An Economic, Environmental and Sustainability Assessment of a large scale biofuel industry in Suriname

A System Dynamics Approach

BSc. Thesis by Devin Diran

August 2015

Source of cover page images:

[SUIKERRIET]. Reprinted from SuriPictures.com website, n.d., retrieved from http://suripictures.com/photogallery/photo00020229 /SUIKERRIET.jpg
Flag of Suriname. Reprinted from Wikimedia.org website, n.d. retrieved from https://upload.wikimedia.org/wikipedia /commons /thumb/6/60/ Flag_of_Suriname.svg/250pxFlag_of_Suriname .svg.png
[TU Delft logo]. Reprinted from TU Delft website, by TU Delft, n.d., retrieved from https://intranet.tudelft.nl/fileadmin/Files/medewerkersportal/mc /huisstijl/Downloads/TU_Delft_logo_RGB.png

An Economic, Environmental and Sustainability Assessment of a large scale biofuel industry in Suriname

A System Dynamics Approach

A Technical Research Report, submitted in the context of phase two of the Bachelor Final Project to obtain the Bachelor degree in Systems Engineering, Policy Analysis and Management.

By Devin Diran, 4207157

Supervised by Dr. Erik Pruyt

Assessed by Dr. Erik Pruyt and Dr. Ir. Ivo Bouwmans

Coordinated by Dr. Ir. Pieter Bots

Faculty of Technology, Policy and Management

Delft University of Technology

August 2015

Preface

This technical research report is written in the context of the second phase of the Bachelor Final Project to obtain the Bachelor degree in Systems Engineering, Policy Analysis and Management.

It covers a System Dynamics study on the impact of a large scale biofuel industry in Suriname. The study has been carried out with the most of care, enthusiasm and affection as it concerns my motherland, Suriname. The skills and knowledge gained during my three years at the Delft University of Technology as bachelor student Systems Engineering, Policy Analysis and Management lead to this product.

Finally I want to address a special thank you towards Dr. Erik Pruyt for introducing me to the world of System Dynamics and despite a very busy schedule finds the time to supervise my work.
Also a special thank you is addressed towards Dr. Ir. Ivo Bouwmans to function as a second assessor, despite also having a very busy schedule with big responsibilities as program manager of the bachelor program in Systems Engineering, Policy Analysis and Management.
Not to forget, is Dr. Ir. Pieter Bots, the module manager of the bachelor final projects for the entire bachelors program in Systems Engineering, Policy Analysis and Management.
Last but not least I want to thank all my friends and family for the unconditional love and support during my education at the TU Delft up till now.

Devin Diran

Delft, August 2015

Abstract

In this study an economic, environmental and economic assessment is conducted on a potential large scale biofuel industry in Suriname, South America. Suriname faces important energy related questions for the future. This with the eye on the rapidly growing economy and energy demand and the responsibility in terms of climate issues and biodiversity- and forest conservation. Biofuels possess great potential to clean up the energy supply for both power generation and transport. Bioethanol can be blended with the traditional fossil gasoline in Suriname, but potentially it can also completely substitute the fossil fuels on the long term. Secondly, an advanced bioethanol industry can complement the hydro-power in Suriname towards a fully renewable power generation. Additionally biofuels could create a new source of income for the state in terms of foreign currency due to the potential export of biofuel. On the other hand a strict and consistent policy framework is required to limit the negative side effects of a biofuel industry with regards to: a) Land use change (LUC) and the associated impact on biodiversity, land erosion and desertification and CO_2 emissions through deforestation, b) intensifying agriculture possibly leading to land depletion and the pollution of the environment and groundwater and c) a possible threat to the food security..

In this study three policy strategies, combining multiple measures, are developed. These are:

1. Domestic Policy (DP): This strategy focusses on establishing a biofuel industry which predominantly serves a local developed biofuel market.
2. Export Policy (EP): This strategy focusses on the export of biofuel to e.g. Europe and the United States. The domestic market is underdeveloped, relative to DP.
3. Bio-based economy policy (BBEP): This strategy combines DP and EP, establishing a developed local market and a biofuel industry with the capacity to export.

It can be concluded that developing a biofuel industry in Suriname will pay off in the future under the condition that a) enough government incentives are implemented as a catalyst in the development of a biofuel industry and local biofuel demand b) the policy not only addresses export, but also establishes a local demand to cope with the uncertainty of the international biofuel market and to also establish local CO_2 reduction and energy security advantages and c) sufficient environmental and forest preservation law is implemented with a strict control mechanism.

When taking these steps in developing biofuel policy in Suriname, the negative consequences regarding LUC (deforestation) and the environment are minimized, while the positive impacts regarding energy security, CO_2 emission reduction, agricultural development, rural development, renewable energy and economic growth and diversification are maximized. Simulations show that DP is the most robust policy to achieve a profitable and sustainable biofuel industry, with a decreased carbon intensity of the power generation and transport, when coping with uncertainty. Meanwhile BBEP is the most effective strategy to achieve large scale profitable biofuel success. With BBEP a completely carbon neutral power sector can be established from around 2070 and the carbon intensity of transport can be strongly decreased leading to CO_2 emissions by transport balancing at around 500,000 ton/year from 2070. However, with this achievement the forest covered area can decrease from around 95% in 2015 to around 76% in 2115, while the Environmental Index slightly decrease.

Table of Contents

List of Figures

List of Tables

1. Introduction

Suriname, a Caribbean country on the South American continent, faces important energy related questions for the future. Suriname is considered the 17th richest country in the world in terms of natural resources by the World Bank, with many of those resources still untouched (Szczesniak, 2000). Almost 95% of the country is covered with dense rain forest, accommodating a rich and diverse biodiversity (Plouvier, Gomes, Verweij, & Verlinden, 2012). Like many developing countries, the demand for energy is increasing together with the economy and the population. Suriname realized an economic growth of 4.4% on average for the period 2000-2013. This is among the highest in Latin America (World Bank, 2015). Considering the rapidly growing economy, mainly boosted by oil and gold and the responsibility in terms of climate issues, biodiversity- and forest conservation, Suriname needs to shift to a more sustainable economy.

Biofuels possess great potential to not only clean up the energy supply, but also boost the economy as a new source of income. Suriname has large agricultural potential due to fertile land, a tropical climate and its position outside the hurricane belt (Derlagen, Barreiro-Hurlé, & Shik, 2013). Conditions which are comparable, if not better, than to those in the areas where bioethanol out of sugarcane is a success in the neighboring Brazil (Coelho, Goldemberg, Lucon, & Guardabassi, 2006). Bioethanol can be blended with the traditional fossil gasoline in Suriname, but potentially it can also completely substitute the fossil fuels on the long term. Secondly, an advanced bioethanol industry can complement the hydro-power in Suriname towards a fully renewable power generation.

In the past many foreign investors have expressed interest in starting biofuel plants in Suriname, but due to politics and bureaucracy none of the initiatives have been carried out. A recent example is a promising plan by the State Oil Company Suriname N.V. (Staatsolie), known as the Wageningen Sugarcane to Ethanol and Sugar Project (WSESP), to initiate a biofuel industry in Suriname (ERM, 2012). The start of construction for WSESP planned for 2015, is however put on hold. Nevertheless the potential still remains and Staatsolie have expressed their interest in this study.

But the realization of a successful and in particular clean and sustainable biofuel industry does not come easy, as biofuels are associated with various sustainability issues. An important issue is that biofuels, to be specific conventional biofuels out of crops which can also serve as food e.g. bioethanol out of sugarcane or corn, have a bad reputation as competitor for food by driving prices up and creating a threat for the food supply (Sandvik, 2008). Secondly, biofuels can contribute to negative land use changes (LUC), e.g. deforestation, in order to grow feedstock crops. Subsequently LUC can lead to an endangered biodiversity, soil degradation and additional CO_2 emissions (European Commission, 2012). Another issue, not sustainability related, behind the difficult realization of a successful biofuel industry is that very strong government involvement and support is needed in terms of policy and various incentives (Franco, Ochoa, & Flórez, 2009).

1.1 The aim of this study and the problem definition.

This research report written from a technical background, concerns a long term study on the impact of a large scale biofuel industry in Suriname with a time span of 100 years. As Suriname has no policy regarding biofuels, this study aims to develop and test possible policies towards a highly sustainable biofuel industry, whereby minimal environmental impacts and maximum sustainability and economic goals are pursued. The problem statement of this study can be stated as:

What is the impact over time of a large scale biofuel industry in Suriname on the local environment, the economy and the energy supply?

