.5: Global overview decision cycle biodiesel producers in EU-28

INDONESIA/MALAYSIA

The decisions performed by the biorefineries situated in Indonesia and Malaysia is similar to those in EU-28 but less extensive. Since the feedstock used in these countries to produce biodiesel is almost exclusively palm oil (see Appendix C), it is assumed that all biodiesel plants are able to process palm oil. At the same time, this is the only type of feedstock a biorefinery can buy. For simplicity, it is also assumed that all plants directly buy palm oil (and thus do not buy and process palm fruit) and the supply of palm oil is always sufficient to cover demand for biodiesel production.

The objective of the biodiesel producers is to maximize profits. The decision cycle of biodiesel producers starts with an evaluation of the financial performance. In the same way as for the biorefineries in EU-28, a biorefinery makes a decision to increase, maintain or decrease the desired capacity utilization of their plant. Different from the biorefineries in EU-28, the biorefineries in Indonesia and Malaysia make a distinction between biodiesel for the domestic- and foreign market. In the model it is assumed that the biodiesel producers in Indonesia and Malaysia firstly fulfil domestic demand and the remaining production capacity is available for export. In literature, numerous indications are found that support this assumption (see e.g. USDA-FAS [2011] and USDA-FAS [2012]). For example, it is found that, similar to EU-28, biodiesel blending mandates (supported with sanctions) are active in Indonesia and Malaysia. Above that, the Indonesian Ministry of Energy and Mineral Resources (MEMR) actively restricts the export of biodiesel to secure supplies to the state-owned fuel company Pertamina. Depending on the magnitude of domestic demand, this restriction is relaxed. As indicated in the conceptual model (see section 4.3), the domestic demand for biodiesel is considered exogenous.

After producing biofuel, the biorefineries start interacting with the distributors/retailers. As clarified and described in section 4.3, this interaction is modelled as an one-shot auction. In this market all offers arrive simultaneously and there is one uniform market-clearing price (or equilibrium price) for all the participating actors, which is set by an external institution.

The offer of a biorefinery is formulated as follows. The quantity offered by a biorefinery contains of all biodiesel produced. In the model no storage facilities are present. That is to say, if any biodiesel is remaining after the market is closed, it is considered lost. The price of the offer is a price floor plus a random profit margin (within certain limits, in line with what is usual in this sector). The price floor of the biorefineries is determined by the sum of the total (expected) benefits and cost, in a similar way as the CBA is performed. In other words, if a biorefinery would sell its biodiesel at the price floor, the profit margin is 0%. For the subsequent year, this entire process described in this section is repeated.

4.5.3. DISTRIBUTORS/RETAILERS

In this section the distributors/retailers are considered. As clarified in section 4.3, the distributors/retailers are modelled as one actor. The objective of the distributors/retailers is to maximize profits. In this section firstly the interaction between the distributor/retailers and consumers is discussed, followed by the market in which the distributors/retailers buy biodiesel. A global overview of the decision cycle performed by the distributors/retailers in EU-28 is given in Figure 4.6.

In the model there is no interaction between the distributors/retailers and the end-users of the biodiesel. For simplicity, the distributors/retailers are obliged to fulfil the demand for diesel in EU-28. This demand is assumed to be known. However, it is up to the distributors/retailers how this demand is fulfilled, by delivering pure fossil diesel or a certain blend of of of fossil diesel and biodiesel. After discussing the CBA, more details on this will be given in this section.

There is a market for domestic produced biodiesel and there is a market for foreign produced biodiesel. At the beginning of the decision cycle both markets are evaluated. The distributors/retails can only participate in one market at a time and the market that is considered most profitable is addressed first. To determine which option is most profitable, the distributors/retailers perform a CBA. In the CBA all (expected) cost and (expected) benefits of domestic biodiesel (originating from EU-28) and foreign biodiesel (originating from Indonesia/Malaysia) are compared. The template used in the model to perform this CBA is given in Table 4.3.

Table 4.3: Template of CBA performed by distributors/retailers (units: US$/$L_{\text{biodiesel}}$)

	domestic	foreign
benefits		
selling (bio)diesel		
subsidy		
cost		
purchase cost biodiesel		
international transport cost biodiesel		
local transport cost biodiesel		
import tariffs biodiesel		
net benefit		

The next step for the distributors/retailers is to participate in the biodiesel markets. As described in section 4.3, both markets are modelled as one-shot auctions. The distributors/retailers buy all biodiesel below a certain maximum price. For this setting this maximum price two criteria are considered to achieve the objective of profit maximization. In section 4.6.5 biodiesel related policies in EU-28 will be described. One of these policies is a blending mandate. To enforce the blending mandate, penalties are imposed. These penalties are necessary, because in general biofuels are more expensive than their fossil counterparts. So from a pure financial perspective, there is no incentive for distributors/retailers to perform blending. In the model, a financial penalty will be imposed in case the blending mandate is not fulfilled.

The distributors/retailers approach this sanction as follows. Assuming equal energy content of fossil diesel and biodiesel, the distributors/retailers have no price preference in case the price of biodiesel equals the price of fossil diesel plus the penalty. In case the price of biodiesel is less than the price of fossil diesel plus the penalty, biodiesel is preferred over fossil diesel for retailing. Similarly, in case the price of biodiesel is higher than the price of fossil diesel plus the penalty, fossil diesel (and the associated penalty) is preferred over biodiesel for retailing. This is modelled by setting the maximum price distributors/retailers are willing to pay for biodiesel equal to the producer price of fossil diesel plus the penalty. In case fossil diesel is preferred, it is assumed that the demand for fossil diesel can always satisfied. In the model a correction is applied for the fact the energy content of biodiesel is lower in comparison with fossil diesel. In the model it is assumed that the energy content of biodiesel is 90% of that of a same amount of fossil diesel [Yusuf et al., 2011].

As already indicated, the expected most profitable market is addressed first. This means that after addressing the "first" market (say market A), a "second" market (say market B) can be addressed. Though both markets are physically separated, it is assumed that there are limitations on the price spread between both markets. To realize this, distributors/retailers need to perform strategic decision making. This is illustrated by means of the following example.

Consider the case that distributors/retailers firstly address the Indonesian/Malaysian biodiesel market. It is expected that the biodiesel price on the EU-28 market will amount to 0.90US$/L and the biodiesel price on the Indonesian/Malaysian market will amount to 0.75US$/L. The ad-valorem import tariff on importing biodiesel originating from Indonesia/Malaysia into EU-28 is assumed to be 10%. All other cost are neglected. If expectations are met, the biodiesel on the Indonesian/Malaysian market is cheaper than biodiesel on the EU-28 market. However, if prices of biodiesel on the Indonesian/Malaysian market are higher than the expectations, the distributors/retails could face a problem. For example, if it turns out that there hardly any offerings on the Indonesian/Malaysian market below 0.85US$/L, it is unlikely that the Indonesian/Malaysian market is still more profitable than the EU-28 market (note that the prices on the EU-28 biodiesel market only become known upon participation in that market).

In the model this problem is "solved" by the distributors/retailers by means of the following (basic) strategy. They consider a second criterion for the maximum price to pay for biodiesel during participation in market A. This second criterion is the expected price level of market B, corrected for any tariffs. If the demand is not met, the remaining demand is directed to market B. In the example above, the distributors/retailers would not pay more than (0.90 - 0.09 =) 0.81US$/L on the Indonesian/Malaysian biodiesel market. In other words, if during participation in market A it is expected that market B will be more profitable, the strategy of distributors/retails is to prefer market B. After addressing market B, it is not possible to return to market A. It is recognized that this is a rather crude configuration, but it creates the desired interconnection between both markets while both markets are still physically separated.

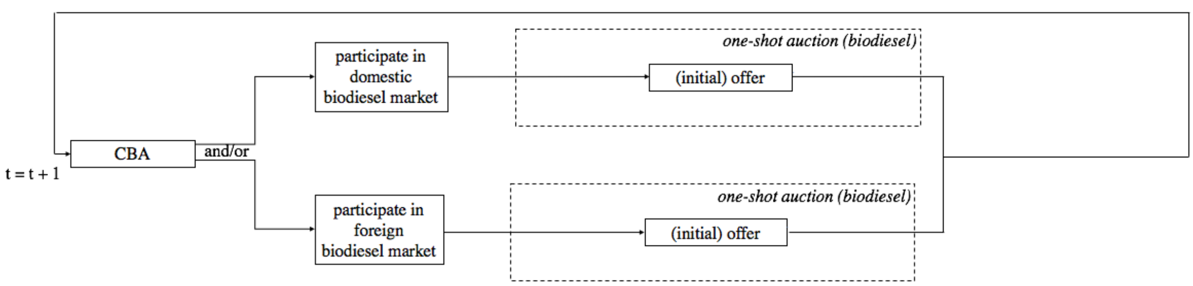

Figure 4.6: Global overview decision cycle distributors/retailers in EU-28

4.6. QUANTIFICATION MODEL PARAMETERS

4.6.1. GENERIC MODEL ELEMENTS

ECONOMIES OF SCALE

In literature, various values can be found for the scale factor α (see Equation 4.1). A rule of thumb for estimating α is the value 0.6 (see Tribe and Alpine [1986]). However, in literature also some values for specific applications can be found. According to IRENA [2013], the scaling factor for biodiesel plants is estimated to lie between 0.65 and 0.89. Similarly, de Wit [2011] states that scale factors typically range between 0.6 and 0.9.

However, the information found in literature is not complete. For example, no values for scale factors applicable in agriculture are found. Besides that, no base values are found for production output o_2 and production cost c_2. Above that, the difference between lower and upper estimates of α do significantly affect the approximation of c_1. To overcome this uncertainty, the following approximation method is applied.

With data on the number of farmers (see section 4.6.2) and annual total production of rapeseed and wheat in EU-28 (from USDA-FAS [2017b]), a base production for rapeseed and wheat is derived by determining the average production per farmer. For biorefineries, the data on the production capacities of biorefineries (see section 4.6.3 and 4.6.4) is used to derive the average production capacity. This value is set as the base biodiesel production. The scale factors for farming and biorefineries are derived by assessing values found in literature. During this process it is evaluated whether the resulting cost and benefits were deemed to be plausible. The results are listed in Table 4.4. The base cost of production are not given here, but are described in section 4.6.2 and section 4.6.3/4.6.4 for farmers and biorefineries respectively.

Table 4.4: Parameter values applied for modelling economies of scale

Parameter	Value	Units
base biodiesel production EU-28	$142 * 10^3$	[ton]
base biodiesel production Indonesia/Malaysia	$168 * 10^3$	[ton]
base rapeseed production	23.3	[ton]
base wheat production	23.3	[ton]
economies of scale factor biorefineries	0.80	[-]
economies of scale factor farming (EU-28)	0.80	[-]

CONSUMPTION AND PRICES OF COMMODITIES

In the conceptual model (see section 4.3) it is described that the consumption and prices of a number of commodity are considered exogenous. In this section, the prices of wheat, palm oil and fossil diesel that are applied in the model are in given in Figure 4.7 to 4.9. Above that, the consumption of diesel in EU-28 is given in Figure 4.10. The consumption of biodiesel in Indonesia/Malaysia can be found in Appendix C.

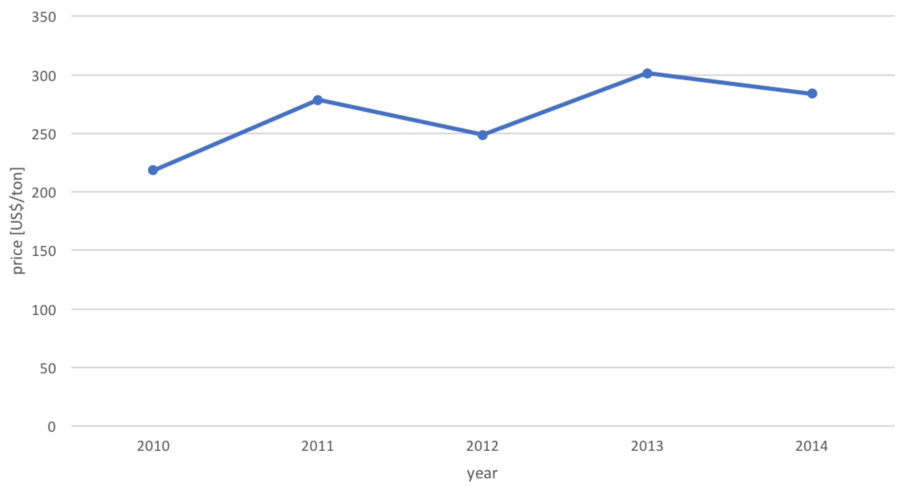

Figure 4.7: Price wheat in period 2010-2014 (no. 2 hard red winter wheat, ordinary protein, F.O.B. USA) [OECD, 2017]

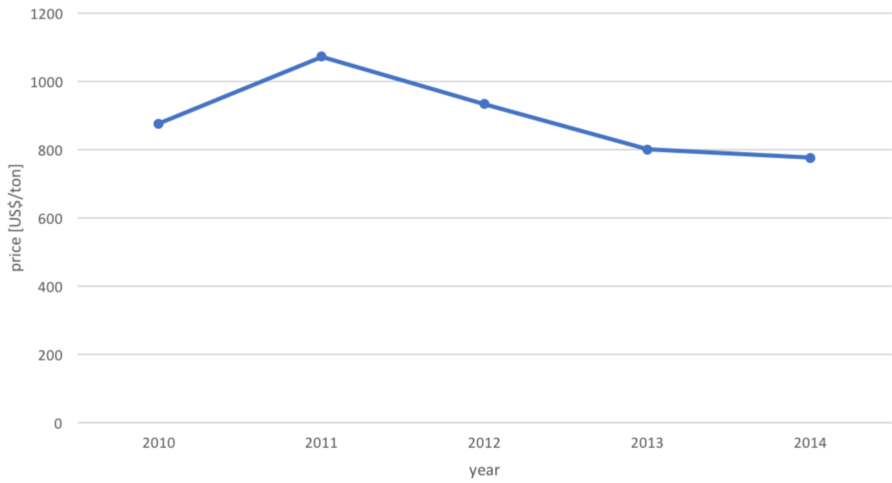

Figure 4.8: Price palm oil in period 2010-2014 (crude, F.O.B. Indonesia/Malaysia), derived from Palm Oil Analytics [2017]

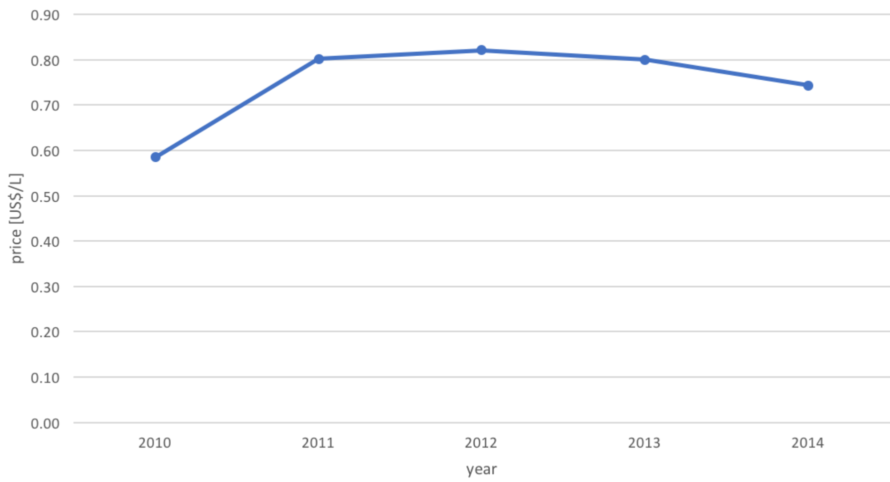

Figure 4.9: Price fossil diesel in period 2010-2014 (no. 2 wholesale price by refiners), derived from [EIA, 2017]

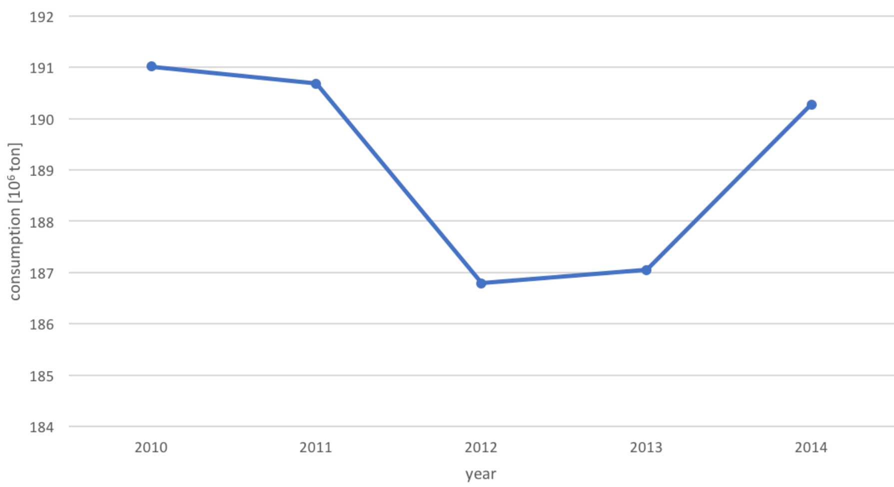

Figure 4.10: Consumption diesel in EU-28 in period 2010-2014 [EIA, 2017]

TRANSPORT COST

In section 3.2.3 it is explained that transport cost play an important role in the biofuel supply chain. In this section an overview of transport cost in the biofuel supply chain is given. This overview is divided in two parts: local transport of biomass and international transport of biofuel and vegetable oil.

An overview of the (local) transport cost of biomass is given in Table 4.5. This table shows that the transport cost varies among sources and among mode of transport. By taking the average of these sources and correcting for the fact that in the model it is assumed that all biodiesel plants are integrated plants (as explained in section 4.4.1), the transport cost of biomass is estimated on 0.06US$/(ton km) in the model. To create a commodity with equal delivery conditions, one transport cost is determined for each cluster. This transport cost is based on the average distance from farmer to biorefinery. Subsequently, this transport cost holds true for every transaction within the cluster. This means that smaller clusters have a cost advantage over larger clusters in terms of transport cost.

Table 4.5: Transport cost biomass

Mode of transport	Cost [US$/(ton km)]	Source
Not specified	0.12	Zhang et al. [2016]
Truck	0.10	Sims et al. [2008]
Rail	0.07	Sims et al. [2008]
Barge	0.04	Sims et al. [2008]
Not specified	0.13	Eksioglu et al. [2015]
Truck	0.137	Khanna et al. [2009]
Rail	0.028	Khanna et al. [2009]

The second topic considers the cost associated with international transport of biofuel and vegetable oils. In literature little information is found on these cost. Yusuf et al. [2011] estimates that it costs 70US$/ton to transport palm oil from Malaysia to EU-28 and 50 US$/ton to transport soybean oil from the U.S. to EU-28. To get a better view on the transport cost of palm oil from Indonesia/Malaysia to EU-28, the price history of two commodities are compared. These commodities are (crude) palm oil FOB Belawan/Dumai (Indonesia) and (crude) palm oil CIF Rotterdam (Netherlands). FOB stands for free on board and CIF stands for cost, insurance and freight. By calculating the difference between the price of these commodities, the cost of insurance and transport of palm oil from Indonesia to EU-28 can be approximated. Price series of both commodities for the period January 2010 to May 2017 are compared (originating from YCharts [2017] and Palm Oil Analytics [2017]) and the average spread turns out to be 46.6US$/ton (or 0.04US$/L). This value is in line with the values reported by Yusuf et al. [2011]. If one considers that the overseas distance between Dumai and Rotterdam is over 15 000 kilometre, it becomes clear that this international transport of vegetable oil is remarkably cheap in comparison with the local transport of biomass. Since Indonesia and Malaysia are geographically situated close to each other, in the model the same derived transport cost is associated with the transport of palm oil and biodiesel from Indonesia and Malaysia to EU-28.

4.6.2. FARMERS

CROP YIELD AND LOCATION

In this section two properties of farmers will be discussed. Firstly the crop yields will be discussed, followed by the geographical position. Farmers may grow crops on their land. However, the yield is dependent on many different factors, like crop type, soil type and climate conditions. In a collaboration between the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA), the GAEZ model was developed (see IIASA/FAO [2017]). GAEZ stands for Global Agro-Ecological Zones. The GAEZ model takes into account various data sources to derive a maximum potential and attainable crop yields for a specific crop and location. The model takes into account climatic conditions data (like precipitation, temperature, wind speed, sunshine hours and relative humidity), soil data, terrain data and crop data [IIASA/FAO, 2012]. Based on a user-specified water supply (e.g. rain fed or irrigation) and agricultural input level (including e.g. equipment, pesticides and nutrients used) the model computes the corresponding yield, typically at 5 arc-minute and 30 arc-second resolutions. Hereto, amongst others, use is made of mean climatic data for a period of 30 years. For a full description of the GAEZ model, the reader is referred to the model documentation (see IIASA/FAO [2012]). An example of the output from the GAEZ model is shown in Figure 4.11. This map shows the maximum potential yield [ton/ha] for rain fed rapeseed with a high input level in Europe.

The data retrieved from the GEAZ model is imported in NetLogo and assigned to the two dimensional grid of "patches" in the NetLogo world. Given the location and amount of arable land of a farmer and assuming a circular area, the (NetLogo) model computes an average yield. This value is subsequently associated with the corresponding farmer when crops are grown. In the GAEZ model it is specified that the crops are rain fed and a high input level is assumed. The latter assumption corresponds to a farming system which is mainly market oriented with commercial production is a management objective [IIASA/FAO, 2017]. In addition, production is fully mechanized, has a low labour intensity and uses nutrients, chemical pest, disease- and weed control in an optimal way. This specification is chosen because it is considered to represent best the prevailing situation in Europe. In section 4.2 it is stated that the model only considers two crop types for farmers in Europe: wheat and rapeseed. To get an impression of the corresponding yields, the area weighted average yield is determined for EU-28. This value amounts 2.6 ton/ha for rapeseed and 6.3 ton/ha for wheat.

The second property of farmers discussed in this section is their location. Since no database is available with the location of every farmer, their locations are assigned randomly. However, two restrictions are applied. The first restriction states that the probability that farmers are situated on a certain patch is proportional to the sum of the yields associated with that patch. The other restriction states that a farmer can only be situated on a patch which has at least one yield (either rapeseed or wheat) larger than zero. During model development it is found that both restrictions result in more realistic yields than assigning the farmers to a pure random location.

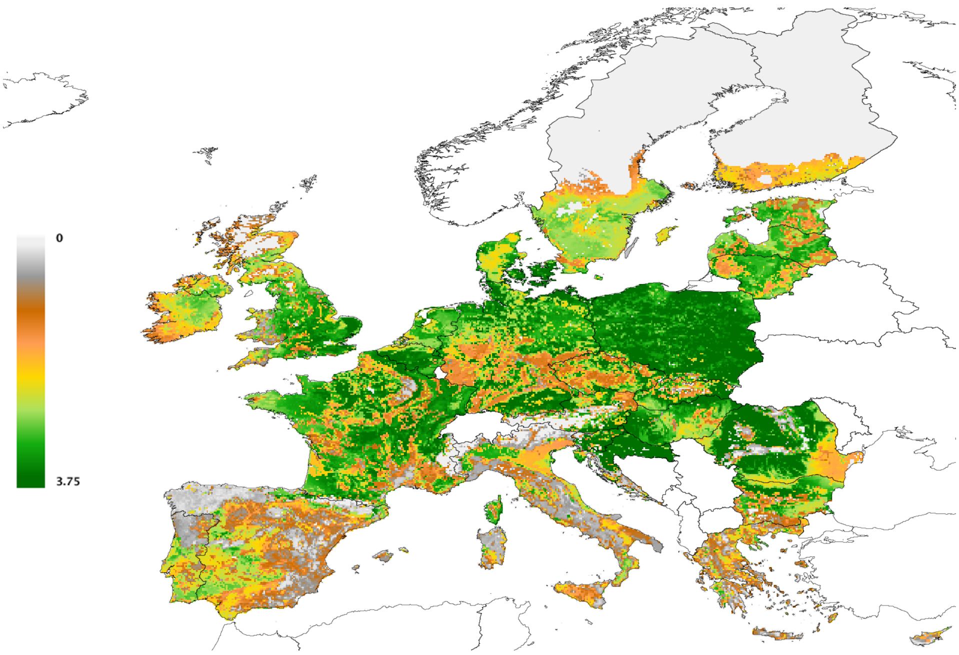

Figure 4.11: Example of data retrieved from GAEZ model: maximum potential yield [ton/ha] for rain fed rapeseed with a high input level in EU-28

SIZE OF ARABLE LAND AND INITIAL ALLOCATION

Farmers have different sizes of arable land. In Table 4.6 the number of farmers in EU-28 with a certain size of arable land is listed. When farmers are created in the model, they are assigned a size of arable land by sampling from Table 4.6. This sampling takes place in two steps. Firstly, one of the nine categories of arable land is selected. The probability that a certain category is selected is proportional to the number of farmers within that category in comparison the total number of farmers with arable land. Secondly, a random number is selected within the boundary values of that category. This number is assigned to the arable land of the farmer. The initial area allocated to rapeseed is set to $6.66*10^6$ ha and the initial area allocated to wheat is set to $26.3*10^6$ ha (derived from USDA-FAS [2017b] for year 2009). This means that the total arable land amounts to $33.5*10^6$ ha.

Table 4.6: Number of farmers and size of arable land in EU-28, derived from Eurostat [2017]

arable land [ha]	number of farmers in year			
	2005	2007	2010	2013
> 0 - 1	3 787 540	3 498 840	2 907 830	2 474 190
1 - 1.9	1 765 970	1 701 840	1 350 920	1 234 030
2 - 4.9	2 030 200	1 965 240	1 534 260	1 442 680
5 - 9.9	990 770	977 990	825 390	773 420
10 - 19.9	653 610	628 180	569 570	549 730
20 - 29.9	265 370	256 360	243 660	238 730
30 - 79.9	455 940	443 680	435 810	431 040
80 -149.9	149 050	150 860	156 850	160 000
150 or over	93 440	98 320	106 320	112 340

PRODUCTION COST

In general, data on production cost for farmers is scarce in literature. However, the research of Toft [2011] provides some interesting information. In this research eight farms throughout EU-28 are followed for a period of three years. For each of these farms a build up of the cost of production for both wheat and rapeseed is traced. The cost of production includes direct cost (like pesticides, fertilizer and seeds), operating cost (like labour, machinery and energy), buildings cost, land cost and other cost. From these numbers it appears that for both wheat and rapeseed, the cost for fertilizer, machinery and land are important determinants for the cost of production.