The main problem statement can be broken down in the following sub questions:

1. *What is the export potential of Surinamese biofuel?*
2. *What is the influence of government policies on the biofuel production over time?*
3. *What is the effect of a biofuel industry on LUC and the local environment over time?*
4. *How will international biofuel market developments influence the Surinamese biofuel industry over time?*

In an attempt to answer these research questions, a dynamic simulation model is built of a possible biofuel industry in Suriname, named BioSU. The study follows the System Dynamics methodology. According to Sterman (2002) and Pruyt (2013), System Dynamics (SD) is a comprehensive methodology, which fits the purpose of this study to generate a better understanding of the dynamic and complex biofuel system and to conduct “what if” policy analysis.

1.2 Problem demarcation

For this study important choices are made regarding the problem demarcation. That is what will be taken into account and what not?

This study takes into account the total Surinamese transportation sector in the form of its fuel demand and consumption. Hereby diesel has been left out of the study and the focus is on gasoline, as the study focusses on bioethanol production which can be blended with fossil gasoline. Biodiesel is not considered in the study, in order to fully focus on bioethanol in detail. Biodiesel has its own characteristics and would require a significant expansion of the scope leading to a far too big system and a study not feasible with the available resources, if it was to be studied in the same detail as bioethanol. Besides, gasoline is much more common in Suriname (World Bank, 2015).

Although biofuels and the security of food supply are closely related (Sandvik, 2008), the study does not consider food security in detail. However it is assumed that food supply always has the highest priority, relative to all other industrial activities including a biofuel industry. When studying the LUC, food agriculture is taken into account in terms of the competition for land between food agriculture and biofuel agriculture.

Further the complexity of the financial sector is outside the scope of the study. BioSU incorporates a simplified financial model to take along the investments crucial for a biofuel industry.

Next, detail population developments and interactions are left out. The models works with an average population growth based on the historic development and certain current and expected economic developments.

Finally the development of the fossil oil sector in Suriname and internationally, locates outside the boundary of this study. However, the local oil prices and the subsequent influence on the oil demand and the potential biofuel demand is taken into account.

1.3 Outline of the report

First this report discusses background information on the study in chapter 2, consisting of information on Suriname’s energy market and a literature review of various System Dynamics studies in the field of biofuels. Then the methodology of the study is presented in chapter 3, together with the conceptualization and operationalization of BioSU. In chapter 4 the model is used to test and analyze biofuel policies on effectiveness and robustness. Finally the report is concluded and a reflection of the model and the study is discussed in chapter 7. The rest of the report consists of the Appendices.

2. Background information

This chapter contains useful background information on biofuels and Suriname as the case. The information provides insights to get a better picture on the country considered in this study and is purposed to help to understand the case. Background information on Suriname and its energy supply is followed up by literature on previous System Dynamics studies in the field of biofuels.

2.1 Suriname and its energy supply

As mentioned in the introduction, Suriname is located in the north of South America bordering to French Guiana, Guyana, Brazil and the Atlantic Ocean. The country is rich in natural resources like gold, oil and bauxite. The extractive industry dominates the GDP of the country for over 50% (Inter-American Development Bank [IDB], n.d.). The land area of Suriname is 15,600,000 hectares, making it the smallest country South America. Suriname has the status as World's Greenest Nation, with 14,758,000 hectares of forest, accounting for nearly 95% of the land area (Ministry of Planning and Development Cooperation, n.d.).

Hydro power is accountable for nearly 53% of the Surinamese power supply in 2013, via the Afobaka Hydro power plant with a capacity of 189MW. The rest of the power supply, is covered with petrol powered generators. N.V. Energie Bedrijven Suriname (EBS) operates a capacity of 133MW of diesel generators, while Staatsolie operates 62MW of generators on Heavy Fuel Oil (HFO). Suriname is also rich in natural resources which can be used to generate electricity with today's technology. Examples are: uranium, oil, gas, sunlight, hydro-power and biomass (Government of the Republic of Suriname, 2006). The Government of Suriname (2006) even states a total hydro-power potential of around 2419MW. However, despite of the enormous domestic resources in terms of energy, about 18.3% or US$264 million of the country's total import were accounted for by energy in 2009 (IDB, 2013).

In the transport, predominantly gasoline is consumed. This fuel is imported, despite the fact that Staatsolie is producing 15,000 barrels of oil per day which is equal to the domestic demand (IDB, 2013). This oil is mainly exported, while the refinery of Staatsolie produces diesel products for the local industrial demand. Staatsolie recently took a new refinery worth nearly US$ 1 billion, into partial operation. With this refinery gasoline and diesel for the local market and export will be produced, making Suriname practically independent of energy imports. However, the dependency on fossil fuels cannot continue forever. These resources are finite and not in line with the responsibility towards the world and future generations, to decrease Greenhouse Gas (GHG) emissions, in order to limit climate change. That is where biofuels might come into the picture as a potential candidate to build a future clean and green energy supply upon.

Up till now Suriname has not yet developed policy regarding biofuels. However, the expertise and support to develop biofuel policy is requested at various multilateral organizations e.g. the International Development Bank (IDB) by the government (Shah, Philippidis, Dulal, & Brodnig, 2012). This indicates that the interest is present for biofuel, but the knowledge and experience are not present sufficiently. The vast availability of land and water along with an appropriate climate for agriculture are among positive drivers behind a possibly successful biofuel industry in Suriname (Shah, Philippidis, Dulal, & Brodnig, 2012). However some obstacles in the way of successful biofuels in Suriname are: the lack of government incentives for both biofuel production and consumption, weak research and development (R&D) experience, insufficient transport infrastructure and manpower (Shah, Philippidis, Dulal, & Brodnig, 2012)

To kick-off a biofuel industry in Suriname, Staatsolie has a plan, known as the Wageningen Sugarcane to Ethanol and Sugar Project (WSESP) (ERM, 2012). WSESP includes a sugarcane plantation, a bioethanol refinery, a sugar factory and a power plant in Wageningen, a community resort and agricultural area located in the district of Nickerie in Suriname. But due to changes in the vision and policy of the Surinamese government, as 100% shareholder of Staatsolie, this plan, of which construction was planned to start in 2015 is currently put on hold. This to the joy of biofuel opponents and supporters of the gold sector. The financial resources reserved for WSESP are namely invested in a state participation of 25% in the Merian Gold Project owned and operated by Surgold, which is fully owned by the American company Newmont (Newmont Mining Corporation, 2014). Many share the opinion that this vision is not in line with a sustainable development in Suriname.

This study will explore the possible development of a large scale biofuel industry in Suriname. A biofuel sector, guided by a strict and consistent policy framework, could have an enormous positive spin-off in Suriname. Clear examples of these spin-off advantages are: a) a new source of income for the state in terms of foreign currency due to the potential export of biofuel, b) less dependency on the extractive industry, c) facilitating the growth in energy demand in a clean and sustainable way via bio-power, d) a structural support of food related agriculture due to the infrastructure in terms of irrigation, logistics and R&D experience and e) the development of communities in rural areas by creating jobs. On the other hand a strict and consistent policy framework should limit the negative side effects of a biofuel industry with regards to: a) LUC and the associated impact on biodiversity, land erosion and desertification and CO_2 emissions through deforestation (Fearnside, 2005), b) intensifying agriculture to increase yields on the land available by using chemicals and fertilizers, often artificial, leading to faster land depletion, the pollution of the environment and groundwater and possibly water scarcity (Ros, et al., 2010) and c) a possible threat to the food security in terms of food supply and prices (Sandvik, 2008).

2.2 Literature overview on System Dynamics studies in the field of biofuels

This study was started with an intensive literature study on biofuel systems, in particular ethanol, and the specific characteristics of Suriname. SD studies in the field of biofuel policies and biofuel supply chains have been conducted by various institutions and scientists. Each of the studies has its unique character, applying SD in the comprehensive field of biofuels.

Relevant information to understand the structure and behavioral dynamics of biofuel systems could be obtained from studies such as Barisa, Romagnoli, Blumberga, and Blumberga (2015), studying the future biodiesel policy and consumption patterns in Latvia. Franco, Ochoa, and Flórez (2009) study the mechanisms and causes behind the difficulties in reaching the blending percentage of biofuels in fossil fuels set by the Colombian government. The study is conducted from the perspective of the Columbian government, to determine where the policy lacks effectiveness and what additional and corrective policy is required at de production side. Musango, Brent, Amigun, Pretorius, and Müller (2011) study the sustainability assessment of biofuel technology in the Easters Cape Province of South Africa. With the SD model, the effects of biofuel development on a set of sustainability indicators in the aforementioned area are assessed. The work of Vimmerstedt, Bush and Peterson (2012) and Vimmerstedt, Bush, Hsu, Inman and Peterson (2014) revealed very useful information on various aspects of the complete biomass to biofuel supply chain using SD, e.g. the effects of conversion technology maturation on the supply chain and the associated costs. Their work was important to build the supply-chain part of the BioSU model.
These studies especially focus on the economic and supply chain aspects of biofuel systems, whereby social aspects like labor are often included.