To make the data more suitable for the model, use is made of the data from Ericsson et al. [2009]. These authors determined cost levels for growing crops for different regions in Europe. By combining these cost levels with the data from Toft [2011], production cost for growing rapeseed and wheat in different parts in Europe can be determined. The results are listed in Table 4.7. This table shows that there is a difference in cost of production between rapeseed and wheat: rapeseed is more expensive to grow than wheat. The table also shows that Northern Europe is the most expensive region to grow these crops, while Eastern Europe is the least expensive region. In the model, the values listed in Table 4.7 are assigned to the production cost of the farmers situated in the corresponding country.

Table 4.7: Production cost rapeseed and wheat for different regions in Europe, authors' own calculations based on Toft [2011] and Ericsson et al. [2009], used exchange rate: 0.75US$/€

		production cost [US$/ton]	
Region	Countries	rapeseed	wheat
Northern	Sweden, Denmark and Finland	343	170
UK and Ireland	UK and Ireland	285	122
Western	Belgium, the Netherlands, Germany and France	245	111
Alps	Austria	238	108
Southern	Greece, Italy, Portugal and Spain	231	105
Eastern	Estonia, Latvia, Lithuania, Poland, Czech Republic, Slovakia, Hungary, Slovenia, Romania, Bulgaria and Croatia	229	105

ADOPTION THRESHOLD

In section 4.5.1 it is explained that farmers will only start growing rapeseed if two conditions are met. One of these conditions states that the local adoption of rapeseed must exceed the adoption threshold of the farmer. The adoption thresholds assigned to the farmers are sampled from a normal distribution with a mean of 20% and a standard deviation of 10.2% (in line with the specifications of Rogers [1995]). The adoption thresholds are assigned randomly. When the farmers are initialized, the initial land allocated to rapeseed is assigned to those farmer with the lowest adoption thresholds, because it is assumed that these farmers are the first adopters and thus their adoption threshold is most "easily" met.

4.6.3. BIODIESEL PRODUCERS EU-28

In section 4.5.2 it is stated that the objective of biodiesel plants is to maximize profits. However, various factors may influence the profitability of a biodiesel plant and some factors are more important than others. In Figure 4.12 the most important factors influencing profitability of a biodiesel plant are shown. In this figure it can be seen that biodiesel sales price is the most important factor, followed by plant yield, feedstock (oil) price and glycerol sales price. This overview is taken into account to focus the scope of the literature review with respect to the biodiesel plant (production cost). This section starts with information on location and production capacity. Subsequently conversion efficiency and conversion cost are discussed. The section is concluded with information on by-product credits.

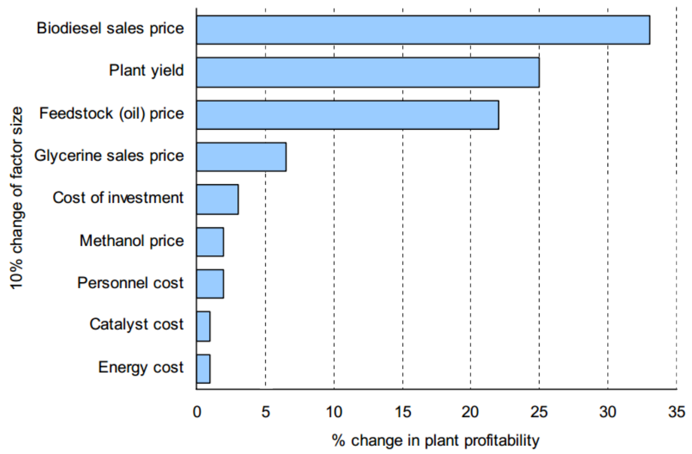

Figure 4.12: Influence various factors on profitability of a biodiesel plant [Meyer, 2007]

LOCATION, PRODUCTION CAPACITY AND FEEDSTOCK

Two important properties of the biodiesel plants are their location and production capacity. Unfortunately, no complete data set for these properties is found available. However, by combining data from various sources, a fairly complete image of the biodiesel plants in EU-28 is retrieved. The result is shown in Figure 4.13. These data set corresponds to 167 biodiesel plants with a total production capacity of $23.6*10^6$ ton/year. A shortfall of the created data set is that the year of start of operation is not specified, but the main part of the data set represent the situation from 2010 onwards. On the data set two checks are performed. Firstly, the production capacities are compared with the production quantities per country as reported by the European Biodiesel Board [2017]. These numbers appear to be in line. Secondly, in Appendix C the development of the biodiesel production capacity in EU-28 is given. This table shows that biodiesel production capacity varied between 23-26 $*10^6$ ton/year in the period 2010-2015. So again, these numbers appear to be in line.

Garlaschi [2011] states that of all the biodiesel plants in EU-28 there are only 80 active producing plants and the capacity utilization is about 50%. In other words, there tends to be overcapacity for the production of biodiesel in EU-28. This finding is confirmed many times throughout literature (e.g. Hamelinck et al. [2011], Lamers et al. [2011], Peters et al. [2012], van Grinsven et al. [2015] and USDA-FAS [2016a]). This is taken into account in the model by specifying the initial capacity utilization. The mean initial capacity utilization is set to 28.7%. This number is derived by considering data presented by USDA-FAS [2016a] and correcting for the fact that only two types of feedstock are considered and the total production capacity. The mean initial share of palm oil as feedstock is set to 8.0%. Like previous parameter, this number is derived by considering data presented by USDA-FAS [2016a] and correcting for the fact that only two types of feedstock are considered. Lastly, in the model the data retrieved from the GAEZ model (see section 4.6.2) is matched with the locations of the biorefineries by means of the Geographic Information System (GIS) extension of NetLogo.

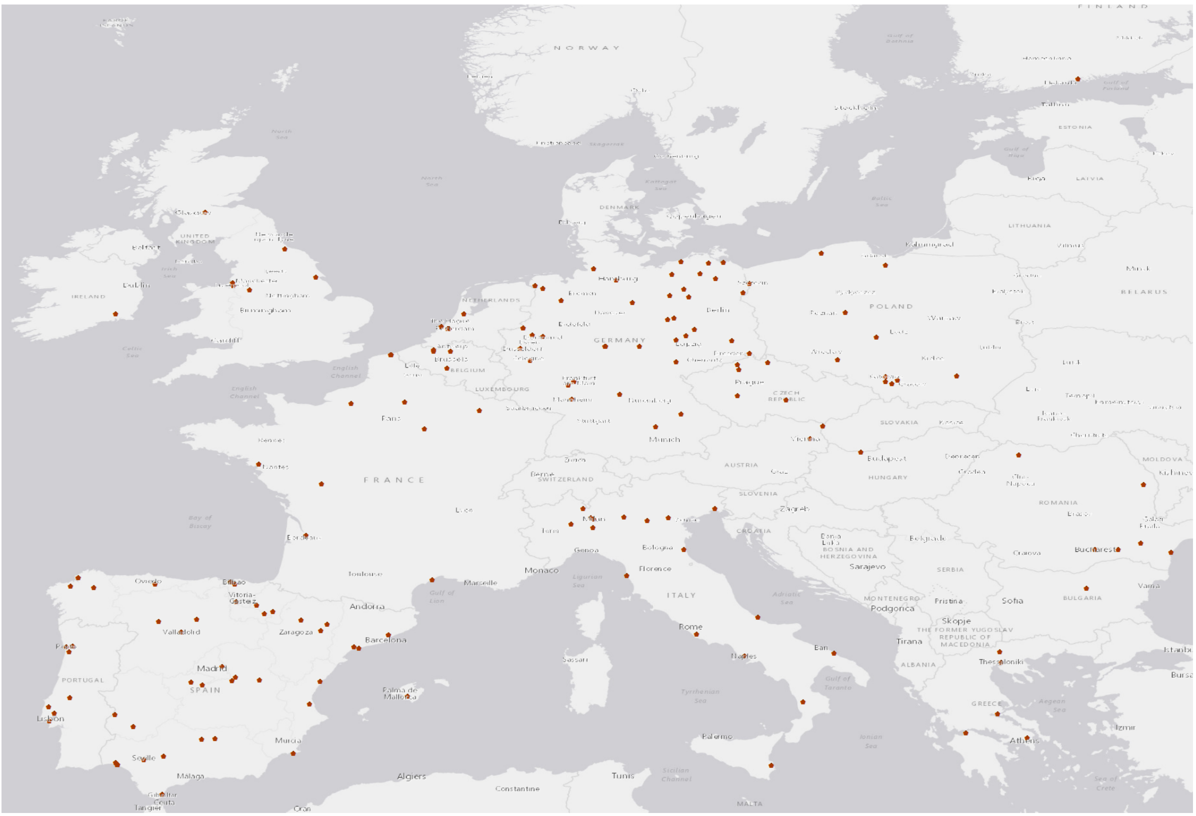

Figure 4.13: Map of biodiesel plants in EU-28

CONVERSION EFFICIENCY

The conversion efficiency (sometimes also referred to as production efficiency or biofuel yield) refers to the number of litres biofuel retrieved from one ton of feedstock. In Table 4.8 a list of conversion efficiencies is given for the main feedstock used in EU-28 to produce biodiesel (see Figure 4.1). This table shows that the conversion efficiency of rapeseed is much higher than the conversion efficiency of soybean and oil palm. On the other hand, the conversion efficiency of soybean and oil palm is similar. If one considers that in general the conversion efficiency of vegetable oils to biodiesel is very close to 100% (see e.g. Peters et al. [2012]), it can be seen that the data presented in Table 3.1 confirms the data presented for the crops rapeseed and soybean presented in Table 4.8. None of the sources listed in Table 4.8 specify explicitly which technology is used for biodiesel production. However, since transesterification is the most common method to convert vegetable oils into biodiesel today [Rajagopal and Zilberman, 2007], it is assumed that all values correspond to transesterification. The values listed in Table 4.8 are assigned to the biodiesel plants in the model. By determining an average value of the numbers found in literature, a conversion efficiency of 427 $L_{biodiesel}$/ton is applied for rapeseed and a conversion efficiency of 99% is applied for palm oil in the model.

Table 4.8: Conversion efficiency for different types of feedstock to produce biodiesel

Crop	Conv. efficiency [$L_{biodiesel}/ton_{fresh\ crop}$]	Source
Rapeseed	429	de Vries et al. [2010]
Rapeseed	434	Berghout [2008]
Rapeseed	396-441	Langeveld et al. [2014]
Soybean	203	de Vries et al. [2010]
Soybean	197-295	Langeveld et al. [2014]
Soybean	205	FAO [2008]
Soybean	212	IEA [2004]
Oil palm	286	de Vries et al. [2010]
Oil palm	230	Langeveld et al. [2014]
Oil palm	230	FAO [2008]
Oil	**Conv. efficiency [$L_{biodiesel}/L_{oil}$]**	**Source**
Palm oil	98%	Ong et al. [2012]
Palm oil	99.5%	Chongkhong et al. [2009] via Piloto-Rodriguez et al. [2014]
Palm oil	98.5%	Boonnoun et al. [2008] via Piloto-Rodriguez et al. [2014]

CONVERSION COST

The conversion cost refer to the cost associated with converting biomass into biofuel (i.e. feedstock cost is not included). Creating an overview of the conversion cost formulated in literature is difficult, because data is scattered and often not fully specified. The latter issue relates to which costs are allocated and which are not, like capital cost, depreciation, amortisation, taxes and subsidies. Above that, the production capacity of the corresponding plant(s) are often missing. To still get an impression of the conversion cost, an overview is given in Table 4.9. The data presented in this table does not include credits from by-products. What this table shows is that the conversion cost are roughly in the range 0.11-0.21 US$/L. Based on this data, the conversion cost is set 0.17US$/$L_{biodiesel}$ in the model.

Two final remarks are made with respect to conversion cost. Firstly, as described in section 4.4.2, production scale has a significant impact on conversion cost. The effect of economies of scale is taken into account in the model (for more details see aforementioned section). Therefore, the value listed above corresponds to the base conversion cost. Secondly, if one combines the information considering feedstock prices and conversion efficiencies (see Table 4.8), it can be seen that the feedstock cost are much higher than the conversion cost. In literature it is widely accepted that feedstock accounts for around 80% of the total production cost of biodiesel (e.g. Watanabe et al. [2012], Yusuf et al. [2011] and Padula et al. [2014]).

Table 4.9: Conversion cost of biodiesel plants in E.U. and U.S. (excluding credits from by-products)

Feedstock	Country/region	Conversion cost [US$/$L_{biodiesel}$]	Source
Rapeseed oil	E.U.	0.17	Yusuf et al. [2011]
Rapeseed oil	U.S.	0.13 - 0.15	IRENA [2013]
Rapeseed oil	Italy	0.21	Padula et al. [2014]
Soybean oil	U.S.	0.13	Yusuf et al. [2011]
Soybean oil	U.S.	0.14 - 0.19	IRENA [2013]
Palm oil	E.U.	0.13	Festel et al. [2014]
Palm oil	U.S.	0.11- 0.18	IRENA [2013]
Jatropha oil	U.S.	0.11	IRENA [2013]

BY-PRODUCT CREDIT FROM MEAL

In the production process of biodiesel various by-products play a role which may yield extra revenues. In this section one of the main by-products is considered: meal. Another main by-product is glycerol, which is examined in the following paragraph. These products are considered to be by-products, because their prices are relatively low in comparison to the value of the produced vegetable oil and biodiesel.

In section 3.1.2 the outputs of processing oilseeds is discussed. In that section is shown that the main outputs of processing oilseeds are vegetable oil and meal. The vegetable oil is used for biodiesel production and meal remains. Meal refers to the solid residue after processing the oilseeds. Meal has a high protein content and is used predominantly for feeding animals, although is is also used as a fertilizer [Parkhomenko, 2004]. As discussed in section 3.1.2, the animal feed market is a billion dollar industry. Whether a biodiesel plant can take into account a by-product credit for meal is dependent on the type of biodiesel plant.

Globally, there are two types of biodiesel plants: a stand-alone plant and an integrated plant. A stand-alone biodiesel plant means that vegetable oil production (at an oil mill) and biodiesel production take place at different locations. In this case, the activities of the biodiesel plant are focussed on transesterification of the externally produced vegetable oil. An integrated biodiesel plant means that vegetable oil production and biodiesel production are integrated in one facility. In other words, the plant buys oilseeds and produces its own vegetable oil. Of course, in reality also intermediate forms exist, whereby an integrated plant complements its vegetable oil demand with externally produced vegetable oil for example.

Korbitza et al. [2004] investigated 16 biodiesel plants in several countries in EU-28 and found that they vary significantly by type (stand-alone plant or integrated plant). Berghout [2008] performed some research on which types of biodiesel plants exist in Germany. According to this author, generally the new generation biodiesel plants have high production capacities, integrated oil mills and are equipped with continuous multi-feedstock process technologies. In addition, it is found that since 2001 the number of integrated plants has been increasing rapidly and the major part of the identified biodiesel plants in Germany have an integrated oil mill. For simplicity, it is assumed in in the model that all biodiesel plants are integrated plants. So a biodiesel plant receives oilseeds (rapeseed) and/or vegetable oil (palm oil) and subsequently produces biodiesel. In this case the biodiesel plant is able to earn a by-product credit from rapeseed meal. The quantity of rapeseed meal produced is derived by means of the data presented in Table 3.1, corresponding to 0.58 $\text{ton}_{\text{meal}}/\text{ton}_{\text{rapeseed}}$.

Given the information above and the fact Germany is the largest biodiesel producer in EU-28, this assumption is deemed reasonable. In section 4.4.1 it is indicated that some corrections are made in the model account for the fact that this assumption does not hold true. To gain more insight into the effect of this assumption, the cost and benefits of a stand-alone plant and an integrated plant are compared. As indicated in the paragraph on conversion cost, feedstock accounts for around 80% of the total production cost of biodiesel. Therefore, this analysis is limited to the cost associated with feedstock. Above that, the same scope as presented in section 4.3 is considered, which means biodiesel production in EU-28 originating from rapeseed (palm oil is not relevant in view of the topic of this section). In that case, the input of a stand-alone plant is rapeseed oil and the output consists of biodiesel and glycerol (see next section). However, in the case of an integrated plant the input is rapeseed and the output consists of meal, biodiesel and glycerol. Since the benefits of the outputs biodiesel and glycerol are the same for both types of plants, these are not taken into consideration for the comparison. For each plant type the feedstock cost and benefits are converted to a (litre) biodiesel equivalent. Hereto, the data listed in Table 4.10 is used. The results are shown in Table 4.11, 4.12 and Figure 4.14. The oil extraction cost are assumed to be constant (at 0.10US$/L), because oil milling is a very mature industry with hardly any potential for further improvements [Berghout, 2008].

If Table 4.11 is considered, it can be seen that the by-product credit for an integrated plant from selling meal is significant. On the other hand, a substantial part of this benefit is cancelled out by the cost associated with extracting the oil from the rapeseed. If an stand-alone plant is considered, only cost associated with buying rapeseed oil are present, as shown in Table 4.12. To compare both type of plants, the cost and benefits are settled into a net profit. These values are plotted in Figure 4.14. This figure shows that the integrated plant and stand-alone plant are well matched. Sometimes the integrated plant is more favourable, while other times the stand-alone plant would be the preferred option. In the period 2000-2012 the spread between both types of plants varied between 0.01 and 0.10US$/L (neglecting 2008 due to outbreak financial crisis). The average spread corresponds to around 8% of the average net profit (excluding 2008) and therefore is considered limited. Taking these findings in to account, it is concluded that from a financial perspective there is no reason to assume that the assumption that all biodiesel plants are integrated plants is not suitable.

Table 4.10: Data used for comparison stand-alone and integrated biodiesel plant

Parameter	Value	Source
Conversion efficiency [$ton_{rapeseed\ meal}/ton_{rapeseed}$]	0.58	Table 3.1
Conversion efficiency [$L_{biodiesel}$ / $ton_{rapeseed}$]	427	Average derived from Table 4.8
Conversion efficiency [$L_{biodiesel}$ / $L_{rapeseed\ oil}$]	1.00	Assumed similar as palm oil (see Table 4.8)
Rapeseed oil density [L/ton]	1087	Murzin [2012]
Rapeseed price [US$/ton]	*series*	FAPRI-ISU [2017]
Rapeseed meal price [US$/ton]	*series*	FAPRI-ISU [2017]
Rapeseed oil price [US$/ton]	*series*	FAPRI-ISU [2017]
Oil extraction cost [US$/L]	0.10	Average derived from Berghout [2008]

Table 4.11: Cost (C) and benefits (B) of integrated biodiesel plant per litre biodiesel (R = rapeseed, for data see Table 4.10)

C/B [US$/L]	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Buy R	-0.46	-0.44	-0.53	-0.69	-0.75	-0.57	-0.62	-0.82	-1.36	-1.08	-0.93	-1.19	-1.36
Extract R oil	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
Sell R meal	0.13	0.20	0.19	0.18	0.27	0.16	0.18	0.20	0.39	0.29	0.26	0.32	0.31
Buy R oil	0	0	0	0	0	0	0	0	0	0	0	0	0
Net profit*	-0.43	-0.35	-0.44	-0.61	-0.58	-0.52	-0.55	-0.72	-1.07	-0.90	-0.77	-0.97	-1.16

Table 4.12: Cost (C) and benefits (B) of stand-alone biodiesel plant per litre biodiesel (R = rapeseed, for data see Table 4.10)

C/B [US$/L]	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Buy R	0	0	0	0	0	0	0	0	0	0	0	0	0
Extract R oil	0	0	0	0	0	0	0	0	0	0	0	0	0
Sell R meal	0	0	0	0	0	0	0	0	0	0	0	0	0
Buy R oil	-0.38	-0.30	-0.41	-0.56	-0.59	-0.58	-0.64	-0.77	-1.36	-0.85	-0.88	-1.06	-1.18
Net profit*	-0.38	-0.30	-0.41	-0.56	-0.59	-0.58	-0.64	-0.77	-1.36	-0.85	-0.88	-1.06	-1.18

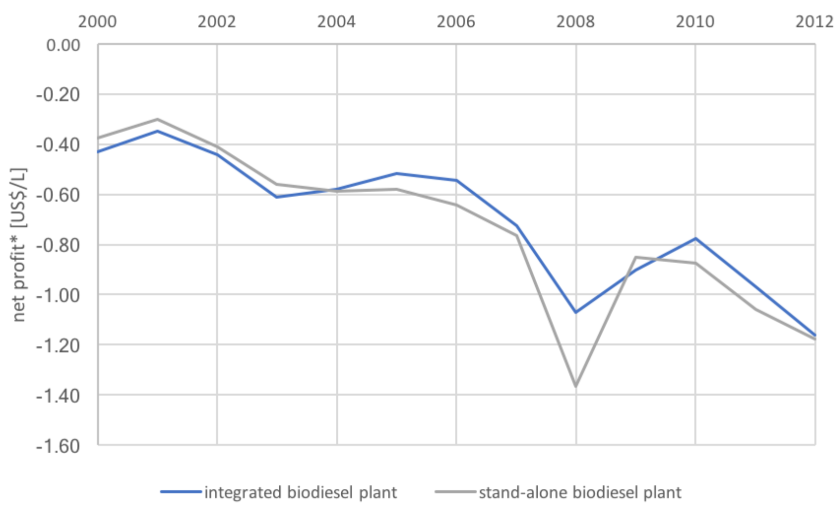

Figure 4.14: Net profit for an integrated and stand-alone biodiesel plant, for data see Table 4.10, 4.11 and 4.12*

* Note: not all benefits (like selling biodiesel) and cost are included in this analysis

BY-PRODUCT CREDIT FROM GLYCEROL

As already indicated, an other main by-product in biodiesel production is glycerol (sometimes also called glycerin). Transesterification is the most common method to convert vegetable oils into biodiesel today [Rajagopal and Zilberman, 2007]. In a nutshell this means that vegetable oils reacts with an alcohol (usually methanol) and yields two products: biodiesel and (crude) glycerol. As background information a schematic overview of biodiesel production is included in Appendix A. The liquid by-product glycerol has many applications, like in the production of cosmetics, liquid soaps, inks, lubricants and dynamite [ICTSD, 2008]. Above that, there are initiatives which aim for converting glycerol into a (second generation) biofuel (like the Dutch company BioMCN). However, these initiatives are relative new and not occurring on the same scale as for first-generation biofuels.

Biodiesel producers can earn a credit from the co-product glycerol by selling it. However, the glycerol market is complex. In this section only a two important points are addressed. Firstly, there are different qualities of glycerol, which affect the price and are dependent on the purity of the product. Biodiesel production results in crude glycerol. Crude glycerol in general has a purity between 80-88% [Berghout, 2008]. However, different applications of glycerol require different quality standards. By processing the crude glycerol the purity of the glycerol can be enhanced.

Secondly, the market for glycerol is volatile [IRENA, 2013]. In literature it is widely accepted that the increasing pace of biodiesel production pushed glycerol prices downward (see e.g. Lamers [2006], Berghout [2008] and Meeusen et al. [2009]). However, whether the co-product credit from glycerol is significant for biodiesel production or not, is subjected to discussion in literature. One strand of literature argues that the credit from glycerol improves the economics of biodiesel production significantly (e.g. IEA [2004]). One other strand argues that this credit has a marginal effect on the biodiesel production margin (e.g. Panichelli [2012]). This discrepancy is explainable in view of the volatility of the glycerol market.

This section is concluded with some numbers on glycerol production. In literature some estimations can be found with respect to the credit earned with selling the by-product glycerol. This data is summarised in Table 4.13. If this data is compared with the conversion cost of biodiesel plants, as presented in Table 4.9, it becomes clear that in an optimistic case the co-product credit from glycerol can recoup a substantial part of the conversion cost. By taking the average of the values found in literature, a credit of 0.05US$/$L_{biodiesel}$ is derived. This value is applied in the model. For completeness, a list of yields of crude glycerol in biodiesel production is given in Table 4.14 . This table shows that each ton of biodiesel produced is associated with around 100 kilograms of crude glycerol. This yield is more or less independent of the type of vegetable oil used for biodiesel production.

Table 4.13: Credit from by-product glycerol in biodiesel production

Credit [US$/$L_{biodiesel}$]	Source
0.05-0.10	IEA [2004]
0.05	Agra CEAS [2009]
0.01-0.06	IRENA [2013]

Table 4.14: Yield of crude glycerol in biodiesel production

Yield [$ton_{crude\ glycerol}$ / $ton_{biodiesel}$]	Source
0.10	Padula et al. [2014]
0.11	Peters et al. [2012]
0.10	Panichelli [2012]
0.10	Meeusen et al. [2009]
0.10	IEA [2004]
0.11	De Wit et al. [2010]
0.10	Lamers [2006]

4.6.4. BIODIESEL PRODUCERS INDONESIA/MALAYSIA

In this section the biodiesel producers in Indonesia/Malaysia are discussed. These actors will not be discussed at the same level of detail as for the EU-28 biodiesel producers, because a lot of information presented in section 4.6.3 also holds true for the biodiesel producers in Indonesia/Malaysia. In this section only the deviations from the data presented in previous section are discussed.

Like EU-28, Indonesia/Malaysia accommodates a large scale biodiesel industry. By combining information from different sources an image of the biodiesel plants in Indonesia/Malaysia is retrieved. With respect to Indonesia, 26 plants are identified with a total capacity of $4.9*10^6$ ton/year. With respect to Malaysia, 22 plants are identified with a total capacity of $2.8*10^6$ ton/year. A shortfall of the created data set is that the year of start of operation is not specified. If the data is compared with the data from an other source (as presented in Appendix C), it appears that these numbers are very similar. If the production capacity in Malaysia is considered, it can be seen that this is constant in the period 2008-2016. However, if the production capacity in Indonesia is considered, it can be seen that the production capacity more than doubled in the period 2008-2016. In the model this is taken into account by scaling the capacities of the biodiesel plants according to the data specified in Appendix C. In the same data it can also be seen that, like in EU-28, the capacity utilization of the biodiesel plants in both countries is low (ranging from 10-50% for Indonesia and 5-30% for Malaysia), corresponding to a substantial overcapacity.