Next to the economic and supply chain related aspects, there are also various studies focusing on the environmental aspects of biofuel systems. Various studies focus on the relation between biofuel policies and the LUC dynamics. Warner et al. (2013) study the direct and indirect land use changes induced by, among other human drivers, the increase in demand for crop-based biofuels. Panichelli (2012) focusses specifically on the land use change and associated GHG emissions in Argentina induced by the biofuel industry intended for export to the EU. Such an export potential is also plausible in the case of Suriname.

Pruyt and De Sitter (2008) developed a SD model to study the interaction between the agricultural food production and bioenergy production on a global level. The thesis of Sandvik (2008) sheds light on the enhaced link between the food and energy markety caused by biofuels. He suggests that current biofuel policies, combined with peak-oil production, could lead to a future food crisis.

These studies have provided a better understanding in the complexity and dynamics of biofuel systems. This specifically in terms of the underlying structures and the associated behavior of biofuel systems. From the literature overview the following main findings can be summarized:

1. Supporters of biofuel consider biofuel as the potential replacement for fossil fuels on the short to medium term, while opponents fear the potential danger which biofuel impose for the environment in terms of biodiversity, water use etc., the food security and the LUC.
2. Biofuel systems are complex and multi-disciplinary systems where environmental, economic and social issues come together. A holistic method is required to study biofuel systems effectively.
3. Sustainability challenges behind the biofuel production are one of the main obstacles in the way of a much stronger biofuel demand and production growth.
4. A strong and consistent policy framework with a control/monitoring mechanism is required to guarantee sustainable biofuels.
5. Biofuel systems are more or less composed out of: a biofuel production sector, a biofuel demand sector and a feedstock supply sector. Depending on the scope and aim of the study common additions are: a land use sector, (agricultural) food sector and sectors of various rest products.

These aspects are all considered in designing the dynamic simulation model for this study. The next chapter goes in on the BioSU model.

3. The BioSU simulation model

In chapter 3, the various steps taken to eventually have a functional BioSU dynamic simulation model, are discussed. The applied methodology is followed by the conceptualization phase and subsequently the operationalization of the model. The last sub chapter discusses the fitness for use of BioSU.

3.1 Methodology

As mentioned in the literature overview, biofuel systems are complex, multi-disciplinary and multi-actor systems in which there is a strong interdependency between various environmental, economic and social aspects. Ziolkowska (2014) also supports this description of biofuel systems. Specific examples of the various aspects are: LUC, food security, job opportunities in rural areas etc. To study and understand these type of dynamic and complex systems, a comprehensive methodology, fitting the purpose is System Dynamics (SD) (Sterman, 2000). According to Pruyt (2013) SD starts form the assumption that system behavior is primarily caused by the structure of the system. Hereby system structure consist not only of physical and informational characteristics, but also policies and traditions which are important to the decision making process (Pruyt, 2013). Hence SD covers all aspects which are important to understand the behavior of a biofuel system in Suriname in order to develop, test and analyze policies for a Surinamese biofuel future. The SD model built for this study, named BioSU, can be considered as a support tool for policy makers to develop robust and effective biofuel policy.

The SD modelling process generally consists of the following steps (Pruyt, 2013):

1. Problem identification, where the issues are identified and documented in a problem statement.
2. Model conceptualization, where causal theories are developed on the issues to be addressed.
3. Model formulation, where a dynamic simulation SD model is developed, starting from the causal theories. In this study the model is built on the Vensim software platform, by Ventana Systems.
4. Model testing, where various tests are conducted to gain confidence in the usefulness of the model.
5. Model use, where the model is applied to develop, test and analyze policies and strategies, possibly under various scenarios.

In BioSU a set of differential equations, to be integrated forward in time, is coded. This establishes the behavior of the biofuel system over time, as a whole of the interdependence among parameter changes and the relations between variables in the biofuel system (Vimmerstedt, Bush, Hsu, Inman, & Peterson, 2014). A unique aspect of the BioSU model, is that long term policy- and strategy analysis is possible. Whereas, various models encountered in the literature overview are specifically built to model short to medium term (operational) issues on specific parts of the biofuel supply chain. BioSU consists of mechanisms, which make it possible to study the long term evolution of biofuel and the entire supply chain in Suriname, together with the associated LUC, the nation's energy supply and environmental impact.

With the BioSU model, exploring future developments in terms of mainly behavior, is far more important than generating very accurate quantitative forecasts. This makes BioSU useful for: a) design and analysis of policies b) generating scenarios and testing the policies for robustness under the various scenarios and the associated uncertainty and c) identifying levers with a high impact on system behavior, the so called policy levers.

In the next sub chapter the conceptualization will be discussed.

3.2 Conceptualization of BioSU

Before the dynamic simulation model BioSU was built a thorough conceptualization was made of biofuel systems, based on the reviewed literature and the specific characteristics of Suriname. This will be discussed in sub chapter 3.2.

3.2.1 Model boundary

Based on the aim and boundary of the study, a categorization was made of the extent to which factors will be incorporated in the model. The first category are the thoroughly modeled internal variables, these are considered to be the core of the biofuel system and modelled in detail. These factors are predominantly directly linked to the biofuel supply chain, whereby the following aspects are taken into account: a) production and logistics cost of both biofuel and feedstock, b) prices of biofuel and feedstock, c) yields, d) supply of biofuel and feedstock, e) biofuel and biomass export, f) environmental aspects like CO_2, SO_4 and NO_x emissions and soil degradation g) power generation, h) LUC, i) government measures and j) investments. These factors are the backbone of the model.

The second category is the *superficially modelled internal factors.* These are also considered an integral part of the biofuel system but are on a lower level on a scale of importance relative to the thoroughly modelled factors, so to speak. Hence they are modelled to a lesser extent of detail to prevent the model becoming too large. These factors are predominantly in fields which are on a higher level of aggregation e.g. a) fuel and electricity demands, b) environmental aspects which are dependent of much more factors than considered in the biofuel system, c) agricultural production and d) technological developments of which the modelling is often very difficult and highly uncertain.

The third category are the *external factors.* These cannot be influenced by the stakeholders in the biofuel system or they are outside the scope of the study, however, they are inevitable to successfully understand and study biofuel systems. They have a significant influence on the system as a whole and thus the outcome of biofuel policy. These variables are in the field of: a) foreign biofuel policy and the international biofuel and biomass demand, b) population growth, d) amount of cars and the average fuel consumption and e) the success of biofuel alternatives. These factors cannot be neglected when studying biofuel systems. However their inclusion as endogenously modeled variables could make the model to large and uncontrollable for the modeler, with the risk occurring that the model loses its credibility and usefulness for the aim of the study.

Finally there are excluded or intentionally omitted factors to keep the model manageable and fit for use. These factors are for example: local and international oil industry development, government fiscal system, Surinamese export- and entrepreneurship legislation and food security. It has to be mentioned that however these factors are not modeled explicitly, effort has been made to at least include there effects in factors which are modeled explicitly. In this manner they are not completely neglected. For further consultation on this classification, please consider Appendix A1.

3.2.2 The Causal diagram and feedback loops

The causal diagram provides a comprehensive and detailed overview of the factors in the biofuel system and the causal relations between them. The diagram is thus useful for qualitative “what if?” analysis, by providing understanding in the influence of changes in factors on other factors and subsequently on the system as a whole (Enserink, et al., 2010). Furthermore interesting relations, effects and important feedback loops can be identified and studied. This forms a firm basis for quantitative system modeling and simulation for the purpose of policy analysis through the System Dynamics methodology. The causal diagram is on a higher level of aggregation, relative to the BioSU model. Factors in the causal diagram are modelled in more detail in the BioSU model. Nevertheless, general mechanisms and aspects of the biofuel system are all covered in the causal diagram. The causal diagram is included in Appendix A.2, for further consultation.

The causal diagram can be classified in four sectors or sub systems. A sector diagram is constructed, from the causal diagram, providing a less detailed, but clear and clean view of the various interdependencies between the sectors. The sector diagram thus leaves out the internal relationships between factors in the sub models and only focusses on the interaction between the sub models (Pruyt, 2013). The sector diagram, illustrated in figure 1, provides a clear big picture overview of the biofuel system to the extent that the causal diagram fails in that purpose due to its detail. For this reason the causal diagram is only displayed in Appendix A.2, and the choice is made to display the cleaner sector diagram in this sub chapter.