Remarkable is the increase in the number of biodiesel plants in Indonesia, despite the prevailing overcapacity. This can be clarified by means of the prevailing optimism on the Indonesian biodiesel industry. This optimism originated from a number of factors. Firstly, blending mandates were implemented in Indonesia and are expected to grow rapidly, from around 1% in 2008 to 20% in 2025, for different sectors like transport, industry and electricity generation. Secondly, biodiesel exports were expected to grow substantially (driven by foreign blending mandates). Thirdly, the Indonesian Ministry of Energy and Mineral Resources (MEMR) presented expectations on substantial biodiesel shortages in Indonesia during the period 2016-2020 and therefore encouraged the biodiesel industry to expand production capacity. Contrary, the number of biodiesel plants in Malaysia did not grow for many years. One of the reasons is the stop on issuance of new licenses for biodiesel plants by the government of Malaysia.

The initial capacity utilization of the biorefineries is set as found in the data presented in Appendix C. Lastly, Yusuf et al. [2011] estimates the conversion cost of biodiesel plants in Malaysia at 0.12US$/$L_{\text{biodiesel}}$. Therefore, this value is applied for the base conversion cost of biodiesel plants in Indonesia/Malaysia. This makes the conversion cost of these biodiesel plants slightly lower than those in EU-28 (see page 49).

4.6.5. POLICIES

In this section the policies implemented in the model are discussed. Firstly the policies deployed by EU-28 are discussed, followed by the policies deployed by Indonesia/Malaysia. The information presented in this section is mainly based on FAO [2017]. Additional sources for cross-checking this information were found very limited in number and extent. Therefore, the data presented is subjected to an expert validation.

EU-28

In this section the policies deployed by EU-28 are discussed. Three different types of policies are discussed: blending mandates, subsidies and import tariffs.

Blending mandates In 2003 the EU introduced a regulation that prescribes that biofuels must account for at least 5.75% (on energy content basis) of all transport gasoline and diesel as of 2010. In 2009 a new target of 10% was set for 2020. In 2015 an important change for this objective was proposed for the new Renewable Energy Directive (RED II, addressing the period 2021-2030). This change is a cap for first-generation biofuels, while maintaining the general 10% target. This cap would decline gradually from 7% in 2021 to 3.8% in 2030. The target was revised due to the perceived risk of unintentionally harming the environment or disturbing food markets. However, as of today, the RED II is still being negotiated and the details of the new regulations are not known. For example, it is not known whether there will be any compensation for actors that made investments while anticipating on the original 10% blending mandate.

Many member states have their own interpretation in fulfilling the target imposed by the EU. For example, some member states impose intermediate targets, by gradually raising the target each year. Additionally, some member states also create different targets for specific types of biofuels, take into account net green house gas savings and allow for double counting for some types of biofuels. For an overview of biofuel blending mandates implemented by EU member states, the reader is referred to USDA-FAS [2017a]. The available time for this research does not allow to for implementing different forms of blending mandates for each member state. Therefore, the blending mandate is simplified by setting a general 5.75% target. Since not sufficient details are known about the blending mandates in the period 2020-2030, the original blending mandate of 10% is applied for the policy exploration (see section 5.7).

In literature clear indications can be found that the 2010 blending mandate is not fulfilled. For example, it is estimated that in 2013 only a share of 4.5% is reached [USDA-FAS, 2016a]. An explanation can be found for this by recalling that biofuels are in general more expensive than their fossil counterparts. So from a pure financial perspective, there is no incentive for distributors/retailers to perform blending. To overcome this price differential, penalties are imposed in case of non-fulfilment. The penalties mainly address the distributors/retailers. In literature little information is found on the specification of these penalties. What is found is that penalties are different among member states. For example, some member states do not allow for selling diesel that does not comply with the set rules. Other member states impose fines in case of non-compliance, for example on energy, volumetric and/or green house gas saving basis. For an overview of imposed penalties in EU-28 the reader is referred tot RES LEGAL Europe [2017]. Like for the target, time restrictions do not allow to for implementing penalties specific for each member state. Therefore, based on aforementioned source, the penalties are approximated by imposing a penalty of 0.75US$ per litre of biodiesel not blended to fulfil the blending mandate to the distributors/retailers.

Subsidies The blending mandates and associated penalties described above can be seen as a form of indirect subsidy on biodiesel production and consumption. However, also direct subsidies are present. These mainly address the production of crops. In the model farmers in EU-28 are able to grow two types of crops:wheat and rapeseed. Therefore, subsidies for these crops are considered in this section.

In section 4.5.1 a number of reforms of the CAP are described. In that section it is stated that subsidies were decoupled from agricultural production to let farmers respond more strongly to prevailing market conditions. However, that does not necessarily mean that no subsidies are granted any more to farmers. Since a literature review on subsidies for growing rapeseed or wheat would be too time consuming to perform, the following approach is adopted. Via the statistical office of the EU (Eurostat) data on the total amount of subsidy granted to farmers for growing a certain type of crop is retrieved. From the same source data on agricultural production is retrieved. Subsequently, these numbers are combined to determine an average subsidy for both crops.

So contrary to the described decoupling of subsidies from agricultural production, subsidies are linked to agricultural production. This assumption is considered suitable, because the implementation of the single payment scheme (SPS, as part of the CAP reform in 2003) needed to be fulfilled only before 2013. In addition, it was up to the member states to decide how and when to realize this. Above that, it appears that the number of member states in which subsidies are involved in growing rapeseed and wheat is limited (see Table 4.16). Together, these countries are responsible for a small share of the total rapeseed and wheat grown in EU-28. Therefore, the effect of coupling subsidies to agricultural production is considered limited.

A global overview of subsidies is given in Table 4.15. From this table it can be seen that on average, the subsidies are higher for rapeseed than for wheat. Additionally, a downward trend in agricultural subsidies is visible. Above that, the subsidies for both crops are low in comparison with the total cost of production (see section 4.6.2). Eurostat also provides the same data as presented in Table 4.15 on country level. Since large differences among member states appeared to be presented, these values are applied in the model. This data is given in Table 4.16. From this table it can be seen that only in a limited number of member states (Croatia, Italy, Lithuania, Poland, Portugal and Finland) subsidies are paid for rapeseed and wheat.

Table 4.15: Average subsidies for growing rapeseed and wheat, derived from Eurostat [2017]

year	2010	2011	2012	2013	2014
subsidy rapeseed [10^6 US$]	109	110	91.8	89.6	58.2
production rapeseed [10^6 ton]	18.5	19	21.5	20.6	19.2
average subsidy rapeseed [US$/ton]	5.91	5.77	4.26	4.35	3.03
subsidy wheat [10^6 US$]	590	475	352	403	316
production wheat [10^6 ton]	137	139	134	144	157
average subsidy wheat [US$/ton]	4.31	3.41	2.63	2.79	2.01

Table 4.16: Average subsidies for growing rapeseed and wheat on country level, derived from Eurostat [2017]

	subsidy rapeseed [US$/ton]					subsidy wheat [US$/ton]				
	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
Belgium	0	0	0	0	0	0	0	0	0	0
Bulgaria	0	0	32	0	0	0	0	0	0	0
Czech Republic	0	0	0	0	0	0	0	0	0	0
Denmark	1	0	0	0	0	0	0	0	0	0
Germany	0	0	0	0	0	0	0	0	0	0
Estonia	10	0	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	0
Greece	0	0	0	0	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0	0	0	0
France	0	0	0	0	0	0	0	0	0	0
Croatia	142	96	227	94	216	78	50	44	35	94
Italy	0	0	0	0	0	39	21	15	23	18
Cyprus	0	0	0	0	0	0	0	0	0	0
Latvia	0	0	0	0	0	0	0	0	0	0
Lithuania	82	75	68	82	70	40	66	32	40	36
Luxembourg	0	0	0	0	0	0	0	0	0	0
Hungary	0	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	0
Netherlands	0	0	0	0	0	0	0	0	0	0
Austria	0	0	0	0	0	0	0	0	0	0
Poland	31	30	17	12	0	20	17	10	8	0
Portugal	0	0	0	0	0	9	23	18	13	3
Romania	0	0	0	0	0	0	0	0	0	0
Slovenia	0	0	0	0	0	0	0	0	0	0
Slovakia	0	0	0	0	0	0	0	0	0	0
Finland	0	75	123	108	128	0	0	0	0	0
Sweden	0	0	0	0	0	0	0	0	0	0
United Kingdom	0	0	0	0	0	0	0	0	0	0

Import tariffs In this section import tariffs on two commodities will be discussed. Firstly, biodiesel will be considered, followed by palm oil. Besides the applied numbers, also some context is given. An overview of the numbers applied in the model is given in Table 4.17.

Initially, biodiesel from Indonesia and Malaysia was allowed to enter EU-28 duty free. In 2012 the European Biodiesel Board (EBB, an interest group of the European biodiesel industry) filed a complaint at the EU with respect to the policy regimes deployed by the Indonesian (and Argentinian) government. In short, the complaint consisted of two elements. Firstly, the complaint encompassed the observation that foreign biodiesel entered the European market at very competitive prices, which could not be met by the European biodiesel industry. This price difference could originate from high subsidies or low cost of production for the foreign producers, for example. Secondly, these governments would make use of a differential export tax (DET) regime. This regime contains of high export rates imposed on raw commodities, while low export rates are imposed on the processed commodities. This favours the exports of processed commodities over the exports of the raw commodities. It is reasoned this beneficial for the development of the industries situated higher in a value chain. Summarizing, the EBB argued that unfair trade practices were taking place, which harmed the European biodiesel industry. Following this complaint, the European Commission started an investigation.

Following the investigation, from mid-2013 onwards provisional anti-dumping duties were imposed on the imports of biodiesel and biodiesel blends originating from Indonesia to address the low-price imports of biodiesel. These protectionist policy measures were company-specific and ranged from 0 to 84 €/ton of biodiesel. At the end of 2013, the provisional anti-dumping duties were replaced with definitive ones. These definitive anti-dumping duties are significantly higher than the provisional ones and will be present for a period of at least five years. The company-specific anti-dumping duties ranged from 0 to 180 €/ton of biodiesel. With respect to the second part of the complaint, the European Commission indicated that not sufficient evidence was found that the DET regime applied by the Indonesian government could be considered as a form of (unfair) subsidy. Therefore, proposals of anti-subsidy duties were postponed.

In the model it is assumed that biodiesel is blended at the country of destination. In addition, since no data is found on which biorefineries belong to which companies, one import tariff is applied for all biorefineries. According to FAO [2017], the imposed duties correspond to an ad valorem rate of 18.9% on average. This value is applied in the model. With respect to biodiesel originating from Malaysia, biodiesel was also allowed to enter EU-28 duty free. However, in 2014 changes with respect to the General System of Preferences (GSP) scheme took place. The GSP scheme is a preferential tariff system to support less developed countries. From 2014 onwards Malaysia lost its preferential status under the new GSP scheme. As a consequence of this, an ad-valorem rate of 6.5% is charged on biodiesel imports.

The second commodity considered in this section is palm oil. In the model it is assumed that all imported palm oil by EU-28 is crude palm oil (CPO). Like for biodiesel, palm oil originating from Indonesia and Malaysia was allowed to enter EU-28 duty free. However, as described, in 2014 the GSP scheme was adjusted. With these changes also the import tariff on CPO was raised for CPO originating from both countries to 3.8%. Though Indonesia still has a GSP status, CPO is excluded because this sector is classified as a well developed sector.

Table 4.17: Import tariffs on biodiesel and CPO originating from Indonesia and Malaysia (ad valorem)

	Year	2010	2011	2012	2013	2014
Indonesia	GSP beneficiary	Yes	Yes	Yes	Yes	Yes*
	import tariff biodiesel [%]	0	0	0	0/anti-dumping duties	anti-dumping duties
	import tariff CPO [%]	0	0	0	0	3.8
Malaysia	GSP beneficiary	Yes	Yes	Yes	Yes	No
	import tariff biodiesel [%]	0	0	0	0	6.5
	import tariff CPO [%]	0	0	0	0	3.8

* Some sectors are excluded, like biodiesel and CPO.

INDONESIA/MALAYSIA

In this section the policies deployed by Indonesia/Malaysia are discussed. Three different types of policies are discussed: subsidies and export tariffs.

Subsidies In the model the price of palm oil is considered exogenous (see section 4.3). Since the subsidies (if any) for the production of palm oil will already be embedded in the price level of palm oil, it is not necessary to specify these subsidies in the model. This section focuses on the subsidy provided for biodiesel production. From 2009 onwards the Indonesian government started supporting biodiesel producers with subsidy, depending on price developments of fossil fuel and palm oil. This support was implemented to overcome the price disadvantage of biodiesel in comparison with its fossil counterpart and to stimulate the production and consumption of biodiesel. The Malaysian government adheres a similar policy structure. In Table 4.18 an overview of the provided subsidies is given. If one considers that historically the producer price of biodiesel in EU-28 tends to be in the range of 0.80-1.30US$/L, it can be seen that the subsidy provided by the Indonesian government is substantial. The subsidy provided by the Malaysian government, on the contrary, is limited.

Table 4.18: Subsidies for biodiesel production in Indonesia and Malaysia, derived from FAO [2017]

	2010	2011	2012	2013	2014
Indonesia [US$/L]	0.22	0.29	0.27	0.29	0.13
Malaysia [US$/L]	0.01	0.01	0.01	0.01	0.01

Export tariffs With respect biodiesel no export taxes are present for biodiesel originating from Indonesia and Malaysia in the period after 2010. Contrary, export taxes used to be present for the export of CPO. In Figure 4.15 an overview of the export tax rates imposed by the governments of Indonesia and Malaysia is given. A complicating factor for reviewing these export taxes are the frequently applied changes. Not only the general tax systems are changed, also the rates applicable within these general tax systems are usually changed on a monthly basis. The review in this section considers the period starting from 2010. For an overview of the period preceding 2010, the reader is referred to Rifin [2010].

In Figure 4.15 the tax rate for palm oil originating from Indonesia is shown. In this figure it can be seen that the tax rate is changed frequently. One of the drivers for raising or lowering the tax rate are changes in the prevailing market conditions. The change in tax system at the end of 2011 was an adjustment in the way the tax rate was set. In general, it can be seen that in the considered period the export tax rate showed a downward trend. This is related to the deteriorated market conditions for CPO: in 2011 CPO was sold for around 1100US$/ton, contrary to less than 600US$/ton in 2015 (also see Figure 4.8). In section 4.6.5 it is described that the European biodiesel industry complained about a differential export tax (DET) regime deployed by Indonesian government, by deploying high export tariffs on palm oil and low export tariffs on biodiesel. This literature review confirms this assertion. However, at the end of 2014 this structure disappeared.

Up and to 2012, the Malaysian government deployed a different tax structure in comparison with Indonesia. The Malaysian government applied a duty free quota for the export of CPO. In 2010, 2011 and 2012, this quota amounted to 3, 3.6 and 5 million ton respectively. From 2013 onwards the Malaysian government adopted a similar tax structure as applied by the Indonesian government. From Figure 4.15 it can be seen that in general, the export tariff on Malaysian palm oil is below or equal to the Indonesian counterpart. In the model, annual averages of the export tax rates shown in Figure 4.15 are applied.

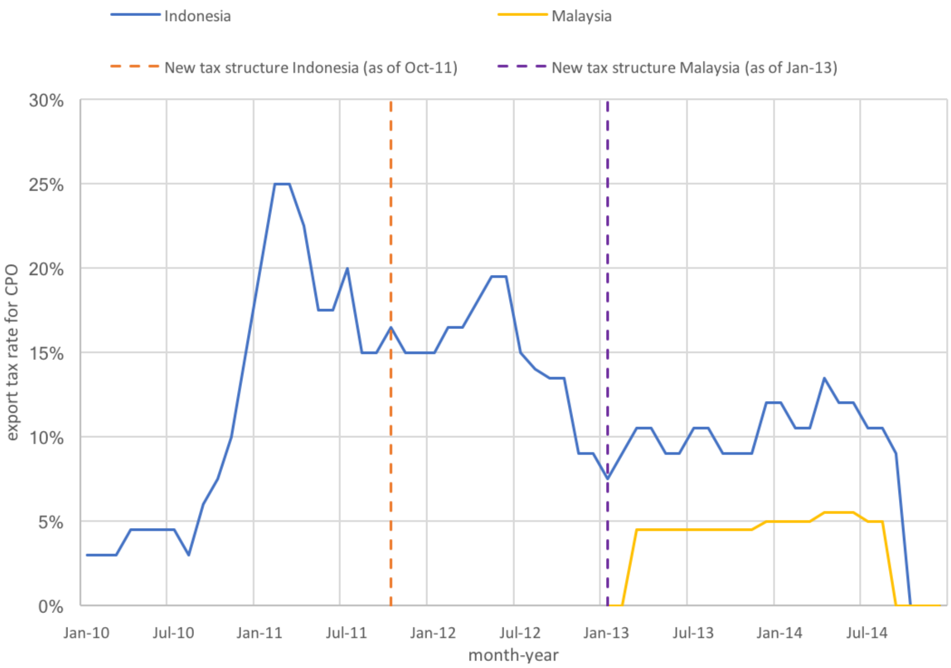

Figure 4.15: Export tax rate CPO imposed by Indonesia and Malaysia (ad valorem), derived from FAO [2017]

4.7. SUMMARY

In the preceding sections a lot of information is given on the model. In this section it is attempted to summarize this. The summary is divided into three parts: a pseudo code (section 4.7.1), a list of the main assumptions (section 4.7.2) and an overview of the model parameters (section 4.7.3).

4.7.1. PSEUDO CODE

In this section a pseudo code of the model is given. The entire procedure situated between "to go once" and "end" represents one tick, which corresponds to one year.

to go once
  determine rate of adoption of rapeseed in clusters
  update cost farmers and biorefineries (for economies of scale)
  let actors create outlooks for various commodity prices and tariffs
  let biorefineries evaluate financial performance and perform CBA
  let biorefineries set strive capacity utilization and strive feedstock composition
  let farmers determine whether they are willing to adopt rapeseed or not
  let distributors/retailers perform CBA
  interaction farmers and biorefineries for biomass contracts (CDA)
  interaction farmers with food market
  let farmers grow biomass according to contracts
  exchange biomass and money between farmers and buyers
  let biorefineries buy palm oil
  let biorefineries produce biodiesel
  interaction between biodiesel producers and distributors/retailers (one shot auctions)
  let distributors/retailers blend biodiesel with fossil diesel and hand over to consumers
end

4.7.2. ASSUMPTIONS

In this section an overview of main assumptions of the model is given:

- Biodiesel (related) policies are exogenous to the modelled system.
- The price of wheat, palm oil and fossil diesel are exogenous to the modelled system.
- The demand for diesel in EU-28/biodiesel in Indonesia/Malaysia are exogenous to modelled system.
- There is no investment in expansion of biodiesel production capacity in EU-28.
- Actors cannot go bankrupt.
- Contracts between farmers and biodiesel producers are always respected.
- One general volumetric blending mandate holds true for all members states of EU-28.
- Agricultural subsidies are linked to production.
- The US$ is a representative currency unit and exchange rates do not play a role.
- There are no storage facilities for commodities (i.e. overproduction of biodiesel is lost).
- Commodity markets cannot crash (i.e. close definitively).
- Actors do not collaborate (i.e. legally allowed) and/or collude (i.e. legally not allowed).
- The geographical situation of ports does not affect the import of commodities.
- Weather conditions do not affect crop yields.
- Biodiesel is blended with fossil diesel at the country of destination.
- Distributors/retailers will always meet consumer demand for diesel.
- All biodiesel plants are integrated biodiesel plants.
- The rapeseed market for food purposes is separated from the rapeseed market for energy purposes.
- The buyers in food market for rapeseed are price takers and will absorb all supply.
- Only the multi-feedstock biodiesel plants are able to process palm oil.
- Biodiesel plants in Indonesia/Malaysia only buy palm oil (and thus do not buy and process palm fruit).
- The supply of palm oil is always sufficient to cover demand for biodiesel production.
- Biodiesel producers in Indonesia/Malaysia always fulfil domestic demand first.
- The demand for fossil diesel in EU-28 can always be satisfied.
- Taxes on commodities do not play a role.

4.7.3. PARAMETERS

For completeness an overview of the model parameters and their values is given. In essence, this summarizes the values introduced in section 4.6. However, a limited number of parameter are not discussed not explicitly because these speak for themselves. Above that, some values will be clarified in the next chapter (chapter 5).

Table 4.19: Base parameter values (R = rapeseed, B = biodiesel, P = palm oil, sd = standard deviation)

Name	Value	Units	Comment
General			
number of farmers	4 000	[-]	see section 5.2
price change rate	5	[%]	see section 4.5.1
price damping coefficient	0.98	[-]	see section 5.6
propensity to exploration biorefineries	1.02	[-]	see section 5.6
yield rapeseed	*data set*	[ton/ha]	see section 4.6.2
yield wheat	*data set*	[ton/ha]	see section 4.6.2
location biodiesel plants	*data set*	[-]	see section 4.6.3
capacity biodiesel plants	*data set*	[-]	sec. 4.6.3/4.6.4
cluster radius increment	5	[km]	see section 4.4.1
minimal operation capacity rate	5	[%]	for biorefineries
conversion efficiency rapeseed to meal	0.58	[ton_{meal}/ton_R]	see section 3.1.2
conversion efficiency rapeseed to biodiesel	427	[L_B/ton_R]	see section 4.6.3
conversion efficiency palm oil to biodiesel	99	[%]	see section 4.6.3

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Table 4.19 – *Continued from previous page*

Name	Value	Units	Comment
energy content biodiesel relative to fossil diesel	90	[%]	see section 4.5.3
share multi feedstock biodiesel plants	43.2	[%]	see section 4.5.2
initial land allocated rapeseed	$6.66*10^6$	[ha]	see section 4.6.2
initial land allocated wheat	$26.3*10^6$	[ha]	see section 4.6.2
total arable land	$33.5*10^6$	[ha]	see section 4.6.2
theoretical capacity fulfilment biorefineries	90	[%]	see section 4.4.1
biodiesel density	1 136	[L_B]	Lamers et al. [2011]
Probability distributions			
mean noise level	0	[%]	see section 5.5
sd noise level	5	[%]	see section 5.5
mean adoption threshold rapeseed	20	[%]	see section 4.6.2
sd adoption threshold rapeseed	10.2	[%]	see section 4.6.2
mean profit margin farming	3	[%]	assumption
sd profit margin farming	1.5	[%]	assumption
mean profit margin biodiesel producers	3	[%]	assumption
sd profit margin biodiesel producers	1.5	[%]	assumption
mean initial capacity utilization biorefineries EU-28	28.7	[%]	see section 4.6.3
sd initial capacity utilization biorefineries EU-28	7.2	[%]	assumption
mean initial capacity utilization biorefineries Indonesia	9.4	[%]	see section 4.6.4
sd initial capacity utilization biorefineries Indonesia	2.4	[%]	assumption
mean initial capacity utilization biorefineries Malaysia	8.4	[%]	see section 4.6.4
sd initial capacity utilization biorefineries Malaysia	2.1	[%]	assumption
mean initial share feedstock palm oil	8.0	[%]	see section 4.6.3
sd initial share feedstock palm oil	2.0	[%]	assumption
Costs			
total cost of production rapeseed (region specific)	*data set*	[US$/ton]	see section 4.6.2
total cost of production wheat (region specific)	*data set*	[US$/ton]	see section 4.6.2
credit glycerol	0.05	[US$/$L_B$]	see section 4.6.3
base oil extraction cost	0.10	[US$/$L_B$]	see section 4.6.3
base conversion cost biorefineries EU-28	0.17	[US$/$L_B$]	see section 4.6.3
local transport cost EU-28 rapeseed	0.06	[US$/$ton_R$/km]	see section 4.6.1
international transport cost biodiesel	0.04	[US$/$L_B$]	see section 4.6.1
international transport cost palm oil	0.04	[US$/$L_P$]	see section 4.6.1
base conversion cost Indonesia	0.12	[US$/$L_B$]	see section 4.6.4
base conversion cost Malaysia	0.12	[US$/$L_B$]	see section 4.6.4
Economies of scale			
base biodiesel production EU-28	$142*10^3$	[ton]	see section 4.4.2
base biodiesel production Indonesia/Malaysia	$168*10^3$	[ton]	see section 4.4.2
base rapeseed production	23.3	[ton]	see section 4.4.2
base wheat production	23.3	[ton]	see section 4.4.2
economies of scale factor biorefineries	0.80	[-]	see section 4.4.2
economies of scale factor farming (EU-28)	0.80	[-]	see section 4.4.2
Consumption and prices			
consumption diesel EU-28	*data set*	[ton/year]	see section 4.6.1
biodiesel consumption Indonesia	*data set*	[ton/year]	see section 4.6.1
biodiesel consumption Malaysia	*data set*	[ton/year]	see section 4.6.1
price wheat	*data set*	[US$/ton]	see section 4.6.1
price palm oil	*data set*	[US$/ton]	see section 4.6.1

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Table 4.19 – *Continued from previous page*

Name	Value	Units	Comment
producer price fossil diesel EU-28	*data set*	[US$/L]	see section 4.6.1
price rapeseed meal	*data set*	[ton]	see Appendix E
price rapeseed EU-28 (2009)	414	[US$/ton]	OECD [2017]
producer price biodiesel EU-28 (2009)	1.07	[US$/L]	OECD [2017]
producer price biodiesel Indonesia/Malaysia (2009, F.O.B.)	0.63	[US$/L]	Platts [2014]
Policy			
biodiesel blending mandate 2010	5.75	[%]	see section 4.6.5
biodiesel blending mandate 2020	10	[%]	see section 4.6.5
biodiesel blending mandate penalty	0.75	[US$/L]	see section 4.6.5
subsidy growing rapeseed (country specific)	*data set*	[US$/ton]	see section 4.6.5
subsidy growing wheat (country specific)	*data set*	[US$/ton]	see section 4.6.5
import tariff palm oil EU-28 (ad valorem)	*data set*	[%]	see section 4.6.5
import tariff biodiesel EU-28 (ad valorem)	*data set*	[%]	see section 4.6.5
subsidy biodiesel production Indonesia	*data set*	[US$/L]	see section 4.6.5
export tariff palm oil Indonesia	*data set*	[%]	see section 4.6.5
subsidy biodiesel production Malaysia	*data set*	[US$/L]	see section 4.6.5
export tariff palm oil Malaysia	*data set*	[%]	see section 4.6.5

5
SIMULATION RUNS

In this chapter the outcomes of the simulation runs are presented. Firstly, in section 5.1, a plan for performing the simulation runs is discussed. This section attempts to clarify the relation among the different runs. The simulation runs can be categorized into an assessment of the number of replication runs (section 5.4), a sensitivity analysis (section 5.5), a calibration (section 5.6) and a policy exploration (section 5.7). In short, assessing the number of replication runs and the sensitivity analysis are preliminary work for the model calibration. Subsequently, the results derived in the calibration are applied in the policy exploration. For more explanation, the reader is referred to section 5.1.

5.1. METHOD OF APPROACH

In this section a plan for performing the simulation runs is discussed. An overview of the sets of simulation runs is given below. In this section each element of the list will be introduced.

- Number of replication runs (section 5.4)
- Sensitivity analysis (section 5.5)
- Calibration (section 5.6)
- Policy exploration (section 5.7)

The model developed for this research contains many stochastic elements. Due to these stochastic elements, a single simulation run may not yield representative results. Therefore, multiple replication runs are necessary to statistically underpin the model outcomes. Hereby, replication runs refer to simulation runs of the model with same parameter settings but different random numbers. This approach is associated with an important question: how many replication runs are sufficient to get statistically significant results? This question is addressed for the developed model in section 5.4.

Next, a sensitivity analysis is conducted. A sensitivity analysis can be described as a systematic exploration of how responsive the outputs of a model are to changes in the model parameter values. In this way, one can develop more understanding about the model and the corresponding real system. In addition, a sensitivity analysis allows us to point out the importance of the uncertainty in parameter values: the higher the sensitivity, the higher the importance of the uncertainty and vice versa. In section 5.6 it will be discussed that the parameters the model is most sensitive to are interesting candidates to evaluate via calibration. In this way, sensitivity analysis is a tool that can provide guidance in the POM approach applied in this system (see section 4.1) to reproduce observed patterns in real systems. Taking all these aspects into account, in this research also a sensitivity analysis is incorporated. In section 5.5 different forms of sensitivity analysis will be discussed. Subsequently, one method is selected and applied.

In section 4.1 the POM approach to reproduce observed patterns in real systems is discussed. Part of the POM approach is calibration. During calibration (or fitting) the model is run with different values for its parameters, subsequently the model outcomes are compared with observed patterns in real systems to determine which combination succeeds best. In general, calibration of an ABM is about fine-tuning the model by reviewing the values of a limited number of parameters. According to Railsback and Grimm [2011], calibration serves three purposes. Firstly, by forcing the model to match (historical) observations of a real system as well as possible, it is assumed that the model with the calibrated parameters will produce more accurate and credible results while considering other conditions. Secondly, calibration allows us to estimate parameter values for which no value can be established. In other words, calibration can be seen as "inverse modelling".

Thirdly, calibration enables us to test the structural realism of the model. If we are able to match the observed patterns within a reasonable range, this provides confidence in the realism of the model. Therefore, calibration is also applied in this research.

In the formulation of the objective of research (section 1.4) it is described that by developing a model of the international liquid biofuel markets, the interaction between policies and patterns of trade flows can be investigated. Subsequently, the retrieved insights can be used to fill the current knowledge gap with respect to how policies affect the international biofuel markets. This can contribute to reduce or even prevent unintended effects and associated negative consequences for the biofuel industry itself and the realisation of underlying policy objectives. Using the results of the previous simulation runs, we are now able to realize this line of thought by performing a policy exploration for the case study.

The objective of the policy exploration is twofold. Firstly, the selected pattern of Lamers et al. [2011] is examined. Secondly, the objective is to gain insight into the expected influence of different policy combinations on the international trade flows of palm oil and biodiesel originating from Indonesia and Malaysia and directed towards EU-28 until 2030. Based on these insights, a number of policy recommendations are formulated.

5.2. GENERAL SIMULATION RUN SETUP

Each simulation run performed in this chapter will have its own specific setup. However, we can distinguish a common denominator among these runs with respect to the setup. The aim of this section is to describe this general simulation run setup. It will hold true for all subsequent simulation runs unless indicated otherwise.

The simulation runs are performed using a computer running Windows 10 (64 bit) with an Intel Core i5-4200M 2.50GHz processor and 4GB DDR3 working memory. The model is implemented and run in NetLogo 6.0.2. For various simulation runs, the NetLogo model is run via the external software package R (version 3.4.1). This is necessary, because the statistics- and analysis tools in NetLogo itself are very limited. Therefore, R scripts are made that run the NetLogo model. R can be extended by packages. To create the link between R and NetLogo use is made of the package *RNetLogo*. For various simulation runs additional packages are used. These include (amongst others) the GIS and the Rnd extension. The packages specific for certain simulation runs will be mentioned at the specification of the corresponding description of the setup.

In general, the time span considered in the simulation runs covers a period of five years: from 2010 up and to 2014. In the last set of simulation runs (section 5.7) this period will be extended to 2030. Each tick is assumed to correspond to one year and thus the model runs for five ticks. A tick is considered equivalent to one year, because rapeseed and wheat are annual crops and thus the farming cycle occupies a period of one year. In other words, biorefineries can switch feedstock only once a year. This is limitation is considered decisive for setting the time step.

In the subsequent sections, the text will sometimes refer to model outcomes, -outputs or -results. Most ABMs include many different type of agents, states, properties, interactions and so forth. In such case, it would be practically infeasible to analyse all data retrieved from the model. One approach to overcome this problem is to limit the analysis of model outcomes to a select few. Railsback and Grimm [2011] call these "currencies", summary statistics or key outputs which are indicators of model behaviour expressed in a single number. It is also indicated that in most cases, one currency is not sufficient because the model needs to be viewed from multiple different perspectives.

In this research the import of biodiesel and palm oil for biodiesel purposes by EU-28 are considered the main model outcomes. These two outputs are chosen, because, as described in section 4.1, the POM approach will be applied in this research. In that section it is also explained that the focus of this research is to reproduce the following pattern found by Lamers et al. [2011]: import duties are key influencing factors on trade volumes. If we also consider the model scope presented in section 4.2, the import of biodiesel and palm oil for biodiesel purposes by EU-28 are considered suitable currencies.

In the model use is made of random numbers. These random numbers are used many times in the model, for example for generating price offers of different agents, assigning locations of farmers, sampling of arable land of farmers and so forth (see section 4.5). These random numbers are derived via a random seed of the random number generator. During the simulation runs, each run will be performed with a different value of the random seed. In section 5.4 this topic will be discussed in more detail.

The largest group of actors in the model are the farmers. In section 4.6.2 it is shown that the numbers of farmers which grow rapeseed and wheat in EU-28 is in the order of hundred thousands of farmers. If this group of actors would be modelled 1:1, this would significantly affect computational time. Therefore, scaling is applied to this group of actors. According to Gräbner [2016], model outcomes of an ABM that are the result of interactions among the components might require a certain minimum group size of these components. To examine this, it is suggested to examine the degree of scale invariance of the properties by controlling for the number of the agents. For this research the following approach is applied. The model is run with the same random seed a number of times. For every new simulation run the number of farmers is raised. After each simulation run the selected currencies and other model outcomes are compared with previous model runs. This process is repeated for a number of different seeds until it was found that raising the number of agents did not affect model outcomes anymore. This resulted in the choice for 4 000 farmers.

5.3. MODEL VERIFICATION AND VALIDATION

Model verification refers to checking whether the model is implemented correctly. Model verification in this research is performed in various ways. Firstly, during model development, every added model element is tested. For more simple model elements, writing (interim) simulation results to the command center sufficed. For more complex model elements, simulation results are written to a text file. In general, these checks usually required only a few lines of code. After using them, the corresponding lines of codes are disabled, but they are left behind in the code to allow future users to reuse and (re)check them.

For some results it was possible to perform a check by means of a hand calculation. By comparing the outcomes of the hand calculation and the outcomes of the model, errors could be discovered. Like the major part of the checks described earlier, these hand calculations are documented. A number of checks are considered more important than others (for example checks on the conservation of mass and money). Above that, for some checks it was possible to automate them. Therefore, a number of checks which fulfilled these criteria are equipped with an error message. Every time as the model runs, these checks are performed. This forms an extra safety net for subsequent model development. Lastly, verification checks are performed with the final model. These checks include single-agent tracing, minimal model testing (running model with minimal number of agents), extreme value testing and multi-agent testing (see [Van Dam et al., 2012]).

Model validation refers to checking whether the (simulation) model is an accurate representation of the real-world system under study [Kleijnen, 1995]. Model validation can take various forms, like historic replay (comparison simulation outcomes and historical data), expert validation (interviews, workshops and checks performed by experts in the field), literature validation (compare outcomes with results found in literature) and model replication (use different modelling approaches). Although in general model validation is a good practice in science, some approaches are difficult to apply for this research.

Firstly, historic replay requires a suitable data set. During this research it appeared that the data collection process is a very time consuming process due to many data collection issues (this will be discussed in more detail in the reflection on ABM, see section 6.3.3). In addition, data for historic replay should not overlap with data used for model development (like calibration). In this research, the import of biodiesel and palm oil for biodiesel purposes by EU-28 are considered the main model outcomes (see section 5.2). For example, this could require a time series of 5 years for calibration and could be complemented with a time series of 5 years for validation. No data set is found available to fulfil this need within a reasonable time span. However, various other model outputs (like yields, area allocation, biodiesel production, biodiesel feedstock composition) are checked on the correctness of the order of magnitude. Above that, expert validation is applied in this research via interaction with the supervisors of this research project and an external person (see section 4.6.5). For model replication it also holds true that this would be too time consuming for the time available for this research.

5.4. NUMBER OF REPLICATION RUNS

The model developed for this research contains many stochastic elements. These stochastic elements, for example, include sampling from probability distributions and the random ordering of elements of agent sets. This latter aspect affects the order in which agents are asked to perform certain actions, for instance. Due to these stochastic elements, a single simulation run may not yield representative results. Therefore, multiple replication runs are necessary to statistically underpin the model outcomes. Hereby, replication runs (or repetitions or iterations) refer to simulation runs of the model with same parameter settings but different random numbers. These different random numbers are derived via a different value for the random seed of the random number generator. This approach is associated with an important question: how many replication runs suffice to get statistically significant results? This question is addressed in this section for the model developed in this research.

According to Thiele et al. [2014], an established and generally accepted strategy for determining adequate number of repetitions for ABMs is missing and often ad hoc solutions (like 10 or 50 replications) are applied. There is also a practical consideration: the simulation runs must finish within a reasonable amount of time. To find a balance between sufficient replication runs and time it takes to complete these simulation runs, Van Dam et al. [2012] recommend the following strategy. The first step is to perform 100 replication runs of a small number of model configurations across the parameter space by means of Latin Hypercube Sampling (LHS). Hereby, the parameter space refers to all possible combinations of model parameter values. In addition, LHS is a statistical method for generating samples. An alternative to LHS would be assigning random values to the parameters of the model. In this approach values are assigned by considering only one parameter at a time. Contrary to this approach, LHS takes into account the entire set of parameters and finds where in the parameter space simulation runs should be performed to get the most representative subset of the parameter space, given the dimensions of the parameter space and the number of model configurations [Van Dam et al., 2012].

The second step is to apply descriptive statistics on these model configurations to identify the most variable model outcome. Next, the corresponding model configuration is used to estimate the number of replication runs required to obtain a certain confidence level. This number of replication runs is applied to every subsequent simulation run in this chapter (except for the policy exploration in section 5.7). According to Thiele et al. [2014], in view of the lack of an established and general accepted strategy, this approach is a good starting point to avoid ad hoc assumptions about appropriate numbers of replication runs.

5.4.1. RESULTS

For determining the number of replication runs for the model developed in this research, the above described method proposed by Van Dam et al. [2012] is used. This method is implemented in a R script that runs the NetLogo model. Hereto, use is made of the packages *RNetLogo* and *lhs* in R. To analyse the results, it is assumed that the outcomes of the replications are normally distributed. According to Dekking et al. [2005], it is not uncommon to apply confidence intervals for normally distributed data even if the data is not normally distributed. Hereto, two reasons are mentioned. Firstly, with small deviations from normality the actual confidence level of a constructed confidence interval may deviate only a few percent from the intended confidence level. Secondly, for large data sets the central limit theorem ensures that this method provides confidence intervals with approximately correct confidence levels. Visual inspection of the model outcomes indicated approximation of a normal distribution. Above that, the data set is considered large enough. Therefore, the assumption of normally distributed data is considered acceptable.

If the data is normally distributed, a confidence interval for the mean of the model outcome can be determined by the interval as denoted in Equation 5.1 [Dekking et al., 2005]. Where n is the sample size (replication runs), $\overline{x}_n$ is the sample mean, s_n is the sample standard deviation, $t_{n-1,\alpha/2}$ is the critical value of the t-distribution and α is a significance level. This equation can also be used to determine the sample size, given $t_{n-1,\alpha/2}$, s_n and the maximum error of estimate (difference between the upper/lower bound and the mean).

$$\left(\overline{x}_n - t_{n-1,\alpha/2}\frac{s_n}{\sqrt{n}}, \overline{x}_n + t_{n-1,\alpha/2}\frac{s_n}{\sqrt{n}}\right) \tag{5.1}$$

With the model 50 configurations are considered (derived via LHS) with each 100 replications runs (corresponding to 5 000 simulation runs). In addition, a two-sided 90% confidence interval is applied with a maximum error of estimate of 20% of the mean (10% on each side). The results for the selected currencies are shown for every tick of the simulation in Figure 5.1. Each dot corresponds to the number of replications of one model configuration at the specified tick with above described specifications (and thus at each year 50 dots are displayed). From these figures it can be seen that the most variable model outcome is biodiesel import, which requires 400 replication runs at year 2014. This number of replication runs is applied to every subsequent simulation run to explore the model. The results also show that in general the sample size for both currencies is quite comparable. Lastly, the figures indicate that, in general, the number of replication runs required to achieve the desired confidence interval increases as the simulation proceeds. This can be explained by means of path dependency, meaning that relatively small historical events may have a great impact on the final outcome [Schilling, 2014]. In other words, certain events that occur in the simulation run at a certain point in time are able to set the emergence of model outcomes on a (irreconcilable) different "track". As the simulation proceeds, these differences are more strongly magnified.

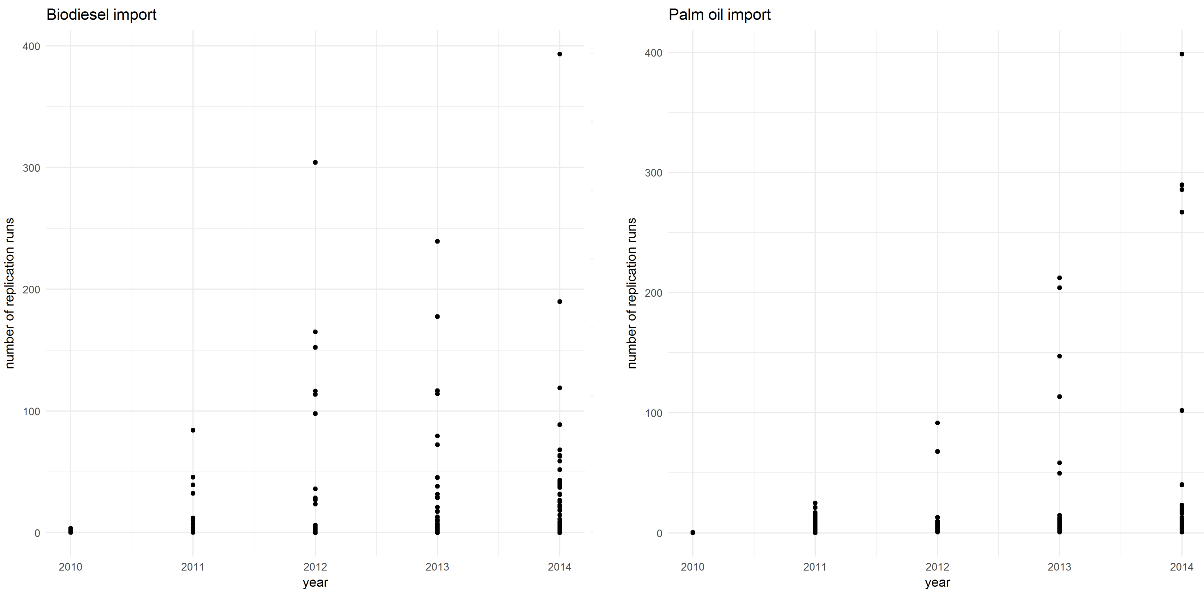

Figure 5.1: Number of replication runs required considering biodiesel import (left) and palm oil import (right)

5.5. SENSITIVITY ANALYSIS

A sensitivity analysis can be described as a systematic exploration of how responsive the outputs of a model are to changes in the model parameter values. For example, if a small change in parameter A significantly affects model outcomes and a similar change in parameter B only slightly affects model outcomes, the model is said to be more sensitive (i.e. less robust) to variations in parameter A than to variations in parameter B. In principle, all model parameters are addressed in a sensitivity analysis. In this way, one can develop more understanding about the model and the corresponding real system. According to Railsback and Grimm [2011], sensitivity analysis should be an integral part of performing analysis by means of ABM. In addition, a sensitivity analysis allows us to point out the importance of the uncertainty in parameter values: the higher the sensitivity, the higher the importance of the uncertainty and vice versa. In section 5.6 it will be discussed that the parameters the model is most sensitive to are interesting candidates to evaluate via calibration. In this way, sensitivity analysis is a tool that can provide guidance in the POM approach (see section 4.1) to reproduce observed patterns in real systems. Taking all these aspects into account, in this research also a sensitivity analysis is incorporated.

In literature different forms of sensitivity analysis can be found, ranging from basic to very sophisticated methods. Thiele et al. [2014] provides a comprehensive literature overview of the available methods for sensitivity analysis of ABMs. In this section a summary of this overview is given. For more detailed information the reader is referred to aforementioned paper. Globally, three groups of approaches can be distinguished: local sensitivity analysis, screening methods and global sensitivity analysis. In some aspects these groups do overlap, but there also some clear distinctions. Firstly, in a local sensitivity analysis only one parameter is adjusted at the time, usually within a small range, while other parameters are kept constant (the so-called "one-factor-at-time approach" (OAT)). The sensitivity may then, for example, be expressed as the change in the model output relative to the model output while considering a reference parameter set (i.e. a base- or default case). The main advantage of this approach is its simplicity. A disadvantage of this method is that a suitable reference parameter set is required. In addition, since only parameter at a time is varied, the interactions of the parameters cannot be captured. That is to say, this analysis only holds true for the specified reference parameter set.

The second group of approaches refer to screening methods. With screening methods one can examine, contrary to pure OAT approaches, variations of the parameters over a wide range of values to identify which ones strongly affect model outcomes. Screening methods tend to be computationally efficient and thus suitable to explore a larger set of parameters. Often screening methods make use one-factor-at-time approaches. This method allows us to rank the parameters based on their sensitivity. A widely used method for screening is Morris elementary effects screening. In section 5.5.1 this method will be discussed in more detail. The third and last group of sensitivity analysis methods refers to global sensitivity analysis. In a global sensitivity analysis several parameters are varied simultaneously and over the full range of possible values to examine both the effect of changing one factor at a time and the interactions between parameters. This distinguishes a global sensitivity analysis from a local sensitivity analysis and a screening method. Examples of methods for a global sensitivity analysis are the Sobol method and the Fourier Amplitude Sensitivity Test (FAST).

Now a global overview of methods for sensitivity analysis is given, the next step is to make a selection. Above described groups and methods for a sensitivity analysis differ in many aspects, like computational time, time to understand and implement the method and the information retrieved from the method. In addition, usually multiple methods are combined, since some methods are more suitable for initial exploration (like Morris screening), while other methods are more appropriate for an in-depth analysis (like FAST). In view of time limitations and the objective to guide model calibration, a sensitivity analysis that only provides a ranking of the parameters is considered suitable. Above that, it is chosen to limit the analysis to one method. This leaves the choice to either a local sensitivity analysis or a screening method.

To substantiate the final choice for the method used for the sensitivity analysis, first we need to consider the result derived in section 5.4. In this section it is found that over 400 replication runs are required. This large number of replication runs brings forward the practical problem of computational time. A single parameter configuration with this number of replication runs takes a bit less than 1.5 hours. Since the model consists of around 150 parameters, it would be practically infeasible to examine all parameters. Therefore, the sensitivity analysis in this research is limited to a select few. Hereto, three model parameters are selected: the price damping coefficient, the standard deviation of the noise level and the propensity to exploration of biorefineries (for explanation of these parameters, see below). These three parameters are selected, because in literature no data is found to substantiate these parameters and during model development these parameters are found to substantially influence model outcomes.

There are two reasons why a screening method is preferred over a local sensitivity analysis. Firstly, due to the lack of data to substantiate these parameters, it becomes more difficult to set a reference value for these parameters. It is attempted to manually derive a suitable set of default values, however this did not result in an unambiguous conclusion. Due to this uncertainty a screening method is more suitable in comparison with a local sensitivity analysis, since a screening method allows us to examine parameters over a wider range of values. In this way it is omitted that a suitable parameter set to mimic the patterns of interest is already excluded before calibration is applied. Secondly, although a screening method is more time intensive to understand and implement, a screening method is able to provide more insights (besides the ability to examine parameter ranges) in comparison with a local sensitivity analysis. According to Thiele et al. [2014], this gain outweighs the additional time investment. Therefore, a screening method is chosen. There are multiple methods to perform screening. Thiele et al. [2014] indicates that Morris screening appears to be the most suitable method for performing a sensitivity analysis with ABMs. Therefore, it is chosen to apply Morris screening. This topic will be discussed in more detail in section 5.5.1.

5.5.1. MORRIS SCREENING

As already indicated, a widely used method for screening is Morris elementary effects screening (Morris [1991]. In this section a description of Morris screening is given. For a detailed mathematical formulation of Morris screening, the reader is referred to Saltelli et al. [2004]. This description is started by listing the inputs the user needs to define to make use of Morris screening:

- Number of model parameters k to examine and range for each parameter
- Number of elementary effects e
- Number of levels l
- Number of levels per jump j
- Number of repetitions r to control for stochasticity

In the remainder of this section these inputs will be clarified. In Morris screening the parameter space is discretized into a k-dimensional grid. The granularity of this process is determined by the specified number of levels l, creating the specified number of equally spaced points within each parameter range. This is illustrated in Figure 5.2, with two parameters z_1 and z_2 ($k = 2$ and $l = 5$). This configuration results in l^k points, each specifying a parameter configuration. The idea of Morris screening is to evaluate these points to assess the average effect of each parameter on model outcomes.

However, in many cases, it would be practically infeasible to run the model for all points. Therefore, Morris screening introduces the notion of elementary effects. Elementary effects can be seen as sampled paths within the discretized parameter space. In Figure 5.2 two paths are shown ($e = 2$). Each consecutive set of arrows forms one path. Firstly, the model is run with the parameter configuration of the starting point of a path. Then the value of one parameter is adjusted and the model is again run. Then the value of one other parameter is adjusted (while keeping the previous adjusted parameter at the modified value and the other parameters at their starting values) and the model is run again. Subsequently, the difference in model outcomes of the first and second run is evaluated. This process is repeated until all parameters are adjusted. Looking at this process one can see a parallel with the local sensitivity analysis described in section 5.5, wherein also only one parameter is adjusted at the time. In addition, this also clarifies why Morris screening is sometimes also referred to as Morris one-at-time (MOAT).