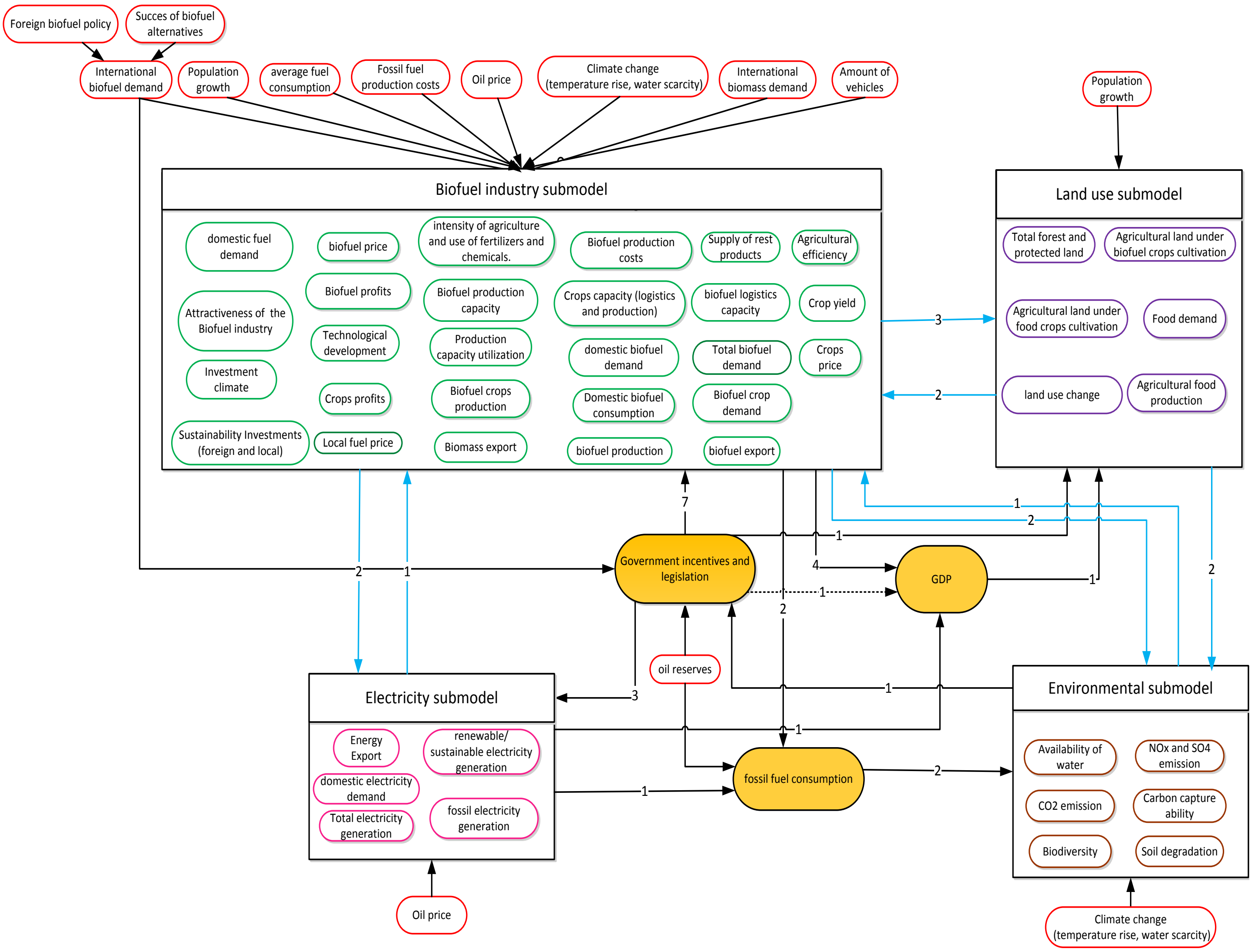


Figure 1: The sector diagram

The four sub models of the causal diagram are:

- The biofuel industry sub model: This the most important sector, it is also closely dependent on the other sectors. This sector represents the biofuel supply chain, consisting of the supply and demand side, both on biofuel and feedstock.
- The electricity sub model: This sector represents the power generation in Suriname. A sector where a biofuel industry can have an enormous impact on, with regards to bio-power out of sugarcane bagasse.
- The land use sub model: LUC is an important consequence of developing a large scale biofuel industry. Hence this sector is essential in the study, to express and study the interdependencies between biofuel and LUC.
- The environmental sub model: an important condition to develop a successful biofuel industry is sustainability in terms of preserving the environment for future generations. The environmental sector holds important factors which could be directly or indirectly influenced by the biofuel industry.

It can be noticed that in the sector diagram there are three factors that aren't part of one particular sub model, but rather they are part of more if not all four sub models. These factors are the *GDP*, *Government Incentives and Legislation*, and the *fossil fuel consumption*. The connected vectors indicate their relationship with the sub models, external factor and each other. These vectors are colored black and marked with a number, this number indicates the precise amount of relations there are, in accordance with the causal diagram. The blue vectors represent the interdependencies between the sub models.

From the causal diagram, the feedback loops essential to system dynamics research will be highlighted. Feedback loops represent, closed loop mechanisms, which have a reinforcing or balancing effect over time. The model consists of a system of connected feedback loops, just to name some of these loops, there is the: *(+) Negative crops profit via decreasing crops cost loop, (+) Positive feedstock attractiveness via production and export loop, (+) Positive attractiveness of biofuel production loop, (+) Positive biofuel production attractiveness via logistics loop (+) Positive biofuel production attractiveness via profit loop, (+) Positive feedstock availability on bio-power loop, (-) Negative government incentives with increasing attractiveness loop, (+) Positive decreasing biofuel price via increasing demand loop, (+) Positive biofuel attractiveness via production and export loop, (-) Negative yield on agriculture intensity loop, (-) Negative influence of LUC on carbon capture loop, (-) Negative influence of soil degradation on agriculture intensity loop, (+) Positive attractiveness of feedstock in biofuel loop, (+) Positive biofuel production cost decrease via technological development loop and the (+) Positive influence of scale on biofuel production cost loop.* The feedback loops are discussed in detail in Appendix A, section A.2.2.

The model thus includes the evolution of biofuel attractiveness in Suriname, via influences through demand, production, export, production- and logistics capacity and profits. But also the stimulation of bio-power via a biofuel industry, learning effects in terms of technological- and cost developments, environmental effects and the effect of policy performance are covered.

In the next sub chapter the BioSU dynamic simulation model will be explained.

3.3 Operationalization of BioSU

Starting from the conceptual model, a simulation model is built on the VENSIM software platform. In accordance with the sector classification of the causal diagram, the BioSU model also consists of four sectors. The sub models representing the four sectors will be discussed individually. Essential structure and equation related aspects will be discussed.

3.3.1 The biofuel industry sub model

This sub model is arguably the most important part of BioSU, as it represents the supply chain of biofuel and biomass (sugarcane) as feedstock. The complete structure is displayed in figure 21, Appendix B. Of this sub model some essentials will be discussed. These are: biofuel demand, biofuel production, feedstock production, investments, production costs and the feedstock and biofuel production and logistics capacity. A list with all parameter values and assumptions, for the whole model, is attached in Appendix C.

In the literature review it can be noticed that biofuel demand is mostly modeled as a function of the fossil fuel demand, considering biofuel blending in fossil fuels is one of the most common implementations of biofuels in existing energy mixes (Turckin & Macharis, 2010). In BioSU this is also done, but with the addition of an extra source of demand for biofuels, namely flex-fuel vehicles. These vehicles have special engines which make it possible to consume from the pure fossil fuels all the way up to pure ethanol (E100) and all the blends in-between (de Freitas & Kaneko, 2011). However fueling pure ethanol requires dedicated infrastructure, which has to be taken into account. The domestic and international biofuel demand is modeled as:

$$Dsur = (Pm\,.Fx) + C_{E100}$$

$Dsur$ = Surinamese biofuel demand
Pm = policy set bioethanol in gasoline blend, constant.
Fx = Suriname's gasoline consumption with a business as usual trend
C_{E100} = Suriname's E100 consumption

$$Dint = (Dint_0 + (\propto .Dint_0\,.U_{Dint}))\,.i$$

$$\propto (= (\propto_0 .e^{-X_1/10}) + (\propto_0 .X_2)$$

$Dint$ = international biofuel demand for the Surinamese biofuel industry
i = government quota on allowed export of Surinamese biofuel, constant
$Dint_0$ = initial international biofuel demand in 2015
U_{Dint} = international biofuel demand uncertainty
$\propto$ = international biofuel demand growth rate
$\propto_0$ = initial international biofuel demand growth rate, constant
X_1 = success of biofuel alternatives
X_2 = international biofuel policy, constant

Secondly, the biofuel production of the total industry, is modeled as the minimum between a certain *desired production* and *the total biofuel demand.* The desired production, is the production equal to the production capacity near full utilization, something very rare in the biofuels industry (Hilbert & Galligani, 2014). The production can also be limited by the available feedstock. The structure of the biofuel production is displayed in figure 2 as part of the bio industry sub model.