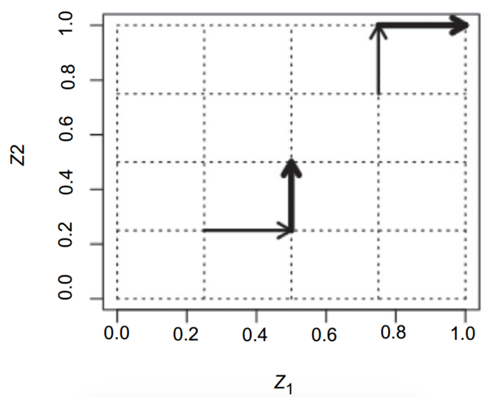

Figure 5.2: Example grid derived for Morris screening [Wallach et al., 2014]

The paths have a random chosen origin. Above that, the order and direction (positive or negative) in which parameters are adjusted are chosen randomly. The magnitude of a parameter value adjustment is defined by j, the number of levels per jump. Morris [1991] recommends taking $j = l/2$ as a guideline to get a certain symmetric treatment of parameters. In Figure 5.2 j equals 1. Once one path is completed, a new path is started and the entire process is repeated. Eventually this results in $e(k+1)r$ model runs. From this equation it can be seen that the number of model runs is linear with respect to k, which is an useful property in view of computational time. After all paths are completed, the changes in model outcomes (gradients) are statistically evaluated to assess their mutual importance for model outcomes. The theoretic basis of Morris screening is that the overall effect and interaction effect of each parameter can be approximated by the mean μ and/or μ^*

and standard deviation σ of the gradients derived from the paths [Gan et al., 2014], see Equation 5.2 to 5.4. In these equations $\Delta y_{i,k}$ denotes the gradient of model outcomes for path i and adjustment of parameter k.

$$\mu_k = \frac{1}{e}\sum_{i=1}^{e} \Delta y_{i,k} \tag{5.2}$$

$$\mu_k^* = \frac{1}{e}\sum_{i=1}^{e} |\Delta y_{i,k}| \tag{5.3}$$

$$\sigma_k = \sqrt{\frac{1}{e}\left\{\sum_{i=1}^{e} \Delta y_{i,k} - \mu_k\right\}^2} \tag{5.4}$$

Saltelli et al. [2004] describe how the outcomes of Equation 5.2 to 5.4 can provide useful insights into the model. These findings are summarized here:

- The importance of the factors with respect to overall influence on model outcomes can best be determined by ranking the parameters according to μ^*. A higher value of μ^* indicates a larger overall influence. μ^* is preferred over μ to rank parameters, because taking the absolute value avoids cancelling out effects due to opposite signs. This will also be clarified in this next item.
- The signs of the influence on model outcomes can be assessed by means of combing μ^* and μ. If μ^* and μ have the same high value, this means that the corresponding parameter has a large overall influence on model output and the sign of this effect is always the same (i.e. the effect is monotonic). Contrary, if μ^* is high and μ is low, this means that that the corresponding parameter has a large overall influence on model output and the sign of this effect is dependent on the examined parameter configuration (i.e. the effect is non-monotonic).
- To detect parameter interaction with other parameters and/or non-linear effects on model outcomes σ can be used. Two parameters are said to interact when their effect on model outcomes cannot be expressed as the sum of their individual effects. To understand the parameter interaction, one needs to recall that during Morris screening only one parameter is adjusted at the time. In addition, since different paths are explored, different parameter configurations are examined. A high value of σ indicates that the changes in model outcomes differ substantially from each other, i.e. the changes in model outcomes may be strongly affected by the values of the other parameters. If this is the case one speaks of an interaction effect. Opposite, a low value of σ may indicate that the changes in model outcomes are (almost) independent of the values of the other parameters. This is referred to as a first-order effect.

5.5.2. SETUP

To perform the sensitivity analysis, a R script is made that runs the NetLogo model. Hereto, use is made of the packages *RNetLogo* and *sensitivity* in R. The simulation run setup for the sensitivity analysis by means of Morris screening is given in Table 5.1. As clarified at the end of the introduction of section 5.5, three parameters will be investigated: the price damping coefficient, the standard deviation of the noise level and the propensity to exploration of biorefineries. Above that, each parameter configuration will be run with 400 repetitions (as derived in section 5.4.1). The number of elementary effects (e) is a designer choice. Recalling that the number of simulation runs is given by $e(k+1)r$, computational time is considered the main determinant for setting e. According to Saltelli et al. [2004], the minimum value for e to place confidence in the results is 4. It is also indicated that previous research has demonstrated that the choice of $e = 10$ and $l = 4$ has produced valuable results. Based on these aspects, e is set 10 and l is set 4. Lastly, because Morris [1991] recommends taking $j = l/2$ as a guideline, number of levels per jump (j) is set 2. This setup corresponds to 16 000 model runs. As described in section 5.2, the observed currencies are the biodiesel import and the palm oil import. The model outcomes are averaged over the duration of the simulation.

5.5.3. RESULTS

The results of the sensitivity analysis are graphically displayed in Figure 5.3. Firstly, the top left graph is considered. This figure considers the import of biodiesel. To examine the significance of their influence, hypothesis (H_0 and H_1) are formulated (as listed below) and tested. Assuming the data is normally distributed, an

Table 5.1: Simulation run setup for sensitivity analysis by means of Morris screening

parameter	symbol	units	value/range
number of model parameters to examine	k	[#]	3
number of elementary effects	e	[#]	10
number of levels	l	[#]	4
number of levels per jump	j	[#]	2
number of repetitions	r	[#]	400
price damping coefficient	β	-	$\{0\ldots1\}$
standard deviation noise level	-	[%]	$\{0\ldots10\}$
propensity to exploration biorefineries	p	-	$\{0\ldots3\}$

one-sample student t-test with a confidence interval of 95% is performed. It is found that for all three parameters H_0 is rejected (for detailed outcomes see Appendix D). This means that there is 5% chance of incorrectly rejecting H_0 and thus it is very likely that all three parameters have a statistically significant influence. If we consider the mutual differences, it can be seen that the propensity to exploration has the largest influence on biodiesel import. In comparison with the propensity to exploration, the price damping coefficient and the standard deviation of the noise level only have a marginal influence. If we consider the sign of the influence of the propensity to exploration, it can be seen that the values of μ and μ^* are the same and thus the corresponding effect on biodiesel import is monotonic and positive.

- H_0: $\mu^* = 0$
- H_1: $\mu^* > 0$

Secondly, the bottom left graph of Figure 5.3 is considered. This figure considers the import of palm oil. Like for the import of biodiesel, hypothesis are formulated (see above) and tested to examine the significance of their influence. Assuming the data is normally distributed, a one-sample student t-test with a confidence interval of 95% is performed. It is found that for all three parameters H_0 is rejected (for detailed outcomes see Appendix D). This means that there is 5% chance of incorrectly rejecting H_0 and thus it is very likely that all three parameters have a statistically significant influence. If we consider the mutual differences, it can be seen that the price damping coefficient has the largest influence on palm oil import, followed by the propensity to exploration and standard deviation of the noise level. In addition, the influence of the standard deviation of noise level is negligible in comparison with the price damping coefficient and the propensity to exploration are influential. If we consider the sign of the influence of the price damping coefficient and the propensity to exploration, it can be seen that the values of μ and μ^* are very similar and thus the corresponding effect on biodiesel import is mainly positive.

Thirdly, the top right graph of Figure 5.3 is considered. This figure considers the import of biodiesel. From the graph it can be seen that there is a weak interaction and/or non-linear effect of the propensity to exploration on biodiesel import. Therefore, the influence of the propensity to exploration on biodiesel import is mainly a first-order effect. Opposite, there is strong interaction and/or non-linear effect for the price damping coefficient and the standard deviation of the noise level. However as found earlier on, their influence on biodiesel import is marginal and thus the importance of this effect is limited. Lastly, the bottom right graph of Figure 5.3 is considered. This figure considers the import of palm oil. From this graph it can be seen that the price damping coefficient and the propensity to exploration (besides their important influence on palm oil import) also have a strong interaction and/or non-linear effect on palm oil import.

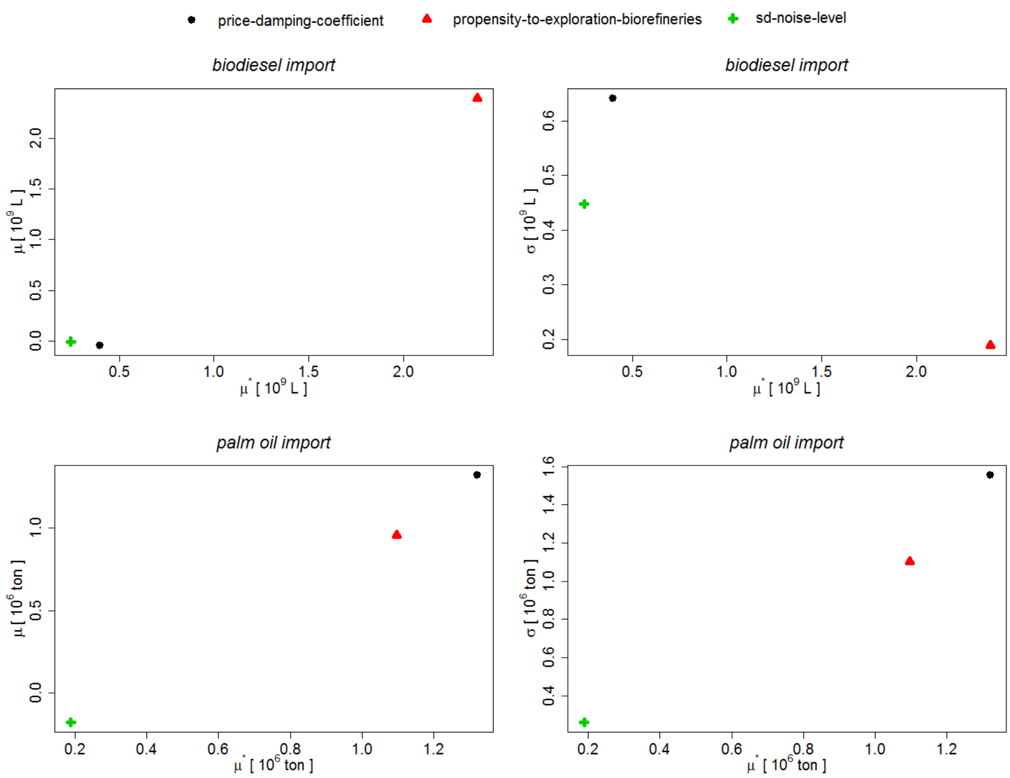

Figure 5.3: Simulation run results for sensitivity analysis by means of Morris screening

5.6. CALIBRATION

In section 4.1 the POM approach to reproduce observed patterns in real systems is discussed. Part of the POM approach is calibration. During calibration (or fitting) the model is run with different values for its parameters, subsequently the model outcomes are compared with observed patterns in real systems to determine which combination succeeds best. According to Railsback and Grimm [2011], calibration serves three purposes. Firstly, by forcing the model to match (historical) observations of a real system as well as possible, it is assumed that the model with the calibrated parameters produces more accurate and credible results than using the same model with non-calibrated parameters. Secondly, calibrations allows us to estimate parameter values for which no value can be established. In other words, calibration can be seen as "inverse modelling". Thirdly, calibration enables us to test the structural realism of the model. If we are able to match the observed patterns within a reasonable range, this provides confidence in the realism of the model. Contrary, if this is not the case, the implemented model mechanism may be reviewed. Calibration can also be seen as a method to address the notion that in the end every model is wrong. To overcome this issue, calibration can be used to project all uncertainty on a limited number of parameters.

In general, calibration of an ABMs is about fine-tuning of the model by reviewing the values of a limited number of parameters. Consequently, the model outcomes should be in the correct order of magnitude before calibration is started. This requirement is fulfilled by reviewing various model outcomes during model development, like yields, area allocation, biodiesel production, biodiesel feedstock composition. The selective character of calibration relates to the issue of overfitting. During calibration one can choose to calibrate more parameters to reproduce the observed patterns better. However, the data used for calibration itself also contains errors and uncertainty. So the downside of using more parameters for calibration is that the "noise" of the observed pattern is too strongly present in the model parameter estimates and thus the model might succeed well in reproducing the observed pattern, but may perform poor in simulating other conditions. Therefore, calibration of fewer parameters is preferred.

5.6.1. SETUP

To restrict the calibration to a limited number of parameters, the results of the sensitivity analysis performed in section 5.5 are applied. The parameters the model is most sensitive to are interesting candidates to evaluate via calibration, because this helps in using less parameters for calibration and thus preventing the issue of overfitting. In the sensitivity analysis it is found that the propensity to exploration of biorefineries and the price damping coefficient are important parameters. The first is most important for biodiesel import, the latter is most important for palm oil import. Therefore, both parameters are selected to calibrate the model with. Please note that it is also found that there is a strong interaction and/or non-linear effect on palm oil import for the price damping coefficient and the propensity to exploration. In principle, it should be avoided that the calibration parameters are dependent. However, as Thiele et al. [2014] indicates, usually parameters interact and are not independent and thus sets of parameters must be calibrated simultaneously.

Globally, two types of calibration can be distinguished: best-fit and categorical [Thiele et al., 2014]. In best-fit calibration, parameter values are derived that best fit the observed pattern. This results in one set of parameter values (one for each parameter). In categorical calibration a range of possible values is derived for each calibration parameter. This is especially useful when the observed patterns are highly variable or uncertain [Thiele et al., 2014]. Since best-fit calibration is considered more simple and the data is considered suitable to perform best-fit calibration, best-fit calibration is selected. Above that, since the change of model outcomes over time is important for this research, it is chosen to make use of time-series calibration. This implies that the fit between model outcomes and observations is reviewed for a time series. To quantify the fit between model outcomes and observations, use is made of the mean square error (MSE). The MSE is defined in Equation 5.5, with n the number of observations, y_i the observations and $\hat{y}_i$ the model outcomes (predictions). The objective during calibration is to minimize the MSE. It is chosen to consider both currencies simultaneously in the objective function, because we would like to explain the concurrent occurrence of both patterns (in line with the POM approach, see section 4.1).

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}\{y_i - \hat{y}_i\}^2 \tag{5.5}$$

One of the last steps before calibrating the model, is defining the calibration criteria. The calibration criteria refer to the patterns used to calibrate the model. The calibration criteria are chosen to be the import of biodiesel and palm oil for biodiesel purposes by EU-28, for the same reasons as specified in section 5.2 for selecting the currencies. The objective function is evaluated in two different forms (A and B).

For objective function A, the currencies are evaluated in terms of absolute numbers. For objective function B, the currencies are evaluated in terms of relative numbers (percentages). In this objective function, the first fraction (f_1) denotes the share of biodiesel import in the total inflow of biodiesel in EU-28, which is assumed to consist of import of biodiesel from Indonesia/Malaysia and domestic production ($0 \leq f_1 \leq 100\%$). The second fraction (f_2) denotes the share of palm oil in total feedstock used for domestic biodiesel production in EU-28 ($0 \leq f_2 \leq 100\%$). Hereby, the total feedstock used is assumed to consist only of rapeseed- and palm oil. The data used for calibration will presented simultaneously with the final results of the calibration (see Figure 5.4 and 5.5).

As already indicated, the objective during calibration is to minimize the MSE. To minimize the MSE an optimization method is required. Hereto, a genetic algorithm is used. A genetic algorithm is chosen, because it is available as a built-in tool within NetLogo. Above that, it is a relative simple optimization method and due to its widespread proven application the literature on this topic is abundant. A genetic algorithm is a meta-heuristic (i.e. a problem independent method) based on theory originating from evolutionary biology. The aim of this method is to find solutions to optimization problems. In short, the algorithm starts with evaluating multiple initial candidate solutions. Subsequently, based on the objective function a new set of candidate solutions is generated. Hereby, high quality solutions have a higher chance of returning in the new set of candidate solutions. This process is repeated until a stopping condition is met (e.g. a convergence criterion). An advantage of genetic algorithms is that good quality solutions can be found within reasonable time. A disadvantage of genetic algorithms is that no guarantee can be given an optimal solution is found. Another disadvantage is that genetic algorithms require the specification of various parameters. No set of parameter settings is available that is universally applicable for generating optimal solutions with a genetic algorithm. Due to time restrictions, (variations on) parameter values are applied in this research that were found to be commonly applied in literature (see e.g. Stonedahl [2011], de Jong [2006] and Mitchell [1999]).

5.6.2. RESULTS

The first results of the calibration are listed in Table 5.2. This table gives the found values for the parameters, while attempting to minimize the MSE for the two different objective functions (A and B) by means of a genetic algorithm. From this table it can be seen that the price damping coefficient is very close to 1 for both objective functions. This value indicates that the rate at which the weight factors fade-out over time is low. In other words, substantial emphasis is put on previous outlooks while marginal emphasis is put on the current observation, resulting in high damping (i.e. smoothing) of price developments. An explanation for this value is the occurrence of multi-year contracts within the biofuel supply chain. These contracts hamper actors in reacting immediately to the current situation. However, taking this into account, the value of the price damping coefficient is still higher than expected. As described at the beginning of this section, calibration can also be seen as a method to project all uncertainty on a limited number of parameters. This is an explanation for not meeting the expectations. A high value of the price damping coefficient also means that the initialization of the exponential smoothing procedure (i.e. setting a first value for $\hat{p}_t$, see Equation 4.2) for the different commodities and actors is an important step.

With respect to "propensity to exploration of biorefineries", different values are found for both objective functions. On the one hand, for objective function A the value of this parameter is close to 1, indicating a proportional reaction to (expected) financial results. On the other hand, for objective function B the value is found to be < 1, indicating a less than proportional reaction to (expected) financial results. For completeness, the root mean square error (RMSE, the square root of MSE) for each objective function is given. Please note that a direct comparison between both values is not possible due to different units. Therefore, the RMSE is normalized by dividing the RMSE by the mean of the historical observations. This is referred to as the NRMSE. Since the results obtained while applying objective function A show a lower NRMSE than while objective function B, these results are considered to give the best fit. An important thing to notice is the large difference for found values of the parameter "propensity to exploration biorefineries". For now it is considered sufficient to be aware of this. In the section on future research (section 6.2) this topic will be discussed.

Table 5.2: Parameter values resulting from model calibration

objective function	A		B	
description	absolute numbers		relative numbers	
parameter	value	units	value	units
price damping coefficient	0.98	[-]	0.99	[-]
propensity to exploration biorefineries	1.02	[-]	0.65	[-]
RMSE	0.58	[10^6 ton]	7.53	[%]
NRMSE	58.3	[%]	63.1	[%]

Subsequently, each parameter configuration is run with the parameters as given in Table 5.2. As derived in section 5.4.1, each parameter configuration is run with 400 repetitions. Figure 5.4 and 5.5 graphically display the simulation outcomes and the historical observations against time. The simulation outcomes are categorized means of nine (equally sized) quantile intervals. Every quantile represents 10% of the sampled model outcomes. The middle quantile (50%) represents the median.

From these figures it can be seen that the model succeeds in producing values in the correct order of magnitude. However, since most of the observations are outside the 90% envelope, it is concluded that the model does not succeed in exactly matching the observations. With respect to general dynamics, it appears that the model does succeed in reproducing these. Firstly, the import of biodiesel showed a surge around 2012, followed by a significant drop. Secondly, the import of palm oil for biodiesel purposes grew rapidly, but slowed down from 2013 onwards. The model succeeds in reproducing these dynamics while applying the parameter values retrieved with both objective functions. A limitation of this evaluation is that it is hard to draw an unambiguous conclusion about the qualitative match with the patterns.

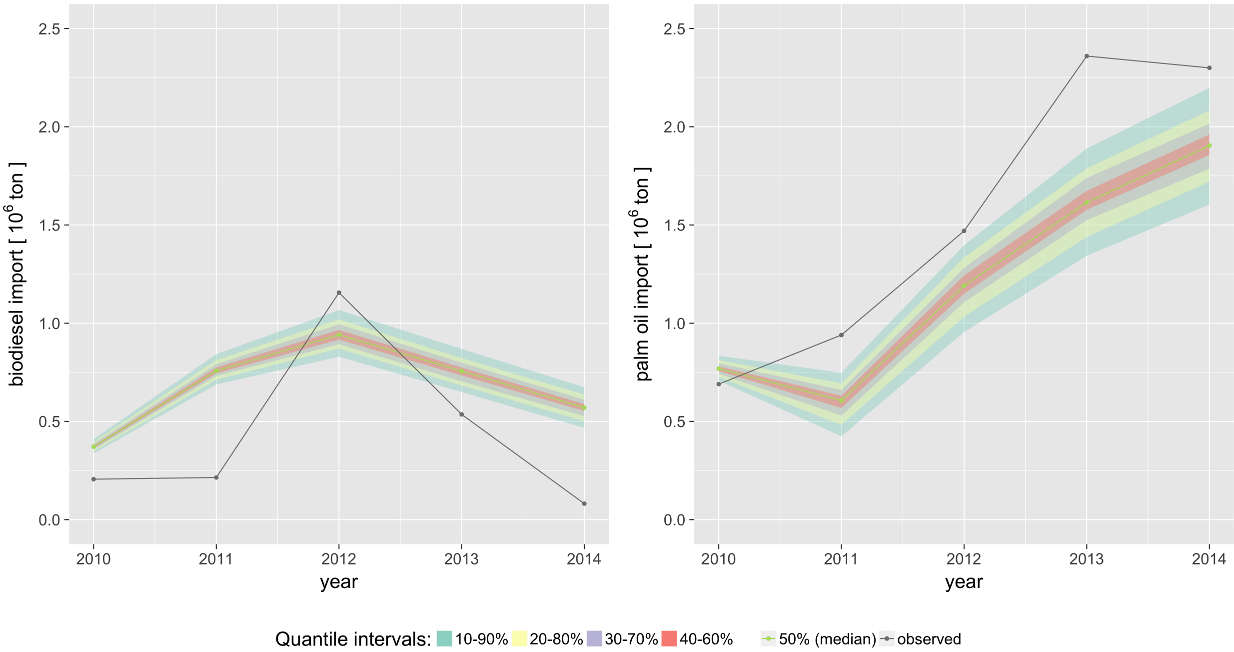

Figure 5.4: Objective function A, simulation outcomes and historical observations plotted against time for biodiesel import (left) and palm oil import (right)

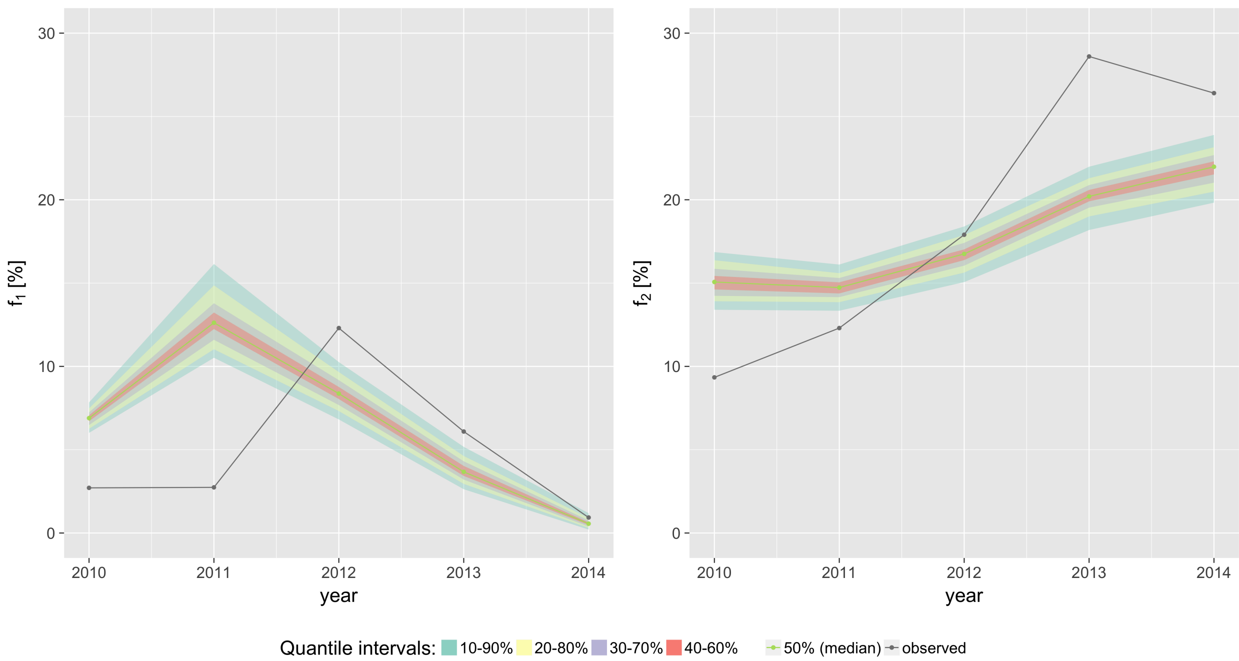

Figure 5.5: Objective function B, simulation outcomes and historical observations plotted against time for fraction biodiesel import in biodiesel inflow (left) and fraction palm oil as feedstock (right)

5.7. POLICY EXPLORATION

In the formulation of the objective of research (section 1.4) it is described that by developing a model of the international liquid biofuel markets, the interaction between policies and patterns of trade flows can be investigated. Subsequently, the retrieved insights can be used to fill the current knowledge gap with respect to how policies affect the international biofuel markets. This can contribute to reduce or even prevent unintended effects and associated negative consequences for the biofuel industry itself and the realisation of underlying policy objectives. Using the results of the previous simulation runs, we are now able to realize this line of thought for our case study. To be more specific, the aim of the simulation runs in this section is to gain insight into the expected influence of different policy combinations until year 2030 on the international trade flows of palm oil and biodiesel originating from Indonesia and Malaysia and directed towards EU-28. Based on these insights, a number of policy recommendations are formulated.

5.7.1. SETUP

In this section different policies are explored. This exploration is organized as follows. At the introduction of the conceptual model (see Figure 4.2) it is shown that a number prices and demands of different commodities are considered exogenous. For each of these parameters, an annual outlook is created up to year 2030. These outlooks are created as follows. Firstly, it is attempted to retrieve outlooks from literature. Hereto, outlooks presented by World Bank [2017] and OECD [2017] are consulted. If no (complete) outlooks are found, historical values found in literature (the same sources as presented in section 4.6) are extrapolated with appropriate trend lines.

Together these outlooks for these parameters form a base case scenario (referred to as scenario 1). Additionally, eight different scenarios are created. These scenarios are created by letting the development of two parameters (price of fossil diesel and palm oil) deviate from their expected values. These two prices are selected, because these are considered important parameters for the model outcomes. Two types of deviations are considered: the price turns to be 20% higher than expected ("high") and the price turns to be 20% lower than expected ("low"). By applying one deviation at a time, nine scenarios are created, as summarized in Table 5.3. The time series for the different scenarios are given in Appendix E.

Table 5.3: Definition of scenarios for policy exploration

	(producer) price fossil diesel		
price palm oil	low	base	high
low	6	4	7
base	2	1	3
high	8	5	9

Subsequently, different combinations of policy parameters are evaluated. Hereto two policies are selected: the import tariff on biodiesel and the import tariff on palm oil, both imposed by EU-28. These two policies are selected for closer examination, because the perspective of one stakeholder is preferred. Above that, the pattern found by Lamers et al. [2011] addressed in this research (see section 4.1) refers to import duties. The other policies are kept constant at their last registered form. The only exception is the raise of the blending mandate in EU-28 from 5.75% to 10% in the year 2020 (see section 4.6.5).

For each combination of policy parameters, the model is run up and including year 2030. The import tariffs on biodiesel and palm oil originating from Indonesia and Malaysia to enter EU-28 are each varied between 10 and 40% (ad valorem) at increments of 10%. This corresponds to the evaluation of 16 combinations of policy parameters. These policies come into effect after 2017 (in the period 2010-2017 the values given in section 4.6.5 apply). In addition, the parameter values derived during model calibration (see section 5.6.2) resulting in the lowest NRMSE (objective function A) are applied. Each parameter configuration is run with 800 repetitions. This number of replication runs is to a certain extent an ad hoc choice. In section 5.4.1 it is derived that 400 repetitions are required for a simulation duration of five years and the specified confidence interval. In the same section it is also found that the number of replication runs required for each tick increases as the simulation proceeds. Since the simulation duration applied in this section is significantly longer (20 years), the statistical underpinning of the outcomes should be approached with care.

In the next two sections, the results of the policy exploration are discussed. The results are distributed over two sections, because the results address different topics. In the first part of the results (part 1), the focus is on the selected pattern of Lamers et al. [2011]. In the second part of the results (part 2), the focus is on gaining insights for governments with respect to policy for liquid biofuels by examining different scenarios.

5.7.2. RESULTS - PART 1

The results of the simulation runs for policy exploration are shown in Figure 5.6, 5.7 and 5.8. On the global x-axis the import tariff on biodiesel is listed and on the global y-axis the import tariff on palm oil is listed. As already indicated, these policies come into effect after 2017. This is depicted in the graphs with a dashed red line. The green lines represent the means over the repetitions, while the gray lines represent error bars of one standard deviation. The top left corner of each figure corresponds to a more liberalized condition, while the bottom right corner corresponds to a more protectionist condition. Since the conversion efficiency of palm oil to biodiesel is nearly 100% (see section 4.6.3), a direct comparison between the numbers of palm oil import and biodiesel import is possible. To keep the analysis simple, in this section only the base case (scenario 1) is considered. In the subsequent section the entire set of scenarios is treated.

Firstly, the results for different values of import tariff on palm oil are considered while keeping the import tariff on biodiesel constant. On the one hand, Figure 5.6 shows that the import of biodiesel is hardly affected by the import tariff on palm oil. On the other hand, Figure 5.7 shows that the import of palm oil is dampened as the import tariff on palm oil increases (and vice versa). This confirms the pattern described by Lamers et al. [2011] that trade volumes are affected by import duties. Secondly, the results for different values of import tariff on biodiesel are considered while keeping the import tariff on palm oil constant. From Figure 5.6 it can be seen that the import of biodiesel decreases as the import tariff on biodiesel increases (and vice versa). So again, this confirms the pattern described by Lamers et al. [2011].

Figure 5.7 shows something else that is noteworthy. From this figure it can be seen that the import of palm oil increases as the import tariff on biodiesel increases (and vice versa). At low levels of import tariffs (e.g. 10%), directly importing biodiesel (say option 1) turns out to be more attractive to the modelled system than the sequence of importing palm oil and processing it to biodiesel in EU-28 (say option 2). As the import tariff on biodiesel increases, option 1 becomes less attractive in comparison with option 2. The simulation runs show that via the import of palm a part of the released bandwidth (due to higher imports on biodiesel) is absorbed. In other words, the "gain" at the biodiesel side is (partially) "lost" at the palm oil side. Consequently, international trade flows may not only be affected by the import tariff on the corresponding commodity, but also by the import tariffs on other (related) commodities. Therefore, it is recommended to policy makers to reflect new policy in the context of other policy measures instead of considering one policy at a time.

The diagonals (top left - bottom right) of Figure 5.6 and 5.7 represent equal levels of import tariff on biodiesel and palm oil. As already indicated, at low levels of import tariffs (e.g. 10%), directly importing biodiesel turns out to be more attractive to the modelled system than the sequence of importing palm oil and processing it to biodiesel in EU-28. As import tariffs increase (shifting to the bottom right corner), both international trade flows are affected. However, the trade flow of palm oil is a lot less affected in comparison with the trade flow of biodiesel. As a result, with an import tariff of 40%, the sequence of importing palm oil and processing it to biodiesel in EU-28 is more attractive to the modelled system instead of directly importing biodiesel. Thus it is concluded that the international trade flow of palm oil is "stronger". As a result, relative more financial pressure must be exerted to reduce the import of palm oil to the same level as for biodiesel. Therefore, it is concluded that the effect of changing the import tariff on biodiesel is greater than the effect of changing the import tariff on palm oil.

In Figure 5.8 the biodiesel production in EU-28 is shown. The international trade flows of biodiesel and palm oil affect the biodiesel production in EU-28. The figure shows that effect of changing the import tariff on biodiesel is greater than the effect of changing the import tariff on palm oil. This is according to expectation, because the same is observed for the international trade flows of biodiesel and palm oil. The figure also shows that the production of biodiesel reaches the highest level with a high import tariff on biodiesel and a low import tariff on palm oil. If the changes in import of palm oil (Figure 5.7) are compared with the changes in biodiesel production in EU-28 for different levels of import tariff on palm oil, it appears that rapeseed is hardly able to replace palm oil as feedstock for biodiesel production. In other words, low import tariffs on palm oil may be beneficial in terms of productivity of EU-28 biodiesel plants.

Lastly, in Figure 5.6 and 5.7 a few "hiccups" are visible. One type of hiccup originates from the change in policy in year 2018. If this policy is substantially different from the last registered value (import tariff of 18.9% on biodiesel and 3.8% on palm oil), this may cause a hiccup in the model outcomes. One other type of hiccup originates from very low or no demand in a biodiesel market. For example, a hiccup is visible in Figure 5.6 in the graph corresponding to 20% import tariff on biodiesel and 40% import tariff on palm oil at 2024-2025. In this case, the price of biodiesel on the EU-28 market becomes very low or even zero (in case there is no demand). The next year(s), more actors will address this market due to the favourable prices and the market is able to recover (partially). These model outcomes are related to the fact that in the model nothing is specified with respect to "market crashes". That is to say, under which conditions a commodity market closes definitively. It also relates to the assumption that actors cannot go bankrupt and the distributors/retailers are modelled as one actor. The model tends to show that the situation just before this type of hiccups returns within a number of years.

A different type of hiccup could originate from the presence of two biodiesel markets (EU-28 and Indonesia/Malaysia). If the price level of both markets come very close or cross, this may cause a hiccup. This type of hiccup can be seen in Figure 5.7 in the graph corresponding to 10% import tariff on biodiesel and palm oil around year 2022. Following a downward trend of biodiesel prices on the EU-28 market, the prices of biodiesel on both markets become very comparable. Since biodiesel originating from EU-28 has an advantage in terms of transport cost, more demand for biodiesel is directed to the EU-28 market, which forces prices on the EU-28 market up. This is followed by more production, and so forth. The hiccup disappears as the "normal" situation (price biodiesel on EU-28 market is higher than price biodiesel on Indonesian/Malaysian market) recovers. This hiccup is also related to the fact that distributors/retails are modelled as one actor and the strategic decision making of the distributors/retailers for buying biodiesel on these two markets (see section 4.5.3) is very basic.

Figure 5.6: Outlook on biodiesel import by EU-28 up to 2030 for different combinations of import tariffs (ad valorem, scenario 1)

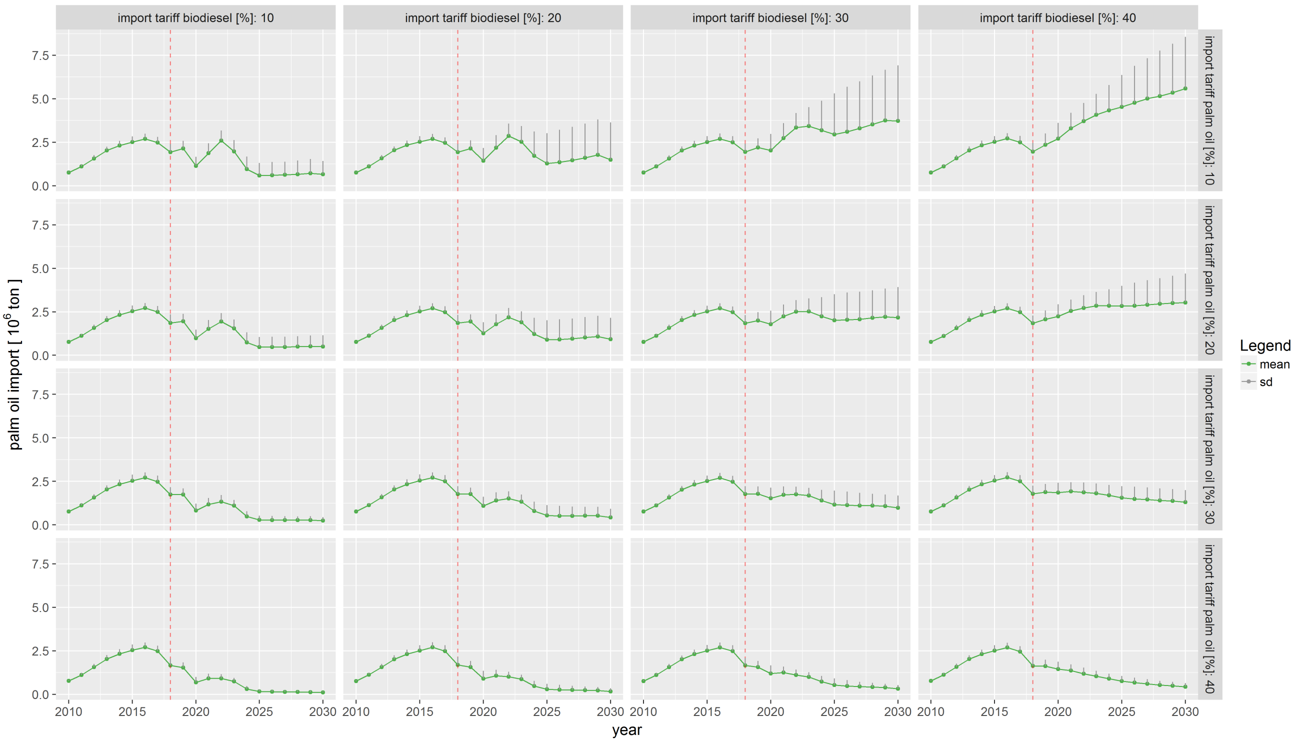

Figure 5.7: Outlook on palm oil import by EU-28 up to 2030 for different combinations of import tariffs (ad valorem, scenario 1)

Figure 5.8: Outlook biodiesel production in EU-28 up to 2030 for different combinations of import tariffs (ad valorem, scenario 1)

5.7.3. RESULTS - PART 2

In this section the focus is on gaining insights for governments with respect to policy for liquid biofuels. Hereto, the results of the simulation runs of part 1 are complemented with the simulations runs for different scenarios for the price development of fossil diesel and palm oil. The results of the simulation runs for policy exploration are shown in Figure 5.9 and 5.10. Again, the import tariff on biodiesel is listed on the global x-axis and the import tariff on palm oil is listed on the global y-axis. Likewise, these policies come into effect after 2017 and are depicted in the graphs with a dashed red line. The scenarios also come into effect after 2017. The lines represent the means over the repetitions.

In Figure 5.9 each plot shows a spectrum of lines. In general, these spectra are enclosed by two scenarios. The upper limit of each spectrum is usually given by an orange line. This line corresponds to scenario 6, indicating a low price scenario for fossil diesel and palm oil (see Table 5.3). The lower limit of each spectrum is for the most part given by a pink line. This line corresponds to scenario 9, indicating a high price scenario for fossil diesel and palm oil. Please note that these two scenarios are reciprocals of each other. The base case (scenario 1) lies somewhere in between the upper- and lower limit.

While shifting from the upper limit to the lower limit, two factors change: fossil diesel becomes more expensive and palm oil becomes more expensive. This has a number of consequences. Firstly, as fossil diesel becomes more expensive, this will enhance the price competitiveness of biodiesel (in general) in comparison with fossil diesel. Secondly, as palm oil becomes more expensive, it will worsen the price competitiveness of palm oil relative to rapeseed for biodiesel producers in EU-28. Above that, it will worsen the price competitiveness of biodiesel originating from Indonesia/Malaysia in comparison with biodiesel originating from EU-28 and fossil diesel, because biodiesel production in Indonesia/Malaysia is tied to using palm oil as feedstock.

The question which then arises is which price change causes the largest overall effect with respect to biodiesel import. To examine this, the effect of shifting from the upper limit to the lower limit is decomposed. Hereto, two sequences are created, which are listed below. If these two sequences are compared, it can be seen that scenario 8 (brown, low fossil diesel price, high palm oil price) is closer to the lower limit than scenario 7 (yellow, high fossil diesel price, low palm oil price). This analysis can also be performed in an analogues matter but in the opposite direction (shifting from the lower limit to the upper limit). In the end this yields the same results. Therefore, it is concluded that a change in palm oil price produces a larger effect with respect to biodiesel import than a same proportional change in fossil diesel price.

- Sequence 1: 6 → 7 → 9 (orange → yellow → pink)
- Sequence 2: 6 → 8 → 9 (orange → brown → pink)

Subsequently, Figure 5.10 is considered. For this figure a same analysis is conducted as performed for Figure 5.9. In Figure 5.10 each plot also shows a spectrum of lines and these spectra are (in general) also enclosed by two scenarios. The upper limit of each spectrum is predominantly given by a yellow line. This line corresponds to scenario 7, indicating a high price scenario for fossil diesel and a low price scenario for palm oil. The lower limit of each spectrum is usually given by a brown line. This line corresponds to scenario 8, indicating a low price scenario for fossil diesel and a high price scenario for palm oil. Again, these two scenarios are reciprocals of each other.

While shifting from the upper limit to the lower limit, two factors change: fossil diesel becomes more cheap and palm oil becomes more expensive. The consequences can be deduced in a similar fashion as described above. To examine which price change causes the largest overall effect with respect to palm oil import, the same decomposition approach is applied. Hereto, two sequences are created, which are listed below. If these two sequences are compared, it can be seen that scenario 9 (pink, high fossil diesel price, high palm oil price) is closer to the lower limit than scenario 6 (orange, low fossil diesel price, low palm oil price). Similarly, shifting from the lower limit to the upper limit in the end yields the same findings. Therefore, it is concluded that a change in palm oil price produces a larger effect with respect to palm oil import than a same proportional change in fossil diesel price.

- Sequence 1: 7 → 9 → 8 (yellow → pink → brown)
- Sequence 2: 7 → 6 → 8 (yellow → orange → brown)

If the simulation runs results are taken into account while making policy decisions, the first thing to be noticed is that the simulation outcomes vary from scenario to scenario. Figure 5.9 and 5.10 show that the size of the spectrum differs among the policy combinations. This is important, because the larger the size of the spectrum, the more likely it is that large deviations in imports occur due to price changes. The spectrum for biodiesel import is the largest for import tariffs on biodiesel in the range 20-30%. The spectrum size is hardly affected by the import tariff on palm oil. The spectrum for palm oil import tends to become larger as the import tariff on biodiesel increases. Above that, the spectrum for palm oil import tends to become smaller as the import tariff on palm oil increases.

For simplicity, the results are analysed in more detail from the base case (scenario 1) perspective. Hereto, use is made of the figures presented in the previous section. For completeness, an upper and lower limit (according to the scenarios analysed) are indicated between brackets. In Figure 5.6 it is shown that the import of biodiesel converges for an import tariff rate of 10% on biodiesel. This ceiling is present due to the prevailing biodiesel blending mandate. Apparently, despite the imposed penalty, biodiesel would still not be cost competitive in comparison with fossil diesel.

The combination of 20% import tariff on biodiesel and 10% import tariff on palm oil most closely resembles the current-day situation (see section 4.6.5). If these policy measures are maintained in the future, the import of biodiesel is expected to grow significantly to around $15*10^6$ ton in 2030 (upper limit: $15.8*10^6$ ton, lower limit: $12.5*10^6$ ton). This would be sufficient to realize a blending mandate of around 8.2% (upper limit: 8.6%, lower limit: 6.8%). Considering the (expected) 10% blending mandate, this would mean that almost the entire blending mandate is fulfilled with foreign biodiesel. At the same time, the import of palm oil is expected to fluctuate between $1\text{-}3*10^6$ ton (upper limit: $3.7*10^6$ ton, lower limit: $0.5*10^6$ ton). This could represent an additional 1.1% point (upper limit: 1.4%, lower limit: 0.7%) for the blending mandate. Therefore, under these conditions palm oil is expected to be less dominant in the European biodiesel market in comparison with imported biodiesel from Indonesia and Malaysia. Taking these aspects into account, around 0.7% point (upper limit: 2.5%, lower limit: 0%) of the blending mandate would remain for the biodiesel industry in EU-28 using rapeseed as feedstock.

Based on the performed exploration, the concerns expressed by the European biodiesel industry (as described in section 4.6.5) seem legitimate. Following the results, the current setup of policy measures deployed by EU-28 does not seem sufficient to prevent collapse of the EU-28 biodiesel industry due to imports from Indonesia/Malaysia. To curb these international trade flows, a raise in import tariffs would be required. It is expected that a raise of import tariff on biodiesel to 40% would be sufficient to maintain the import of biodiesel at a low level. In a worst case scenario (low fossil diesel price and low palm oil price), the import of biodiesel would be around $4*10^6$ ton in 2030. In case the growing import of palm oil is also considered undesired, this import tariff on biodiesel should be complemented with a raise of import tariff on palm oil for biodiesel purposes to at least 20% to maintain the import of palm oil at a similar level as the import of biodiesel ($\leq 4*10^6$ ton). In a worst case scenario (high fossil diesel price, low palm oil price) the simulation results indicate that the import of palm oil may exceed this level. In this case, an import tariff of 30% on palm oil may be necessary. However, it is important to take into account that raising the import tariff on palm oil is not necessarily beneficial in terms of productivity of EU-28 biodiesel plants (as shown in part 1 of the results).

Figure 5.9: Outlook on biodiesel import by EU-28 up to 2030 for different combinations of import tariffs (ad valorem)

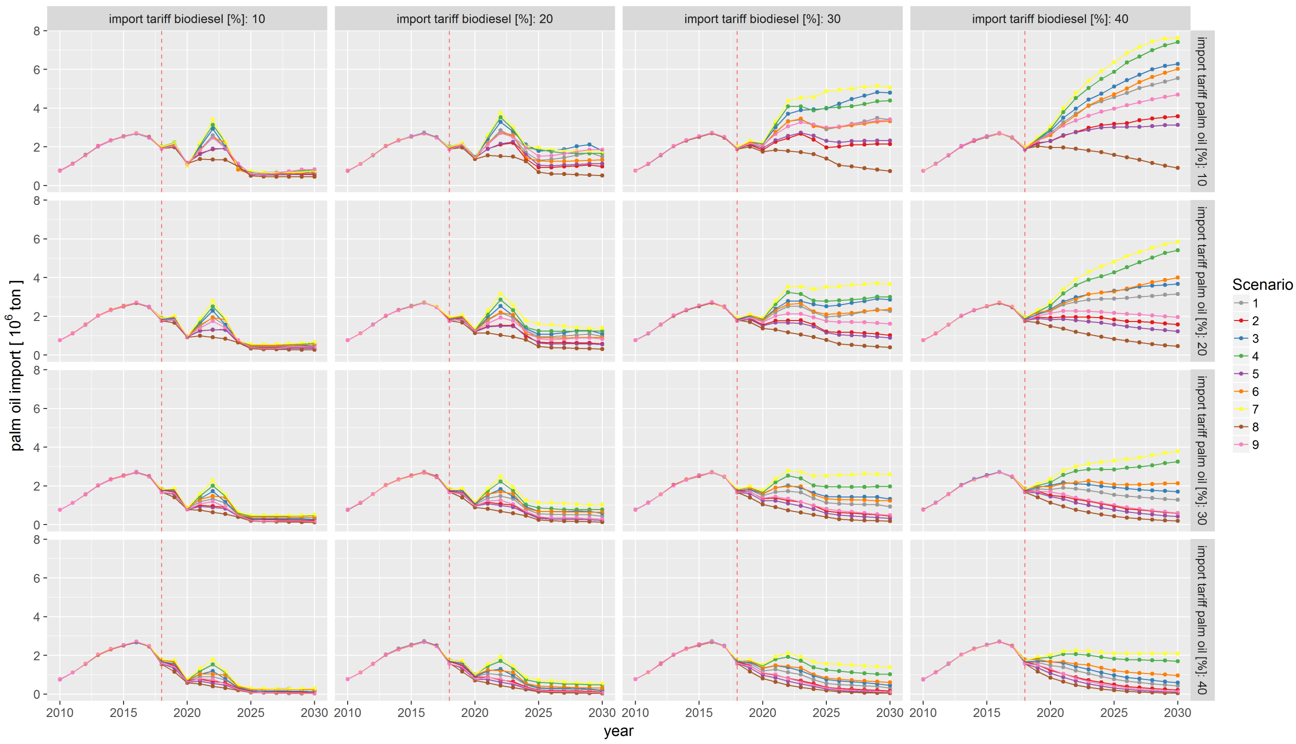

Figure 5.10: Outlook on palm oil import by EU-28 up to 2030 for different combinations of import tariffs (ad valorem)

5.8. SUMMARY

The main findings of the simulation runs are retrieved in section 5.6 (calibration) and 5.7 (policy exploration). For the calibration two (historical) time series of trade flows are considered. Firstly, the import of biodiesel by the European Union originating from Indonesia and Malaysia. Secondly, the import of palm oil for biodiesel purposes by the European Union, also originating from Indonesia and Malaysia. It is found that the model succeeds in reproducing these patterns simultaneously in the correct order of magnitude and with the same general dynamics. The corresponding normalized mean square error amounted to 58.3%.

In a study by Lamers et al. [2011] it is found that trade volumes were largely influenced by import duties, whereas trade routes were mainly driven by tariff preferences. However, the study performed by Lamers et al. [2011] did not explain the underlying mechanism. As indicated in the objective of research (section 1.4), the aim of this research is to fill this knowledge gap. In the policy exploration it is shown that the import of palm oil is dampened as the import tariff on palm oil increases (and vice versa). It is also shown that the import of biodiesel decreases as the import tariff on biodiesel increases. This means that the model confirms the pattern described by Lamers et al. [2011] and thus can explain the underlying mechanism.

In the policy exploration more information is retrieved. It is found that international trade flows may not only be affected by the import tariff on the corresponding commodity, but also by the import tariffs on other (related) commodities. Besides that, it is also observed that relative more financial pressure must be exerted to reduce the import of palm oil to the same level as for biodiesel. Therefore, it is concluded that the effect of changing the import tariff on biodiesel is greater than the effect of changing the import tariff on palm oil. With respect to biodiesel production in EU-28 it appears that rapeseed is hardly able to replace palm oil as feedstock for biodiesel production. In other words, low import tariffs on palm oil may be beneficial in terms of productivity of EU-28 biodiesel plants.

In the policy exploration also different scenarios for the price development of fossil diesel and palm oil are considered. It is found that a change in palm oil price produces a larger effect with respect to biodiesel import than a same proportional change in fossil diesel price. It is also found that a change in palm oil price produces a larger effect with respect to palm oil import than a same proportional change in fossil diesel price.

If the current-day policy measures of EU-28 are maintained in the future, the import of biodiesel is expected to grow significantly in the future. It is anticipated that almost the entire blending mandate is fulfilled with foreign biodiesel. Palm oil is expected to be less dominant in the European biodiesel market in comparison with imported biodiesel. Lastly, it is shown that a small share of the blending mandate would remain for the biodiesel industry in EU-28 using rapeseed as feedstock.

6

Conclusions and future research

This chapter forms the closing piece of this thesis. The conclusions are drawn in section 6.1. Subsequently, recommendations for future research are formulated in section 6.2. Lastly, a reflection is given in section 6.3.

6.1. Conclusions

Biofuels are appealing to policy makers due to their potential for addressing climate change, energy security and economic development. To realize the potential advantages of biofuels, policy makers impose various measures to stimulate the production and consumption of biofuels, such as import- and export tariffs, offering subsidies and mandating blending targets. These policies played a very important role in the history of international biofuel trade. The biofuel markets have an international character, because feedstock production, biofuel production and biofuel demand are not equally distributed around the globe. However, in literature examples can be found of major unforeseen and unintended effects on a global level resulting from the implementation of certain policies.

To reduce or even prevent these effects, decision making by policy makers needs to be better informed. Governments could take into account the potential impact of national policy measures on a global level. However, the influence of policies on global bioenergy trade flows is not well understood. To address this knowledge gap the following question is addressed in this research: *which mechanism can explain the effect of policies on emerging patterns in the international trade flows of liquid biofuels and feedstock?*

To answer this question, an agent-based model (ABM) is developed. This model is used to perform computer-based simulations. To limit the scope of this research, a case study is performed. In this case study a number of key players in the international biodiesel market is considered: the European Union, Indonesia and Malaysia. Since the take-off of the biodiesel industry (around the year 2000), the EU-28 has been one of the largest producers and consumers of biodiesel in the world. Above that, in the past the European biodiesel market has been targeted as an export market for biodiesel and feedstock by various countries. Two of these countries are Indonesia and Malaysia. These countries dominate global palm oil production. Data shows that palm oil covered a large share of the growth in biodiesel production in the European Union in recent years. In addition, like the European Union, Indonesia and Malaysia accommodate a large scale biodiesel industry. The export of biodiesel from Indonesia and Malaysia used to be mainly directed to the European Union. This case study implies that the focus of this research is on first-generation liquid biofuels. The case study is performed to answer the main research question. The answer to this question is twofold:

- For the case study two (historical) time series of trade flows are considered. Firstly, the import of biodiesel by the European Union originating from Indonesia and Malaysia. Secondly, the import of palm oil for biodiesel purposes by the European Union, also originating from Indonesia and Malaysia. It is found that the proposed mechanism succeeds in reproducing these patterns simultaneously in the correct order of magnitude and with the same general dynamics. The corresponding normalized mean square error amounted to 58.3%. This result provides confidence in the realism and accuracy of the model.
- In a study on international bioenergy trade by Lamers et al. [2011], it is found that import duties are key influencing factors on trade volumes. However, aforementioned study did explain the underlying mechanism. The simulation runs show that the import of palm oil is dampened as the import tariff on palm oil increases (and vice versa). It is also shown that the import of biodiesel decreases as the import tariff on biodiesel increases. This means that the model confirms the pattern described by Lamers et al. [2011] and thus can explain the underlying mechanism.