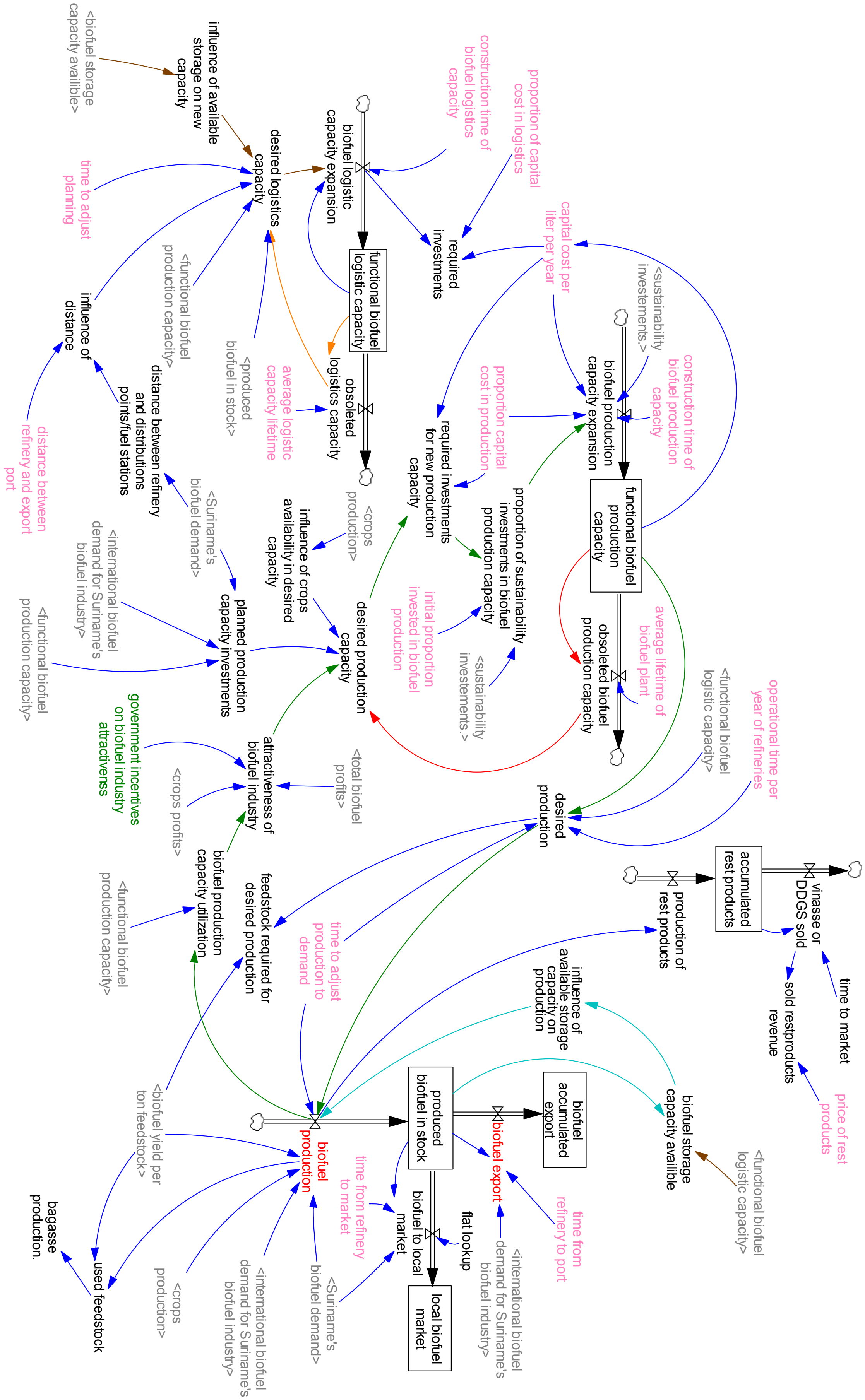


Figure 2: The structure of the biofuel production as part of the bio industry sub model

Figure 3 represents the structure regarding the sugarcane as feedstock production section. This structure and the associated equations are comparable to those of the biofuel production.

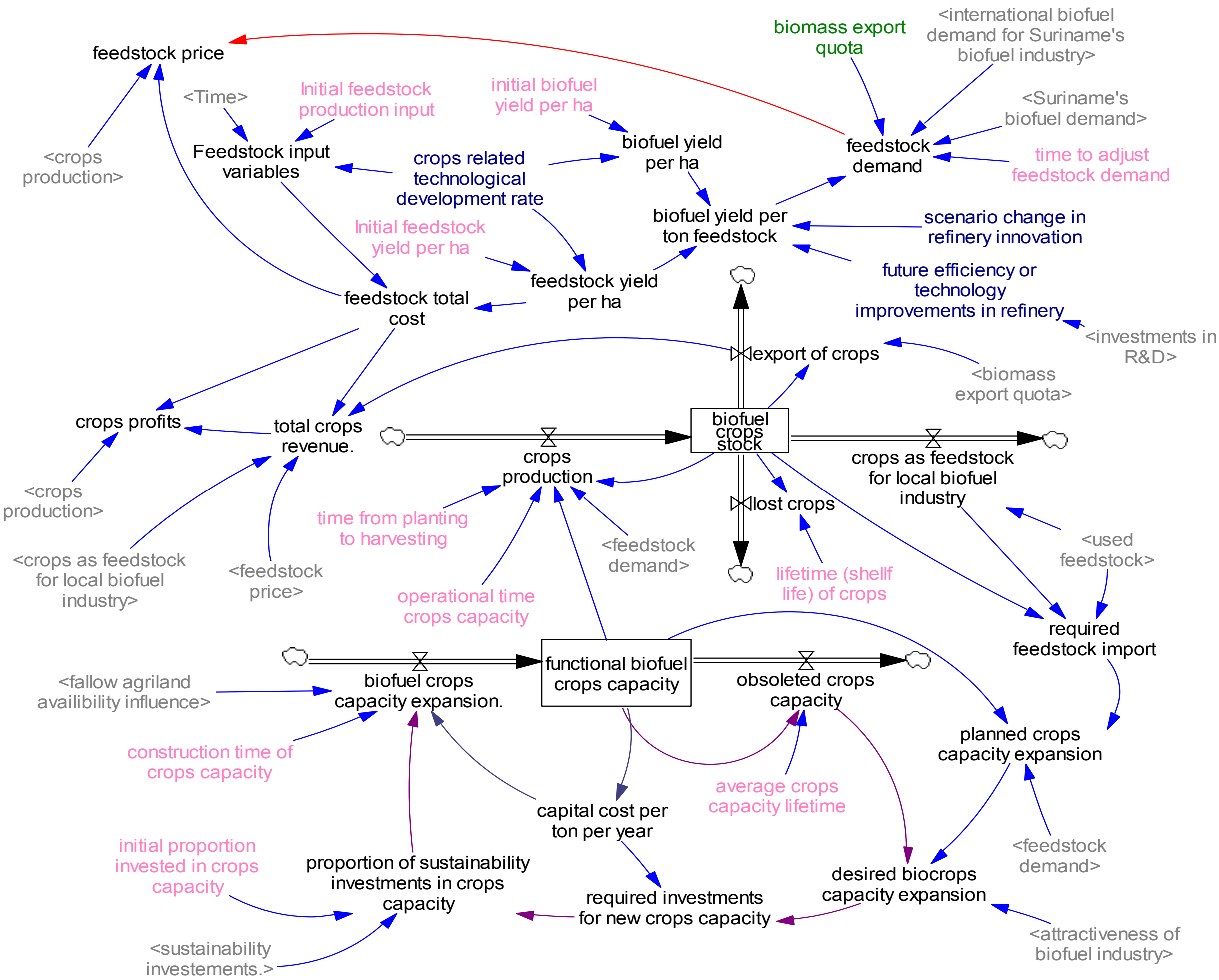


Figure 3: the sugarcane as feedstock production section as part of the biofuel industry sub model

Important functions in this sector are related to the biofuel production and feedstock costs. Cost are an essential aspect to make biofuels economically feasible and attractive for consumers and investors in comparison with the fossil fuels and other alternatives like electric and hydrogen based mobility (Goldemberg & Guardabassi, 2009). First, the total cost associated to the biofuel supply chain considered in the model, is modeled as:

$$C_{biofuel\ total} = C_{feedstock\ per\ liter} + \left(C_{electricity} + C_{refinery\ other}\right).\, e^{-\partial_{R\&D}} + C_{logistics} + \left(X_1 \,.\left(C_{refinery\ other} + C_{feedstock\ per\ liter}\right)\right)$$

$C_{biofuel\ total}$= total cost of biofuel production and logistics

$C_{feedstock\ per\ liter}$= feedstock cost per liter biofuel

$C_{electricity}$= cost for electricity need for biofuel production

$C_{refinery\ other}$ = cost for the refinery inputs other than electricity and feedstock

$C_{logistics}$= cost for biofuel storage, transport and distribution

$\partial_{R\&D}$= technological development, dependent on the R&D investments

X_1= proportion advanced biofuels. Included to represent the increase in costs associated with advanced biofuels.