To answer the main research question, the following sub questions are answered:
1. Which actors are involved in the biofuel supply chain and which role do they fulfil?
A complex trading network underlies the biofuel supply chain. Three groups of actors can be distinguished in this network. The first group includes the biomass producers (farmers), which produce and sell biomass. The production of biomass is usually characterized by a relative large number of small companies (small holders). The second group includes the biofuel producers, distributors and retailers. The actors in this group fulfil different combinations of these functions and thus the roles of these actors show (partial) overlap. Two important sets of actors in this group are oil companies (like Shell, Petrobras and British Petroleum) and agricultural trading companies (like Archer Daniels Midlands, Bunge, Cargill and Louis Dreyfus Commodities). The third group includes the biofuel consumers. These consumers originate from the private- and public sector. Liquid biofuels are almost solely consumed for transport purposes (mainly road transport).

2. Which governance structures and pricing systems are applied for organising transactions in the biofuel supply chain?
Since the biofuel supply chain is a trading network, transactions of commodities are a key element. These transaction can be organised in different ways. In this research transactions of biomass and biofuel are examined. Contracts are the most common form of biomass trade. These contracts offer advantages for the buyer and the seller, in terms of quality control of the commodities, stability of supply of feedstock/income and risk. Contrary to biomass trade, little is known about biofuel trade. This originates from a lack of transparency in this sector and the fact that biofuel trade is a relative recent development. For biofuel trade an important role is present for price reporting agencies (PRAs, such as Platts and Argus). These agencies collect market information and provide actors with (assessed) spot market prices. This assists actors in keeping track of market developments outside their field of vision.

3. To which extent are biomass and biofuels traded internationally?
Biomass trade tends to be local and decentralized. The main reason is the relative high transport cost in comparison with the energy density. In addition, technically mature and cheap processing technologies to enhance this ratio are still missing. Above that, quality degradation (like rotting) may play a role. By examining international trade of the main agricultural commodities, it appears that the share of biomass that is traded internationally varies between 0% and 40%. In other words, the major part of these commodities resides within the country of origin. Palm oil is an exception: nearly 80% of the palm oil produced is traded internationally. This is related to the low price of palm oil in comparison with similar commodities. In comparison with biomass, biofuels are more suitable for long distance transport. However, if international trade of biodiesel and bioethanol is reviewed, it appears that only a small share (<20%) of global production is traded internationally. A reason for this is the relative recent development of biofuel trade. It is expected that international trade in biofuels will continue to grow substantially in the future.

4. How do actors involved in the biofuel supply chain make decisions while fulfilling their role?
For the analysis three actors are considered: farmers, biodiesel producers and biodiesel distributors/retailers. Farmers can grow different types of crops. Hereto, farmers take into account the (expected) profits. However, in literature many indications can be found that farmers are not pure profit maximizers. It appears that many other (non-financial) factors play a role, like knowledge, ease of crop management and moral considerations. These barriers restrain farmers from profit maximization. In literature no research on decision making of biodiesel producers and distributors/retailers is found. Based on the available information it is possible to deduce a number of aspects that play a role. With respect to biodiesel producers, the type of biodiesel plant affects the choice for a certain type of feedstock (composition). Usually, a single-feedstock plant is able to process only one type of feedstock, whereas a multi-feedstock plant is able to process multiple types of feedstock. Additionally, substantial overcapacity for the production of biodiesel is present in EU-28, Indonesia and Malaysia. Therefore, it is concluded that biodiesel plants may face the decision to operate at a certain capacity below the theoretical maximum. Lastly, since biofuels are in general more expensive than their fossil counterparts, governments impose penalties in case blending mandates are not met. These penalties affect the choice of distributors/retailers to deliver a certain diesel blend to the consumers.

6.1.1. CONCLUSIONS FOR POLICY MAKERS

In this section the conclusions for policy makers are formulated. It is emphasized that model outcomes may not be representative as realizations of the exogenous model parameters fall outside the considered scenarios (see Appendix E) or model assumptions (see section 4.7.2) turn out to not hold true.

5. What is the expected influence of different policies on future international trade flows of liquid biofuels and feedstock under different scenarios?

In a policy exploration the international trade flows until year 2030 of palm oil and biodiesel originating from Indonesia and Malaysia and directed towards the European Union are examined. In the exploration, two policies are varied: the import tariff on biodiesel and the import tariff on palm oil, both imposed by the European Union. Furthermore, nine different scenarios are evaluated. These scenarios contain different combinations of price development of fossil diesel and palm oil. The scenarios consider normal (as expected), high (+20%) and low (-20%) price developments.

From the analysis it follows that the upper limit of biodiesel import tends to given by a low price scenario for fossil diesel and palm oil. For the lower limit the opposite holds true. If the effect of price changes of biodiesel and palm oil is compared, it appears that a change in palm oil price produces a larger effect with respect to biodiesel import than a same proportional change in fossil diesel price. The upper limit of palm oil import is predominantly given by a scenario with high fossil diesel prices and a low palm oil prices. For the lower limit the opposite holds true. By comparing the effects of price of biodiesel and palm oil, it is shown that a change in palm oil price produces a larger effect with respect to palm oil import than a same proportional change in fossil diesel price. It is also found that relative more financial pressure must be exerted to reduce the import of palm oil to the same level as for biodiesel. Therefore, it is concluded that the effect of changing the import tariff on biodiesel is greater than the effect of changing the import tariff on palm oil.

If the current-day situation of policy measures are maintained in the future, the import of biodiesel is expected to grow significantly to around $15*10^6$ ton in 2030 (upper limit: $15.8*10^6$ ton, lower limit: $12.5*10^6$ ton). This would be sufficient to realize a blending mandate of around 8.2% (upper limit: 8.6%, lower limit: 6.8%). Considering the (expected) 10% blending mandate, this would mean that almost the entire blending mandate is fulfilled with foreign biodiesel. At the same time, the import of palm oil is expected to fluctuate between 1-$3*10^6$ ton (upper limit: $3.7*10^6$ ton, lower limit: $0.5*10^6$ ton). This could represent an additional 1.1% point (upper limit: 1.4%, lower limit: 0.7%) for the blending mandate. Therefore, under these conditions palm oil is expected to be less dominant in the European biodiesel market in comparison with imported biodiesel. Lastly, around 0.7% point (upper limit: 2.5%, lower limit: 0%) of the blending mandate would remain for the biodiesel industry in the European Union using rapeseed as feedstock.

6. Which recommendations can be formulated for governments with respect to policy for liquid biofuels?

Since the policy measures are investigated from the perspective of the European Union, the recommendations mainly address the involved governments. In the simulation runs it is shown that the import of palm oil increases as the import tariff on biodiesel increases (and vice versa). An explanation for this is that via the import of palm a part of the released bandwidth (due to higher imports on biodiesel) can be absorbed. Consequently, international trade flows may not only be affected by the import tariff on the corresponding commodity, but also by the import tariffs on other (related) commodities. Therefore, it is recommended to policy makers to always consider new policy measures in the context of other active policy measures.

Given the simulation outcomes, the concerns expressed by the European biodiesel industry seem legitimate. Following the results, the current setup of policy measures of the European Union does not seem sufficient to prevent collapse of the European biodiesel industry due to imports from Indonesia/Malaysia. To curb these international trade flows, a raise in import tariffs would be required. It is expected that a raise of import tariff on biodiesel to 40% would be sufficient to maintain the import of biodiesel at a low level. In a worst case scenario, the import of biodiesel would be around $4*10^6$ ton in 2030. In case the growing import of palm oil is also considered undesired, this import tariff on biodiesel should be complemented with a raise of the import tariff on palm oil for biodiesel purposes. However, it is important to take into account that raising the import tariff on palm oil may negatively affect productivity of biodiesel plants situated in the European Union, because rapeseed appears hardly able to replace palm oil as feedstock for biodiesel production.

6.2. RECOMMENDATIONS FOR FUTURE RESEARCH

The recommendations for future research are divided into three parts. Firstly, recommendations from a methodological point of view are given. Secondly, suggestions for model improvement are formulated. Thirdly, potential modelling questions for future research are formulated.

- In section 5.6 the model is calibrated. During calibration two objective functions are used (A and B). The results show that the values for the parameter "price damping coefficient" (β) are very similar, while the values for the parameter "propensity to exploration biorefineries" (p) differ substantially. For future research it is an interesting topic to examine what causes this difference. For example, one could analyse the change in model outcomes if the value of p is varied between the two extremes. An other idea would be to reconsider the current setup to use one value for p for determining the strive capacity utilization rate (Equation 4.5) and the feedstock composition (see Equation 4.6) of biorefineries. For example, by splitting the parameter (e.g. in p_1 and p_2). An other possibility would be to apply heterogeneous values for p by means of a distribution, instead of assigning the same of value of p to every biorefinery.
- The model analysis could be complemented with an uncertainty analysis and robustness analysis. An uncertainty analysis can be used to evaluate to which extent model outcomes change due to different parameter settings. In an uncertainty analysis the model is run with samples from a certain parameter space. Hereby, a number of parameters is specified with an appropriate probability distribution. Subsequently, it is assessed whether the distribution of the model outcomes is wide or narrow in comparison with the specified parameter distributions. In this research the parameters "price damping coefficient" and " propensity to exploration biorefineries" are suitable candidates, because the values for these parameters are uncertain and in the sensitivity analysis (section 5.5) it is shown that the model is relative sensitive to these parameters. In a robustness analysis it is assessed how model outcomes are affected if model elements are modified. Model elements refer to, for example, agent behaviour, agent composition, model initialization and so forth. The model elements of special interest in this type of analysis are those which are considered unrealistic. In addition, these modifications are usually more invasive in nature than only modifying a single parameter. By comparing the model outcomes of the original- and modified model, the robustness of the model and associated conclusions can be assessed.
- In section 2.2 it is stated that models of international trade flows for bioenergy found in literature, are usually general- or partial equilibrium models. Contrary to equilibrium models, ABM are able to include heterogeneous actors with bounded rationality, the ability to learn and intrinsic behavioural traits. Above that, geographical aspects can be incorporated. It was also stated that these factors play an important role in international bioenergy trade and therefore ABM could be of added value to the current strand of literature in which equilibrium models are applied. For future research it is recommended to contrast the model developed for this research with the equilibrium models found in literature and to compare their findings. This activity has two purposes. Firstly, it could provide insight into the added value of ABM over equilibrium models. Secondly, it could serve as a form of literature validation.

During model calibration (section 5.6.1) it is shown that, although the model is able to reproduce general dynamics, most of the observations are outside the 90% envelope. The improvements listed below aim for improving this fit with historical data and the model

- In the policy exploration (section 5.7) it is described that a few "hiccups" are visible in the model outcomes. Although these hiccups were not directly visible during model calibration, it may pay-off to review the model elements which are the origin of these hiccups. As already described in the policy exploration, one origin is the low or very low demand for biodiesel, which causes very low prices. These model outcomes are related to the fact that in the model nothing is specified with respect to "market crashes". That is to say, under which conditions a commodity market closes definitively. It also relates to the assumption that actors cannot go bankrupt and the distributors/retailers are modelled as one actor. A different type of hiccup could originate from the presence of two biodiesel markets (EU-28 and Indonesia/Malaysia). If the price level of both markets come very close or cross, this may cause a hiccup. This is also related to the fact that distributors/retails are modelled as one actor and the strategic decision making of the distributors/retailers for buying biodiesel on these two markets (see section 4.5.3) is very basic. Addressing these elements is expected to be favourable for the realism of the model.

- For the model developed in this research substantial effort is put on capturing geographical aspects. However, a possibility for improvement is the incorporation of the major ports in EU-28 (like the port of Rotterdam, Antwerp and Hamburg). Ports play an important role in the international biofuel supply chain, because (as described in this thesis) transport cost can substantially affect the cost competitiveness and feedstock and biofuel. This manifests itself by large biorefineries being built in the vicinity of these ports. Therefore, it it expected that the incorporation of ports (and associated transport cost benefits for nearby biorefineries) could improve model outcomes.
- One of the commodities considered in the model is biodiesel. Above that, the model assumes that biodiesel is blended at the country of destination. In other words, pure biodiesel (also referred to as B100) is imported and then blended to either B5 (5% biodiesel and 95% fossil diesel) or B10 within the European Union. However, besides pure biodiesel also diesel blends are traded internationally. In addition, the import duties imposed by EU-28 on biodiesel originating from Indonesia apply to diesel blends B20 and higher. In literature indications can be found for the transport of high concentrations biodiesel to the European Union and down-blending to B19 at the port of destination before declaration of the to be imported commodities (see e.g. Lamers [2013]). These kind of practices could undermine the imposed import tariffs by EU-28 and their desired effects. Therefore, it is recommended to examine this in more detail and to subsequently decide whether different biodiesel blends should be incorporated in the model or not.
- In the model no storage facilities for commodities are present. This means that overproduction of biodiesel is lost. In literature it can be found that storage facilities play an important role in the fossil fuel markets (see e.g. Unalmis et al. [2012]). Above that, since overproduction of biodiesel is considered a lost, biodiesel producers may overreact with respect to overproduction. Therefore, it is expected that storage facilities could be of added value for enhancing model results.

Lastly, a number of potential modelling questions for future research are formulated:

- The most obvious recommendation is to make the most of the possibilities the current model already offers. In this research only a two policies (import tariffs on biodiesel and palm oil by the European Union) are examined. However, many other policy parameters are available in the model, like the blending mandate, the blending mandate penalty, agricultural subsidies and the export tariff on palm oil. One could think of investigating which blending mandate penalty suffices to realize a certain blending mandate. The same holds true for analysing more scenarios of important exogenous parameters (like diesel demand in the European Union).
- This research is limited to examining one pattern as found by Lamers et al. [2011]. However, in the corresponding study a second pattern is mentioned. This pattern states that trade routes are mainly driven by tariff preferences. Tariff preferences are offered to GSP beneficiaries. This means that these countries receive a preferential treatment by exposing them to lower tariffs. In the model developed for this research only two sets of countries are present. Therefore, only one trade route is possible. By adding countries to the model, different trade routes could emerge. This would enable the examination of trade routes in relation to tariff preferences. This could provide insight in the occurrence of "triangular trade", such as the splash-and-dash practice. In the light of this practice, interesting countries to add to the model would be Argentina and the USA.
- In the model yields of rapeseed and wheat within EU-28 are assessed by means of the GAEZ model. Although this model takes many factors into account, it only provides one yield per location. However, in literature indications can be found that yields can vary substantially from year-to-year (see e.g. USDA-FAS [2017b]). Usually, these deviations are related to prevailing weather conditions. For example, in the past El Niño had a significant negative affect on palm oil production in Indonesia and Malaysia. With the model it could be possible to assess the effect of these kind of "shocks" on model outcomes.

6.3. REFLECTION

In this section I would like to present a reflection on this research. This reflection touches upon a different number of topics. In general, I would like to give some insights on how I perceived this research project and what I learned from it (besides the pure content wise enrichment). I hope these lessons can be of added value for other researchers as well. Firstly, I will discuss why this research could count as a thesis for the Management of Technology (MOT) curriculum. I will also clarify what evoked my interest in the subject of this research. Secondly, I will discuss the model development and implementation in section 6.3.2. This section gives a description from a general point of view. Subsequently, three specific topics in the field of model development, implementation and usage are highlighted. These topics are ABM (section 6.3.3), NetLogo (section 6.3.4) and the execution of the simulation runs (section 6.3.5).

6.3.1. REFLECTION ON MOT CONTENT AND PERSONAL INTEREST

In this section I will firstly discuss why this research could count as a thesis as part of the MOT curriculum. Subsequently my interest in the subject of this research will be clarified. In the study guide three criteria are put forward to indicate a thesis in the field of MOT. The first criterion states that the work reports on a scientific study in a technological context. The biofuel supply chain derives its right to extensive by means of many different technologies in the field of processing, production, transport, logistics, chemistry and so forth. Therefore, the technological context is considered covered.

The second criterion states that the work shows an understanding of technology as a corporate resource or is done from a corporate perspective. This research is not performed from a corporate perspective, however in my opinion it does show an understanding of technology as a corporate resource for two reasons. Firstly, this research addresses numerous corporations (like farmers, biorefineries and distributors and retailers) in the biofuel supply chain for which technology plays an important role. During model development, the decision making of these actors to create value for their corporation needed to be made explicit. Secondly, though the results of this research are mostly presented from a governmental perspective, they are also of added value from the perspective of corporations situated within (and maybe also outside) the biofuel supply chain. By better understanding how the international trade flows for liquid biofuels emerge, these corporations can perform better informed decision making. For example, actors may be able to respond more timely with respect to policy changes due to an improved understanding of the consequences. This may bring forward improvements with respect to productivity and profitability of a corporation. Taking both reasons into account, this research is considered to show an understanding of technology as a corporate resource.

The third criterion states the usage of scientific methods and techniques as put forward in the MOT curriculum. In my opinion two sets of courses can be distinguished and each of them touch upon subjects which are used in this thesis. The first set contains the courses research methods (MOT2312) and social and scientific values (MOT1442). In these courses subjects like design and execution of research, statistics and development of models and theories are taught. The second set contains the courses financial management (MOT1461) and economic foundations (MOT1421). These courses deal with subjects like financial decision making by corporations, different schools of economics, market theories and fiscal policy. All these subjects directly or indirectly return in this thesis. Concluding, in my opinion this thesis could count as part of the MOT curriculum.

This research project evoked my interest because of three main reasons. Firstly, I am curious about sustainability. Though the sustainability of biofuels is not undisputed, I think important lessons from the world of biofuels can be learned for other sustainability projects. For example, because developments in the field of sustainability are often coupled to policies. Another parallel is the adoption and phaseout of technologies is involved in sustainability projects. Secondly, the research addressed a tangible subject with direct practical applications. I prefer this type of research. Thirdly, during my previous studies I worked with pleasure with ABM to solve logistical problems. In addition, I thought that I might benefit from my prior experience for this research project.

Looking backward, for the first two reasons my expectations are definitely met. For the third reason this only partly holds true. Though parallels are present, in my opinion my prior experience with ABM in the field of logistical problems hardly paid off. I think this is the case because the points of attention are situated differently. In the field of logistic problems the emphasis lies more on topics like optimization, computational time and mathematical formulation of the problem. For the application of ABM in this thesis these topics are less relevant and the emphasis lies more on context of the modelled system, decision making of the agents and usage of historical data. Therefore, I conclude that both applications of ABM are different (scientific) disciplines.

6.3.2. REFLECTION ON MODEL DEVELOPMENT AND IMPLEMENTATION

In this research a large part of the available time is spend on model development and implementation. In my point of view this was the case because both are closely related and together form a capricious process. By means of five statements I will try to clarify why I think this is the case:

- *Progressive insights play an important role in model implementation*
  Model implementation is coupled with learning and rethinking. These progressive insights arise on both a local level (on the fly and less structured) and on a global level (planned and structured). Modelling choices may seem legitimate and useful at first instance. However, as model implementation proceeds you can infer feedback. This feedback allows you (or sometimes even forces you) to rethink your modelling choices. This can result in revising your modelling choices. In other words, model development and model implementation are not linear and contain an inherent aspect of trial-and-error.
- *Simple model elements are not necessarily easy to implement*
  While thinking of elements to add to the model, you automatically developed an idea of the complexity of implementation at the same time. However, I often encountered that a model element may look easy in a formulation of words and diagrams, but was not easy to program. In my point of view one of the reasons for this is that during implementation of a model element you may discover unforeseen aspects. That is to say, while running the model unforeseen "paths" or "sequences of events" occur. To address this, the model is expanded. The more often this occurs, the larger the deviation of expected complexity. A second factor that plays a role is the increase in the number of links within the model as model development proceeds. All these links need to be respected and integrated properly. This tends to make the addition of new model elements more complex as model development and implementation proceeds.
- *The line between a working model and a model that does not work is fine*
  With a model that does not work I refer to a model that either produces a run time error or produces strange results. This line is thin, because a not properly working model may already be caused by forgetting a single comma. In addition, the script must always run properly. If the script results in an error in one out of 100 simulation runs, the script is not usable. If one considers that every time the model is adjusted the of the "correctness" of the model is put at stake, it is imaginable that the thin line between a working model and a model that does not work may form an issue.
- *Debugging is an unpredictable process*
  Debugging is inextricably bound up with programming. My experience is that finding the origin of an error tends to be much more time consuming than fixing the error itself. Sometimes you are able to discover the origin of an error in the order of minutes. Sometimes you may spend an entire day on discovering a similar type of error. The problem is that during the time spend on debugging you effectively did not make any progress.
- *The consequences of increasing model complexity reach farther than model conceptualization and implementation*
  Firstly, from my point of view increasing model complexity should never be an objective as such. It should only be performed if it is considered to pay off in view of the objective of the model. That being said, increasing model complexity increases the time required for conceptualization and implementation of the model. However, it sometimes also backfires via other tasks, like debugging, documentation and data collection. The difficulty is that the extent to which this occurs tends to be hard to foresee.

6.3.3. REFLECTION ON ABM

In this section I would like to reflect on the usage of ABM in this research. Hereto, two findings are discussed. Firstly, one of the strengths of ABM is that you can incorporate explicitly the different behaviour of the actors. However, at the same time this is also one of the weaknesses of using ABM. The explicit specification of the behaviour of the actors itself is already a time consuming process. This is aggravated by the associated need to specify the "handles" or "environment" for the actors in detail. Concluding, the possibility of ABM to specify the individual behaviour of the different actors comes at a cost.

Secondly, in the way ABM is used in this research, there is a large need for data. This data is needed to specify the input of the model (like parameters and time series). I experienced a number of difficulties due to this need for data. First of all, collecting the data is (again) a time consuming process. It is a time consuming process, because you need to locate a suitable data source, the data is scattered over a large number of sources, the data series must be unbroken, the data is usually not available in a suitable file format and in general the data is not given in the desired units and/or number format. All of this hampers a prosperous data collection process.

Another issue with respect to data collection is that it is an iterative process. Data collection is an iterative process due to the iterative character of model development (see section 6.3.2). Therefore, data collection also has no clear start- and end point. So during model development and implementation it could happen that you realize you need more data. Before you proceed, you need to know whether this data is available or not. Therefore, data collection may arise as an undesirable surprise.

Besides these more practical issues, there is also a difficulty from a scientific point of view. Firstly, a good practice is to cross check your data among different sources (if possible). It often appears that data is not fully similar. If the data appears to be more or less in line, then this tends to be okay. However, if different sources show contradictory findings you could have a problem. Secondly, judging the reliability of the data sources forms an issue. Since the sources of the data may have an interest in providing certain numbers, the trustworthiness of the data could be questionable. This may hold true for less developed countries or certain types of regimes, for example. Though no direct indications are found which point out that this holds true for the data used in this research, I would like to emphasize that the possibility exists and thus could affect the model outcomes.

6.3.4. REFLECTION ON NETLOGO

In this research use is made of the software package NetLogo. In Table 6.1 a number of strengths and weaknesses of NetLogo are listed, based on the experience retrieved during this research. Since there are more software packages available to implement an ABM (like Repast, AnyLogic or custom made code in Python), this overview may be taken into account for future research while selecting a programming environment.

Table 6.1: Strenghts and weaknesses of NetLogo

Strengths	**Weaknesses**
Documentation	Possibilities to analyse model outcomes and perform simulation runs
Extensive example models library	Debugging tools
Readily available interface elements (like plots and buttons)	Extensions (documentation, integration and examples)
Easy to learn	Quite different from other programming environments (like Matlab, R and Delphi)
Cross-platform (Windows, macOS, Linux)	Lack of complex functions (e.g. in field of statistics)
Active online communities	

6.3.5. REFLECTION ON SIMULATION RUNS

In this section I would like to reflect on the execution of the simulation runs. In Table 6.1 a number of weaknesses of NetLogo are listed. Two of these limitations are the possibilities to analyse model outcomes and perform simulation runs and the lack of complex functions (e.g. in field of statistics). These formed an obstacle during the execution and analysis of the simulation runs in this research. Firstly the execution is discussed, followed by the analysis. NetLogo has two built-in tools for performing simulation runs: BehaviorSpace and BehaviorSearch. On the one hand, BehaviorSearch is used for model calibration and in my opinion is a very satisfying tool to use. On the other hand, BehaviorSpace is only suitable for basic setups and is hardly customizable. If you are more demanding, you have to take refuge in the available extensions for NetLogo.

An extension that is used in this research to fill this gap is the RNetLogo package in R. This package creates a link between R and NetLogo and thus gives access to the extensive possibilities that R offers (e.g. in the field of statistics). This is a major advantage of using RNetLogo. However, during this research I also experienced some drawbacks. Firstly, this setup for performing simulation runs is a lot less user-friendly in comparison with NetLogo itself. This originates from the limited documentation on RNetLogo and the lack of examples. For example, setting up a working connection between R and NetLogo is already quite demanding. This is dissimilar for the different operating systems, but in general requires precision with respect to software versions, sequence of installation, software settings and (if any) inferences with other software on your computer. One of the underlying reasons this process is complicated is due to the necessary involvement of Java. In addition, while running NetLogo via R interface elements are absent and thus tracing progress or identifying errors becomes more difficult. Therefore, it is recommended to think twice before starting to use RNetLogo.

An important aspect of the model developed for this research is computational time. Via my prior experience with ABM I was aware of the possibility that computational time may form an issue while using ABM. Therefore, I monitored computational time already from the first stage of model development onwards. I would like to recommend other researchers to do the same. It pays off to prevent arriving at a model which is very impractical due to the required computational time. This could require a (lot more time consuming) restructure of your model.

BehaviorSpace offers the possibility to perform multiple simulation runs in parallel (one simulation run per processor core). This yields a significant reduction in computational time. This option can be activated within only a few mouse clicks. It is also possible to perform multiple simulation runs in parallel while using RNetLogo. Contrary to BehaviourSpace, this is a lot less easy to realize. You manually need to implement this in the R script. As a side note, for a large number of other advices on improving computational time, the paper of Railsback et al. [2017] is recommended.