The production cost for sugarcane as feedstock, is the strongest driver behind the feedstock price and subsequently the feedstock cost per liter biofuel included in the biofuel total cost ($C_{biofuel\ total}$). The feedstock production cost is modeled as:

$$C_{feedstock} = \frac{I_0 . e^{(-\partial(t))}}{y}$$

$C_{feedstock}$= feedstock production cost
I_0= initial input for feedstock production
$\partial(t)$= crops related technological development rate, developing over time
y= feedstock yield per ha

Next, the construction of new biofuel refineries is modeled as follows:

$$P_{biofuel\_capacity} = \left(\frac{\propto\ .\ I_s}{C_{capital} . t_{construction}}\right)$$

$P_{biofuel\_capacity}$ = addition of biofuel production capacity
$t = time$
$\propto$= proportion of sustainability investments in biofuel production capacity expansion
I_s= sustainability investments
C_{cap}= capital cost per liter per year
$t_{construction}$= average biofuel refinery construction time

The structure of the investments and revenue mechanism is displayed in figure 4. Investments are considered as flows, which are a function of the revenues generated by the sale of biofuel, biomass, bio-power and rest products. These revenue-to-investments flows, together with a flow representing additional non-revenue related Foreign Direct Investments (FDI), feed a virtual sustainability investment fund. From this fund the investments are allocated over the various sectors.

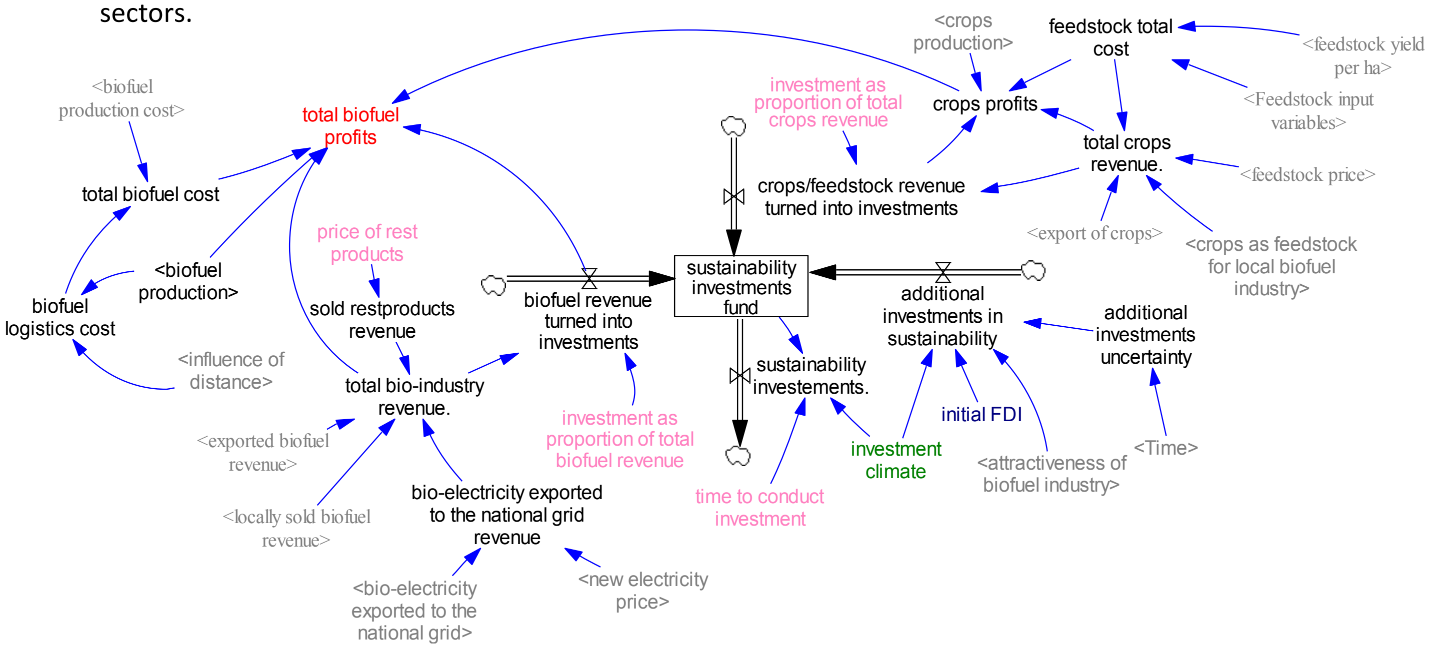


Figure 4: The structure of the investments and revenue mechanism

3.3.2 The electricity sub model

The electricity sub model represents the electricity sector of the causal diagram. The addition of power generation in SD models on the subject of biofuels is unique and not encountered in any of the models in the literature review. This model basically consists of three types of power generation capacity, the actual power generation and the demand. The sustainable electricity generation, as factor in the causal diagram, is split up in hydro- and solar-power on one hand and bio-power on the other hand. The third type of power generation, is petrol based.

Hereby the addition of bio-power capacity is comparable to the addition of biofuel production capacity. However, capacity expansion occurs in capacity blocks of for example 5, 10 or 30 MW which is a characteristic of power plant capacity expansions. Bio-power is strongly driven by the availability of bagasse as combustion fuel, government incentives, the desire for sustainable energy and the desire to decrease biofuel production cost (Hassuani, Leal, & Macedo, 2005). The model structure is displayed in figure 22, Appendix B for further reference.

The electricity demand is based on the increasing trend in the last 10 years. According to Willy Duiker, CEO of Suriname's power supplier EBS, the demand has been increasing with five to ten percent annually (Boerboom, 2014). The average % demand change, complemented with a demand elasticity to price factor and an uncertainty factor included in the % change, leads to the change in electricity demand. The change in demand is defined as:

$$D_{\Delta e} = (D_e . c_{\Delta e}) + ((D_e . c_{\Delta e}) . (P_n - P_0)^{\gamma})$$

$D_{\Delta e}$= change in electricity demand
D_e= electricity demand
$c_{\Delta e}$= % change in electricity demand, varying in time
P_n= new electricity price
P_0= initial electricity price
γ= demand elasticity to price change

Based on the electricity demand, policy can be outlined regarding the share of the various power generation types in the total power generation. The demand for petrol-power is considered as the difference between total electricity demand and the sum of the hydro-, solar- and possibly bio-power. In other words, petrol-power has the lowest priority in the power generation capacity expansion order; considering the aspiration for a sustainable electricity sector.

3.3.3 The land use sub model

LUC is, as mentioned before, a notable consequence of a biofuel industry. With the land use sub model the dynamics of LUC can be studied in the presence of a biofuel industry. For this sub model, inspiration and insight has been gained from e.g. the study of Musango, Brent, Amigun, Pretorius and Müller (2011).

The land use model is in essence a closed loop of stocks, representing the various land use allocations and flows, representing the LUC. The structure is presented in figure 23 in Appendix B for further reference. Land can be allocated towards: a) forest and protected land, b) land reserved for conservation and forest restoration, c) agricultural land which is: 1) fallow, 2) under food crops cultivation or 3) under biofuel crops cultivation, d) land for other purposes such as various urbanization activities both residential and industrial, but also activities like mining and cattle breeding and e) unmanaged land, which is basically all land not classified under any of the other land use categories. The unmanaged land stock, also functions as a temporaty buffer for land that is in the proces of LUC.

3.3.4 The environmental impact sub model

In the environmental model, all considered environmental aspects come together in the environmental index (EI). The structure of this sub model is displayed in figure 24, appendix B, for further reference. The EI is based on environmental indicators used by the UNSD (United Nations Statistics Division) (n.d.) and the OECD (2013), adjusted with own insights. The EI is defined as:

$$EI = 10 - \left(\frac{\Delta Q_1}{Q_{1.2015}}.w_{q1}\right) - \left(\frac{\Delta Q_2}{Q_{2.2015}}.w_{q2}\right) + \left(\frac{\Delta Q_3}{Q_{3.2015}}.w_{q3}\right) + \left(\frac{\Delta Q_4}{Q_{4.2015}}.w_{q4}\right) - \left(\frac{\Delta Q_5}{Q_{5.2015}}.w_{q5}\right)$$

ΔQ_1= change in CO_2 emissions

ΔQ_2= change in NO_x and SO_2 emissions

ΔQ_3= change in water irrigation availability

ΔQ_4= change in biodiversity – plant and animal species threatened

ΔQ_5= change in degradation – erosion and desertification

$Q_{x.2015}$= parameter value in base year 2015

w_{q1}= indicator weight – [0…1]

This EI provides an overall indication on the environmental impact caused by the biofuel industry both directly and indirectly.

The next sub chapter sheds light on the testing of the BioSU model for its fitness for use.