The second limitation of NetLogo is the lack of possibilities to analyse model outcomes. With analysing model outcomes I refer to performing statistical analysis and creating plots. To overcome this I also used R (though Matlab or any equivalent could also be suitable). Prior to this research I worked a number of times with R during my studies. However, the analysis and plots for this research were more demanding than I expected. In my opinion, this was caused by the large number of dimensions of the model output and the application specificness of the analysis (limiting the available examples). This forced me to invest time in learning new features of R.

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APPENDIX A

In this appendix two schematic overviews of processing rapeseed and biodiesel production are shown.

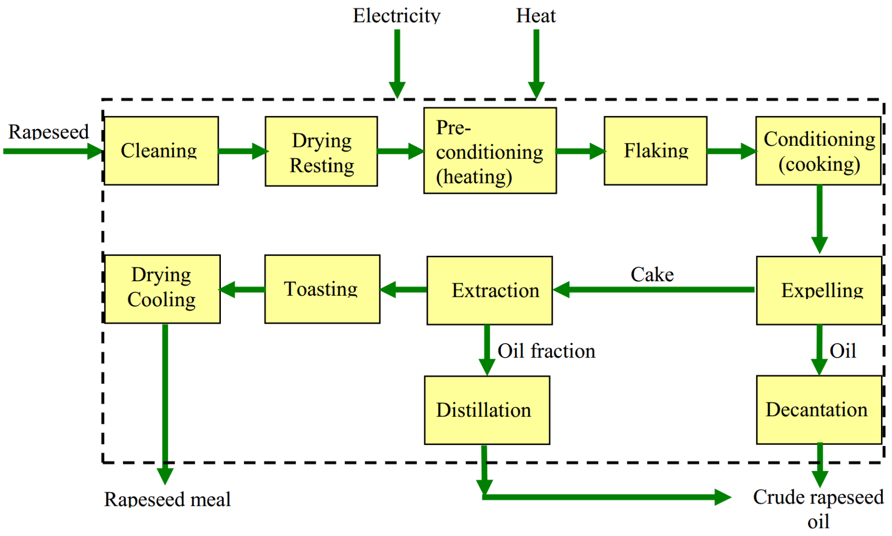

Figure 1: Block diagram of rapeseed processing to rapeseed oil and -meal [Bioref-integ, 2009]

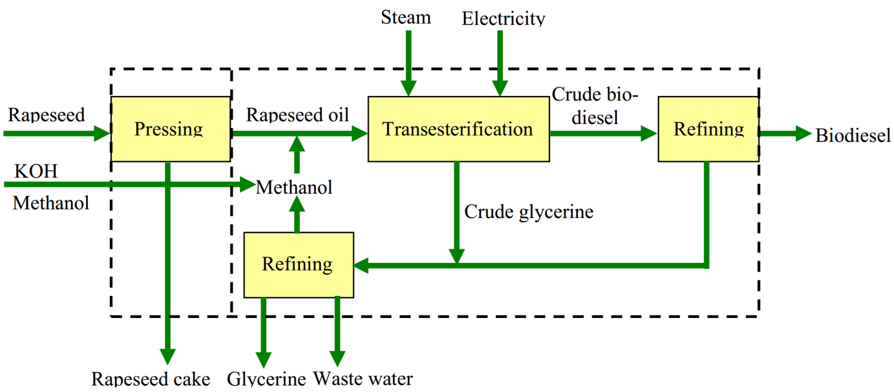

Figure 2: Block diagram of the biodiesel production from rapeseed [Bioref-integ, 2009]

Appendix B

In this appendix four figures are shown. The first two display the trade balances for rapeseed and rapeseed oil for EU-28. The last two figure shows the consumption of rapeseed- and palm oil in EU-28.

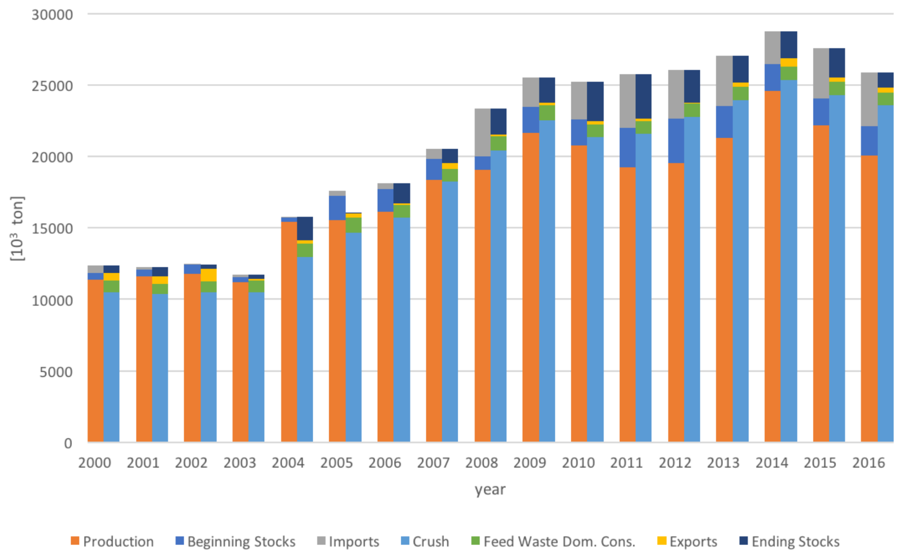

Figure 3: Trade balance EU-28 for rapeseed, derived from USDA-FAS [2017b]

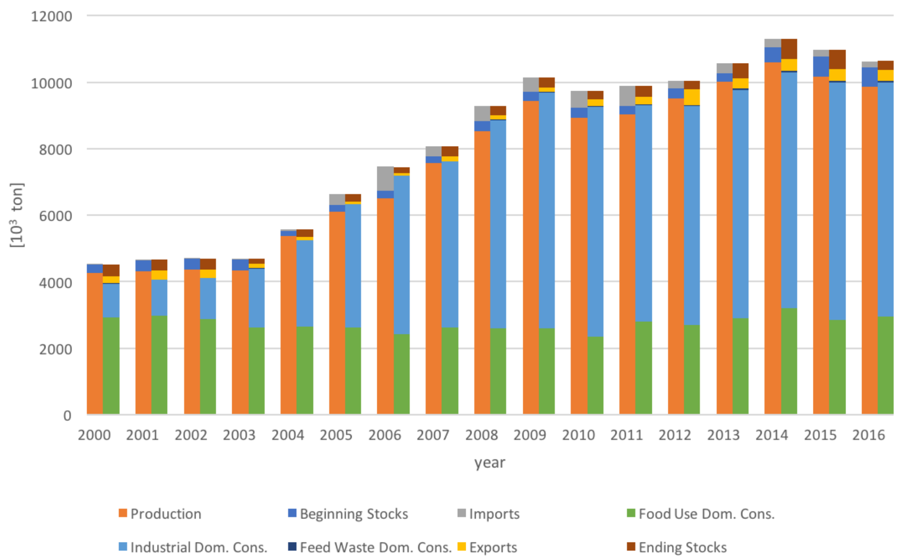

Figure 4: Trade balance EU-28 for rapeseed oil, derived from USDA-FAS [2017b]

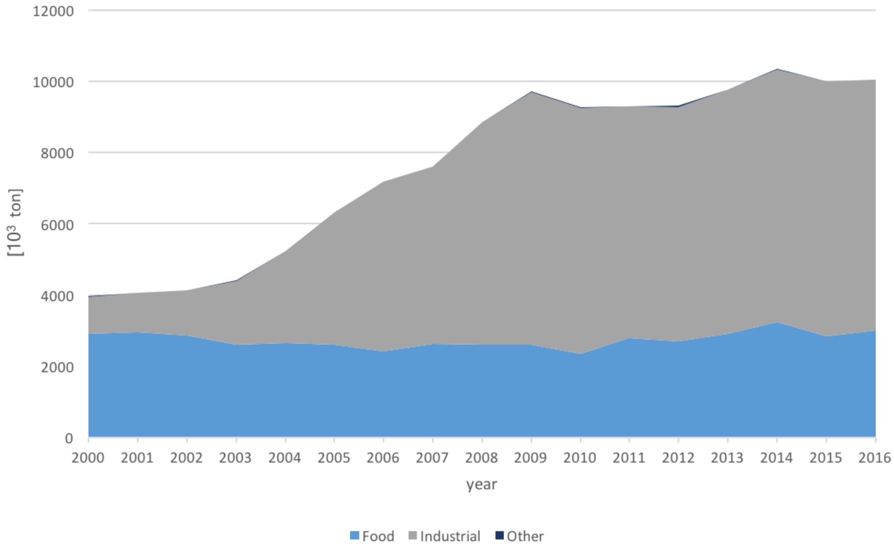

Figure 5: Consumption of rapeseed oil in EU-28, derived from USDA-FAS [2017b]

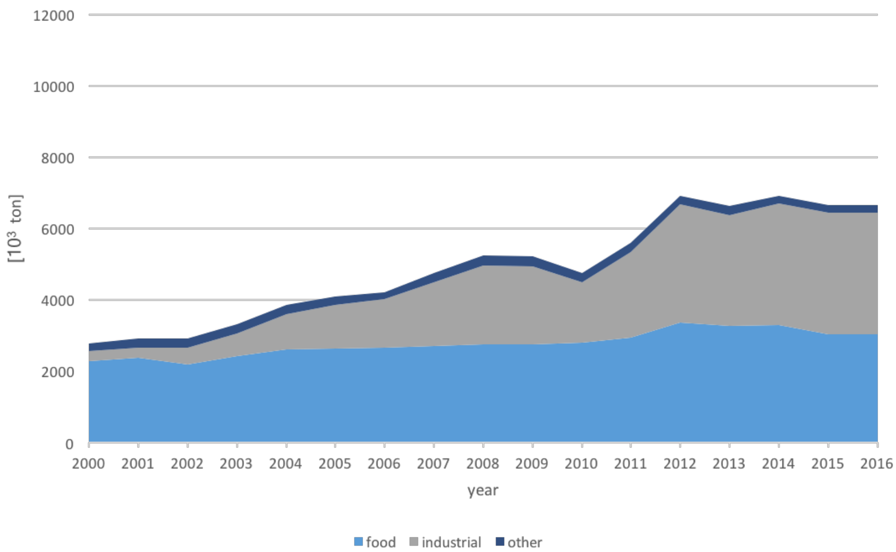

Figure 6: Consumption of palm oil in EU-28, derived from USDA-FAS [2017b]

Appendix C

In this appendix the trade balances of biodiesel and a number of key numbers of the biodiesel industries of EU-28, Indonesia and Malaysia are given.

Table 2: Trade balance biodiesel and key numbers on biodiesel industry of EU-28 [USDA-FAS, 2016a]

Year	2010	2011	2012	2013	2014	2015	2016
Trade balance [10^3 ton]							
Beginning stocks	710	465	495	722	470	484	489
Production	9 425	9 719	9 755	10 548	11 744	11 915	12 042
Imports	2113	2 785	2 899	1 226	556	474	467
Ending stocks	465	495	722	470	484	489	489
Consumption	11 680	12 386	12 325	11 660	12 125	12 170	12 227
Exports	103	88	102	366	161	214	282
Biodiesel industry							
Number of plants	220	234	235	220	210	209	209
Nameplate capacity	20 423	21 767	23 225	22 757	22 394	21 943	21 943
Capacity utilization [%]	44	43	38	40	43	45	45

Table 3: Trade balance biodiesel and key numbers on biodiesel industry of Indonesia [USDA-FAS, 2016b]

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016
Trade balance [10^3 ton]									
Beginning stocks	16	13	71	33	35	48	6	50	30
Production	555	290	651	1 585	1 937	2 465	2 641	1 039	2 157
Imports	0	0	0	0	0	0	0	0	0
Ending stocks	13	71	33	35	48	6	50	30	30
Consumption	20	53	194	315	590	923	1 408	757	1 981
Exports	537	180	496	1 268	1 334	1 585	1 188	302	176
Biodiesel industry									
Number of plants	14	20	22	22	26	26	26	27	28
Nameplate capacity [10^3 ton]	2 762	3 106	3 465	3 768	4 297	4 991	4 991	5 942	6 414
Capacity utilization [%]	20	9.4	19	42	45	49	53	17	34
Feedstock use palm oil [10^3 ton]	580	304	681	1 656	2 024	2 576	2 760	1 086	2 254

Table 4: Trade balance biodiesel and key numbers on biodiesel industry of Malaysia [USDA-FAS, 2016c]

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016
Trade balance [10^3 ton]									
Beginning stocks	13	3	3	29	124	224	343	331	181
Production	164	217	112	165	239	452	397	484	733
Imports	0	0	0	0	0	0	0	0	0
Exports	174	217	85	48	28	167	84	172	185
Consumption	0	0	0	23	110	165	326	462	467
Ending stocks	3	3	29	124	224	343	331	181	263
Biodiesel industry									
Number of plants	20	20	20	20	20	20	20	20	20
Nameplate capacity [10^3 ton]	2 535	2 535	2 535	2 535	2 535	2 535	2 535	2 535	2 535
Capacity utilization [%]	6.5	8.6	4.4	6.5	9.4	18	16	19	29
Feedstock use palm oil [10^3 ton]	195	222	95	96	103	329	263	361	341

APPENDIX D

In this appendix the outcomes of the statistical tests for the sensitivity analysis (section 5.5) are given. These tests correspond to an one-sample student t-test with a confidence interval of 95%. For all three parameters it is found that H_0 is rejected for both currencies.

```
[1] "biodiesel import / price damping coefficient"

One-sample t-Test
t = 1.967, df = 9, p-value = 0.04036
alternative hypothesis: true mean is greater than 0
95 percent confidence interval:
 0.02713644         NA
sample estimates:
mean of x
0.3985802
```

```
[2] "biodiesel import / propensity to exploration"

One-sample t-Test
t = 39.998, df = 9, p-value = 9.497e-12
alternative hypothesis: true mean is greater than 0
95 percent confidence interval:
 2.28066      NA
sample estimates:
mean of x
 2.390205
```

```
[3] "biodiesel import / sd noise level"

One-sample t-Test
t = 1.7257, df = 9, p-value = 0.05924
alternative hypothesis: true mean is greater than 0
95 percent confidence interval:
 -0.01520996          NA
sample estimates:
mean of x
0.2443823
```

```
[4] "palm oil import / price damping coefficient"

One-sample t-Test
t = 2.6892, df = 9, p-value = 0.01241
alternative hypothesis: true mean is greater than 0
95 percent confidence interval:
 0.4204451        NA
sample estimates:
mean of x
 1.320738
```

```
[5] "palm oil import / propensity to exploration"

One-sample t-Test
t = 3.1452, df = 9, p-value = 0.005914
alternative hypothesis: true mean is greater than 0
95 percent confidence interval:
 0.4576143        NA
sample estimates:
mean of x
 1.096929
```

```
[6] "palm oil import / sd noise level"

One-sample t-Test
data:  Summarized x
t = 2.2855, df = 9, p-value = 0.02406
alternative hypothesis: true mean is greater than 0
95 percent confidence interval:
 0.03729898         NA
sample estimates:
mean of x
0.1884288
```

Figure 7: Detailed outcomes one-sample t-test applied during Morris screening

APPENDIX E

In this appendix the time series for the different scenarios, as used in the policy exploration (see section 5.7), are given. These outlooks are created as follows. Firstly, it is attempted to retrieve outlooks from literature. Hereto, outlooks presented by World Bank [2017] and OECD [2017] are consulted. If no (complete) outlooks are found, historical values found in literature (the same sources as presented in section 4.6) are extrapolated with appropriate trend lines. The "high" and "low" scenarios correspond to a 20% deviation from the base case scenario.

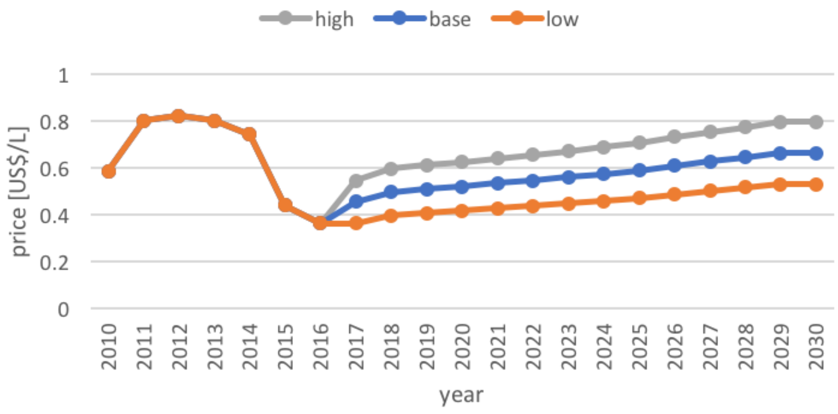

Figure 8: Scenarios (producer) price fossil diesel

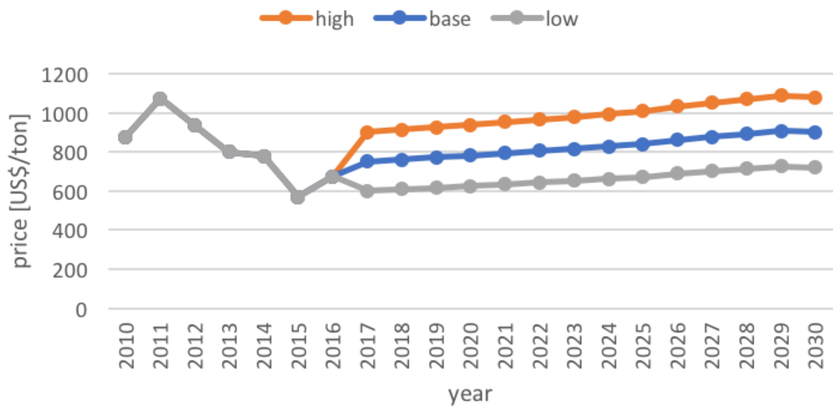

Figure 9: Scenarios price palm oil

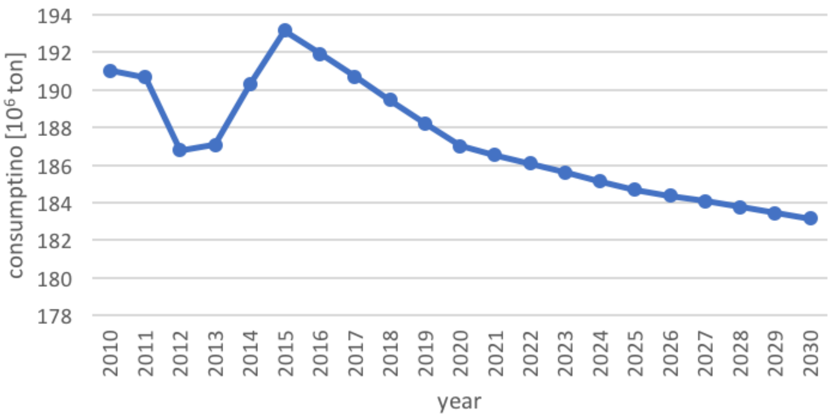

Figure 10: Scenario diesel consumption EU-28

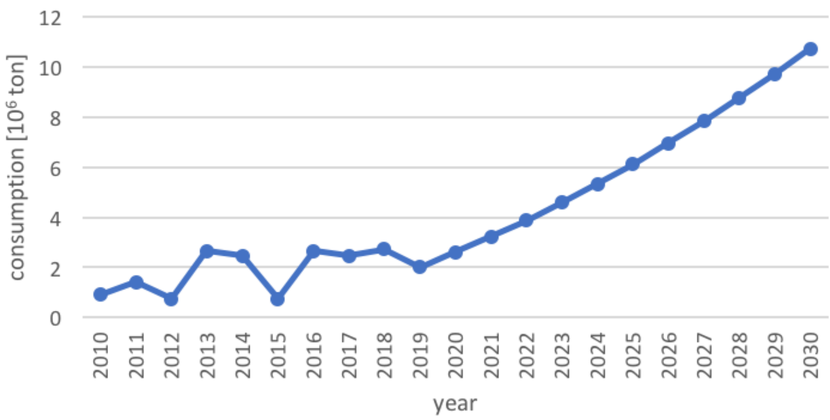

Figure 11: Scenario biodiesel consumption Indonesia

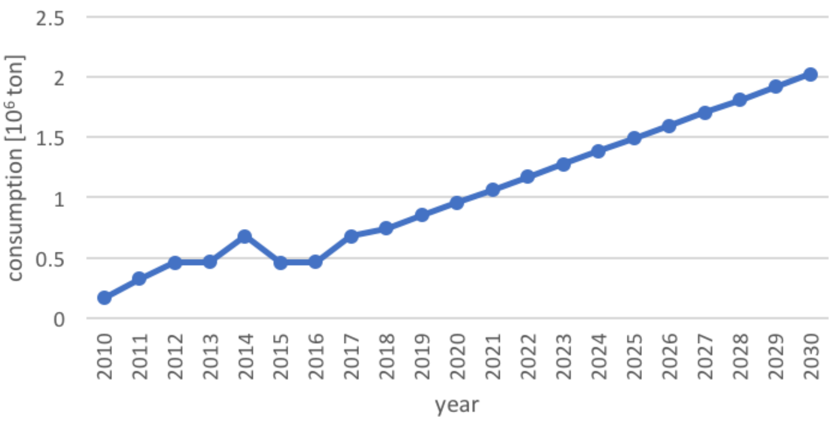

Figure 12: Scenario biodiesel consumption Malaysia

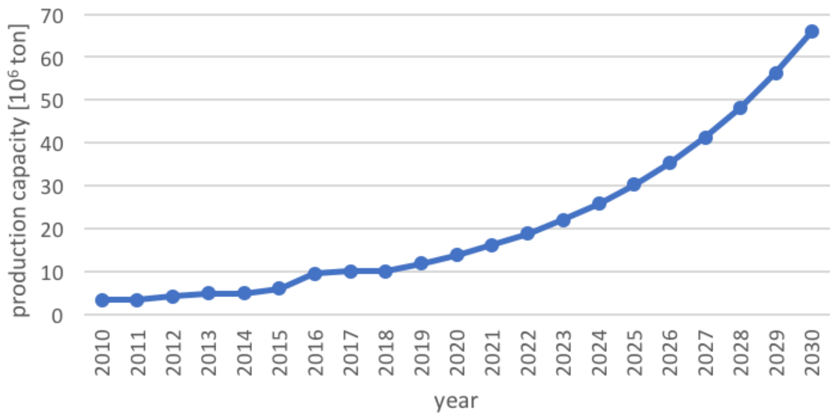

Figure 13: Scenario biodiesel production capacity Indonesia

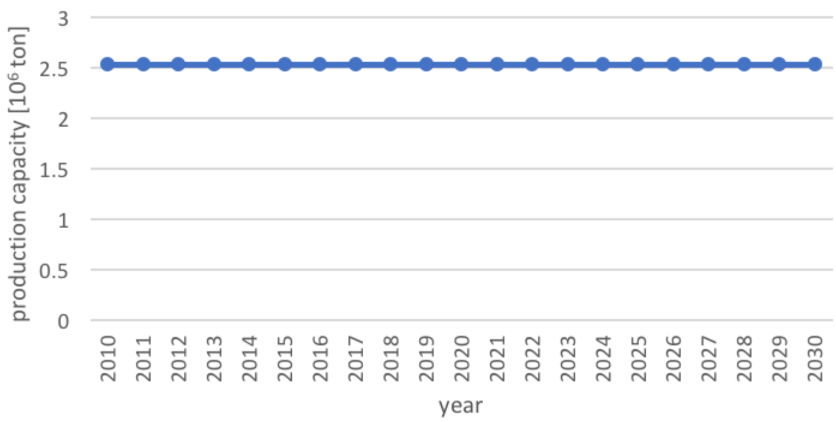

Figure 14: Scenario biodiesel production capacity Malaysia

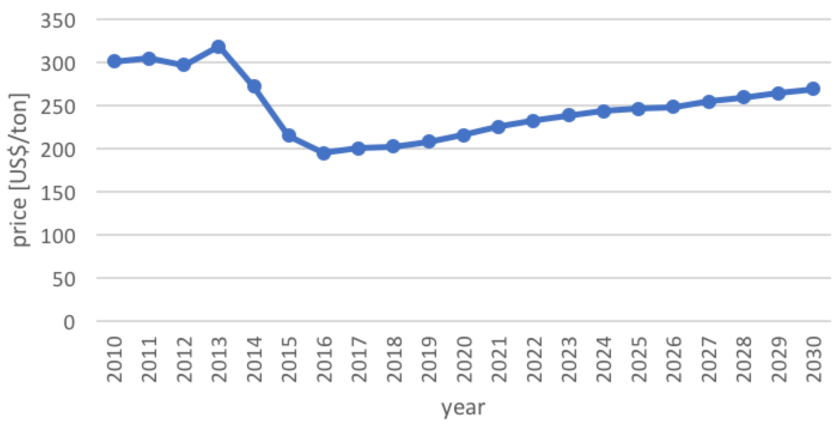

Figure 15: Scenario price wheat

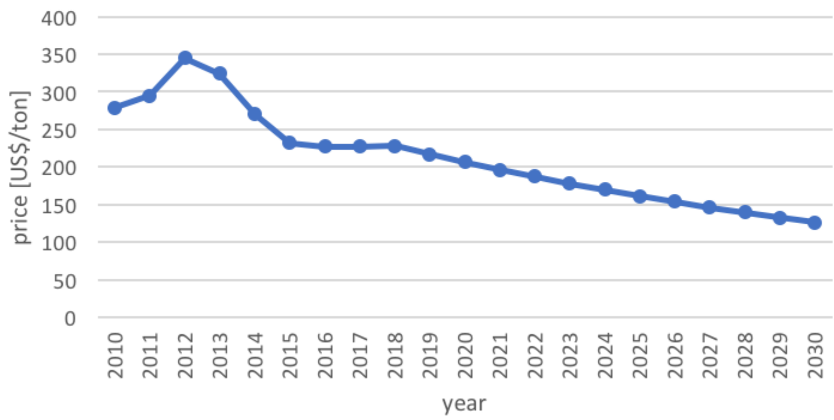

Figure 16: Scenario price rapeseed meal