3.4 The fitness for use of BioSU

In order to test whether the BioSU model is fit for use various test were conducted. The tests have the purpose to verify and validate the model in terms of structure, input data and assumptions and the overall behavior and model output. The process of model verification and validation is very comprehensive, hence in this chapter only important test results will be discussed. If there is any interest in a more detailed and illustrative elaboration of this process, please consider Appendix D.

First of all the model was verified by the following tests (Pruyt, 2013): code error test, numeric simulation settings test and the dimensional consistency test.
These tests were conducted after each model iteration to eliminate errors with every modeling iteration and hereby improving each iteration. In addition during the process of multiple iterations in building the model, the coding was done as careful and well-thought as possible to prevent errors. This kept the errors at a minimum.

In the code error test, all equations and structures in the model, were checked for the occurrence of errors in the code. In the used model all equation- and structure errors are eliminated.

The numeric simulation settings test, reveals errors regarding the integration method and time step; allowing the elimination of these errors in order to get a well running simulation. Finally after many different combinations of time step and integration method were tested, the choice fell on the fixed Runge-Kutta integration method and a time step of 0.0625.
Finally the dimensional consistency test, tests the unit consistency. After various improvements of units, a few errors still occur but those are of no major influence on the results of the model, hence they form no imminent problem.

The goal of model validation as mentioned by Sterman (2000) is to test whether the model fits and is useful for the purpose of the study. This study, as mentioned before, is to test future policy and development of an advanced biofuel industry in Suriname and the subsequent impact on the energy supply, environment and economy. The tests conducted for model validation are in the field of direct structure tests and structure-oriented behavior tests.

First of all it is important to note that the model is considered for the time span of 100 years from the base year 2015, until 2115. Considering the purpose of the model, to explore plausible futures and policies and to get a better understanding of the behavior of the biofuel industry system as a whole, it is not the main goal that the model reproduces past real-data very accurately. Also due to the fact that a biofuel industry is new for Suriname, no past real data in this field is available. For the validation the timespan is extended to 2155 to also study whether the chosen timespan is appropriate considering the purpose of the model. Also, eventual irregularities in the model after 2115 can be detected and corrected in the case the model will be used for longer timespans in the future.

In the direct boundary adequacy test, the boundaries of the model are tested on whether they are set correctly, instead of to narrow or wide. The boundaries of the model are set according to the boundary of the study, mentioned in sub chapter 1.2.

It can be concluded that the boundaries are set adequately to study a system of a large scale biofuel industry with its influences on the electricity generation, land use and environment. To elaborate, emission factors are considered from source (transport, power generation and deforestation) to the atmosphere. Additionally only environmental factors are considered which are significantly influenced by the biofuel industry. In the biofuel supply chain the boundaries are not set too wide, although the whole supply chain: from production, to transport to the port or distribution points, is considered. This creates the ability to focus on the Surinamese biofuel industry, without congestion created by unnecessary factors.

Furthermore from the direct structure assessment test, it can be concluded that the model structure is in accordance with the explored causal relations, based on the real world.

With regards to the structure-oriented behavior tests, first of all a sensitivity analysis (SA) is conducted. Small 10 percent changes, relative to the base case, are implemented in the value of parameters to test the sensitivity of important model factors. The base case can be described as:

A small biofuel industry, comparable to WSESP, with domestic E10 obligations and no bio-power and biofuel export. The biofuel industry grows to merely supply the local demand. The investment climate is bad, according to the real situation (0.8 on a scale from 0 to 1 with a lower grade indicating a better investment climate). Additionally the situation can be described by an international growth in biofuel demand equal to 4% (Goldemberg & Guardabassi, 2009) and a relatively strong preference for biofuel in the international biofuel policy. Biofuel alternatives have a success rate of 5.5 on a scale from 0 to 10, with a higher grade indicating higher success. Finally annual FDI equal to US$ 375 million and a relatively strong technological development in all biofuel related fields are assumed.

The important model factors to monitor the performance of the biofuel system are called Key Performance Indicators (KPI's). They are also useful to test the performance of policies. This will be discussed in chapter 4. These KPI's are displayed in table 1. With this set of KPI's the environmental, economic, sustainability and land use aspects are all taken into account

Table 1: KPI's

KPI	Sub-model	category	unit
Biofuel production	Biofuel industry sub-model	economic	[liter/year]
Biofuel export	Biofuel industry sub-model	economic	[liter/year]
Total Biofuel profits	Biofuel industry sub-model	economic	[US$/year]
Share of bio-power	Electricity sub-model	sustainability	[%]
Forest and protected area	Land use sub-model	Land use	[hectares]
Total CO2 emissions	Environmental impact sub-model	environment	[ton/year]
EI	Environmental impact sub-model	environment	[EI points]

After the SA, It can be concluded that the KPI's are behaviorally non-sensitive to small changes in parameters. On the other hand they are numerically-sensitive to the small changes. The KPI's have wide ranges of numerical differences in the 1000 runs conducted for the SA. The small differences in parameters can thus have a significant influence on the success of a Surinamese biofuel industry. This is taken into account when creating and testing policies and scenarios. Inputs leading to considerable sensitivity are: a) the blending percentage of ethanol in gasoline, with direct impact on the local biofuel demand and production, but also the CO_2 emissions and b) the various government incentives in the biofuel industry.
A worrying observation, is that even with small changes to the base case, a decreasing trend of the EI can be noticed. Hence policy is critical, in order to preserve the environment.

Additionally, as part of the validation process, an uncertainty analysis (UA) is conducted in which the whole plausible uncertainty space is considered including extreme values. It is thus a hybrid uncertainty and extreme values test. This test should expose to which extent the model is still useful under extreme values and uncertainty. Hereby it can be concluded that the model is not particularly fit to handle the following absolutely extreme assumed situation: Suriname produces more than 50% of the world biofuel demand, with a maximum initial demand in 2015 of 200 billion liters, growing at a rate of 15%. In that case the model does not give very useful output. The model indicates that under these conditions, the Surinamese industry can only supply in the world biofuel demand for not more than 30%; considering the local availability of land and other resources.

After the UA, model inputs causing strong model sensitivity can be added to those resulting from the SA. The international biofuel demand, in particular the government quota on how much may be exported is the strongest one. This input has a tremendous impact on the whole industry as it leads to both numerical and behavioral changes. It impacts the scale of the industry, with direct consequences on the amount of investments, the scale advantages and the impact on production cost and subsequently the revenues and profits earned. But more importantly it dramatically impacts LUC and the environment in Suriname. Hence it is important to control this input with policy and legislation in order to realize a sustainable biofuel industry, not jeopardizing the environment

After the validation the conclusion can be drawn that the system behavior of BioSU, is largely according to the theories and empirical relations in a biofuel industry, encountered in the many studies considered in the literature review. Although, simplified to some extent.

Furthermore the applied timespan is appropriate for the purpose of the study, as no relevant changes in behavior occur after 2115 that could change the outcome of policy.

Also the model indicates no significant errors after 2115, meaning that the model could be used to simulate longer timespans with some small time related parameter adjustments.
In short the confidence is built that the model is useful for this study and not less important, it is scientifically sound.

4. Policy Analysis

In this chapter the BioSU model will be used for the main objective of this study: Policy Analysis. SD models are useful to conduct "what if?" analyses. What if this policy is implemented? What is the impact, how will the system behave? For this study three policy strategies are elaborated in sub chapter 4.1. Sub chapter 4.2 discusses the outcome of these policy strategies on the set of KPI's. After that, context scenarios will be discussed. These are used to test the robustness of the policies in 4.4.

4.1 The policy strategies

There are three policy strategies developed to be analyzed in this study. These strategies indicate clearly what intentions the Surinamese government has with a Surinamese biofuel industry. The policy strategies are composed out of several individual policy measures. These individual policy measures, which can significantly influence a biofuel industry, are (Franco, Ochoa, & Flórez, 2009), (Barisa, Romagnoli, Blumberga, & Blumberga, 2015):

1. Mandatory biofuel blending
2. Tax exemptions for biofuel and flex-fuel vehicles
3. Subsidies for flex-fuel vehicles
4. State subsidies for various biofuel related sectors e.g. biofuel production, feedstock production and bio-power
5. Deforestation and forest restoration legislation
6. Biofuel and biomass export quotas
7. excise tax on fossil fuels
8. Improve the investment climate

The three policy strategies are:

1. Domestic Policy (DP): This strategy focusses on establishing a biofuel industry to predominantly serve a local developed biofuel market. More specific the policy measures deployed are: a) domestic E25 obligations, b) subsidies on flex-fuel vehicles refineries and bio-power plants and c) tax exemptions (government take) on biofuel. Hereby only production for the domestic market is allowed.
2. Export Policy (EP): This strategy focusses on the export of biofuel to e.g. Europe and the United States. The domestic market is underdeveloped, relative to DP. More specific the policy measures deployed are: a) domestic E15 obligations, b) allowing production for export, c) deforestation law to minimize deforestation and increase forest restoration, in order to comply with strict EU sustainability criteria and preserve forest, d) subsidies on refineries and bio-power plants and e) tax exemptions (government take) on biofuel.
3. Bio based economy policy (BBEP): This strategy combines DP and EP, establishing a developed local market and a biofuel industry with the capacity to export. More specific the policy measures deployed are: a) domestic E25 obligations, b) allowing production for export, c) deforestation law to minimize deforestation and increase forest restoration, in order to comply with strict EU sustainability criteria and preserve forest, d) subsidies on flex-fuel vehicles, refineries and bio-power plants, e) tax exemptions (government take) on biofuel and f) support the addition of hydro-power.

In the BioSU model, however, not all of the aforementioned policy measure are precisely modelled as described. These measures are transformed to certain policy levers in BioSU with more or less the same effect. Table 2 contains the policy levers of BioSU and their value for each of the policy strategies as assumed in the study, including the base case for reference. These policy levers can be adjusted by the policy makers based on their vision of proper biofuel policy.

Table 2: Policy levers

	P1 [$/l]	P2 [0…1.5]	P3 [%]	P4 [0…1]	P5 [%]	P6 [0…1]	P7 [$/l]	P8 [ton/year]	P9 [%]	P10 [0…1]	P11 [1…100]
BC	0.05	0	10	0	0	0.1	0.50	0	53	0.8	100
DP	0*1	1	25	0.5	0	0.6	0.35	0	53	0.7	100
EP	0*1	0	15	0.7	2018 – 1 2030 – 2 2050 – 5	0.6	0.2	2025 – 3,000,000 2050 – 13,000,000	60	0.5	25
BBEP	0*1	1.3	25	1	2018 – 1 2030 – 2 2050 – 5	0.7	0.15	2025 – 3,000,000 2050 – 13,000,000	2015 – 53 2030 – 73 2050 – 83 2070 – 88	0.4	30

*1 = 0 only if bio-power is generated to power the biofuel industry.

The policy levers are:

P1 - refinery electricity cost: the electricity cost in refineries are a substantial part of the refinery cost, ±30% (U.S. Department of Agriculture, 2006). Via bio-power with possibly government subsidies, these costs can be eliminated and the competitiveness of biofuel can be increased.

P2 - Government incentives on flex-fuel vehicles: this lever can take the value between 0 and 1.5, and represents the intensity of the government incentives. This incentive is not very specific and can thus vary from subsidies to tax exemptions for flex-fuel vehicles. This factor works on the normal expectancy trend for the shift to E100 and flex-fuel vehicles which is modeled as an S-curve, see figure 5. The y-axis represents the share of the E100 consumption for flex-fuel vehicles. P2 can thus strengthen this development to max 90% (1.5 x 60%) in 2115.

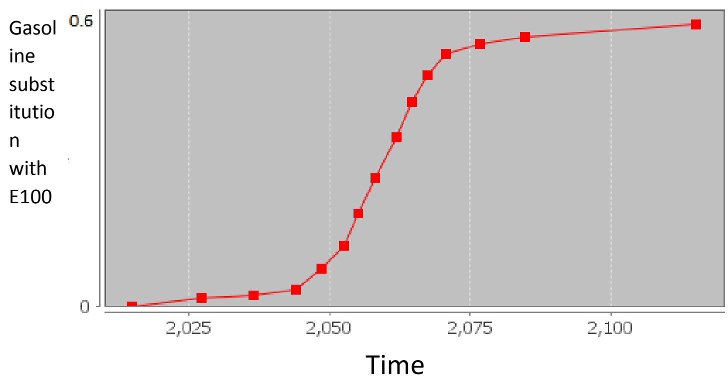


Figure 5: The expected development of the E100 share over time

P3 - Policy determined ethanol-blend in gasoline: This policy lever is simply the percentage of bioethanol being mixed in the traditional fossil gasoline.

P4 - policy based incentive for bio-power: this lever can take the value between 0 and 1, and represents the intensity of the government incentives for bio-power. This incentive is not very specific and can thus vary from subsidies to tax exemptions for bio-power. This factor has an influence on the desired bio-power capacity by increasing the attractiveness to invest in bio-power.

P5 - government quota on allowed export of Surinamese biofuel: with this lever, policy makers can determine how much biofuel may be exported. Basically in percentages of the world demand. This percentage grows as the biofuel industry is developed and the focus is set on export.

P6 - government incentives in biofuel industry attractiveness: this lever can take the value between 0 and 1, and represents the intensity of the government incentives for a more attractive biofuel sector including feedstock production. This incentive is not very specific and can thus vary from subsidies to tax exemptions relating to e.g. refineries or sugarcane plantations.

P7 - government tax on biofuel: The Surinamese government applies a tax on transport fuels known as the Government take, worth $0.50 per liter gasoline (Persdient kabinet van de Republiek Suriname, 2012). With this lever, policy makers can determine to which extent biofuels will be subject to the government take.

P8 - biomass export quota: this lever is comparable to P5 as it determines how much biomass may be exported.

P9 - share of hydro- and solar-power: with this lever policy makers can set targets on the share of hydro- and solar-power in the total electricity generation.

P10 - investment climate improvement: A long known and structural obstacle which complicates investments and business in Suriname is the bad investment climate. With this lever it can be studied what the effect is of an improved investment climate.

P11 - deforestation law strictness: this policy lever provides the ability to set and study the strictness of deforestation restrictions, on the biofuel industry.

In chapter 4.2 the outcome of these strategies are discussed.

4.2 Policy outcome assessment

For each policy strategy some interesting finding will be discussed, coming from the simulation runs for the purpose of policy analysis. Hereby the focus is on the KPI's, but also some other interesting performance indicators will be reviewed. Figure 6 shows the simulation process applied.

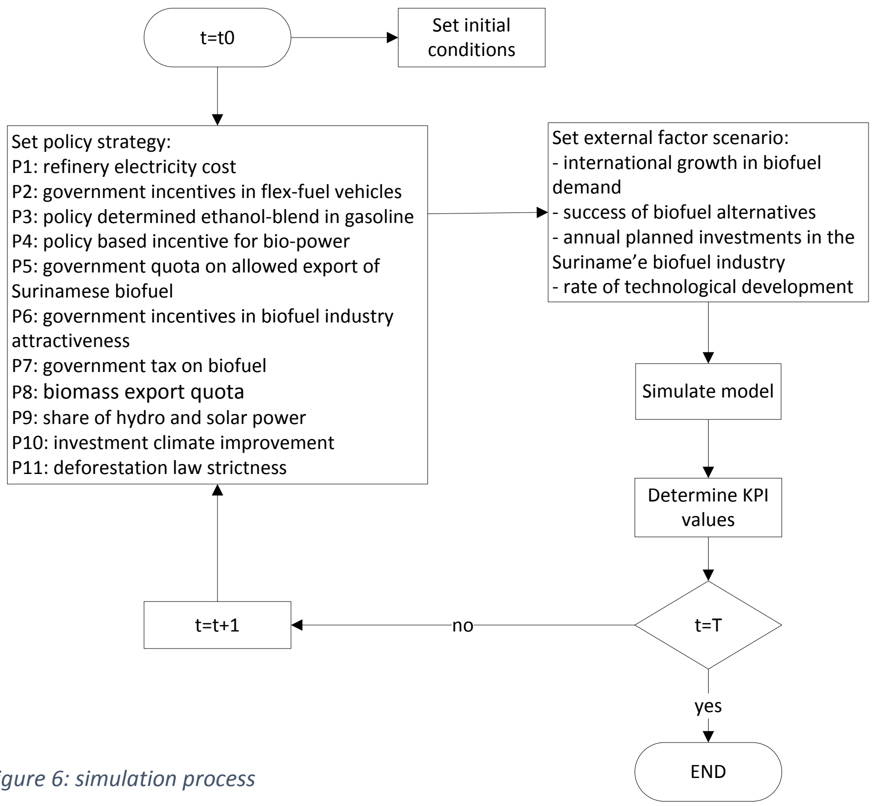


Figure 6: simulation process

4.2.1 The Domestic Policy strategy or DP

This sub chapter discusses the outcome of the policy strategies mentioned in sub chapter 4.1, based on the KPI's and some other interesting factors.

Starting with the DP, DP meets the local biofuel demand to a large extent and in a profitable way. Figure 7 indicates that only in the start of the industry, small losses will occur due to the forehand investments in infrastructure. The biofuel production steadily increases to 1.304 billion liters in 2115, as can be seen in figure 8, to largely cover the local demand of 1.4 billion liters in 2115. Some import of biofuel is thus needed to cover the entire local demand.

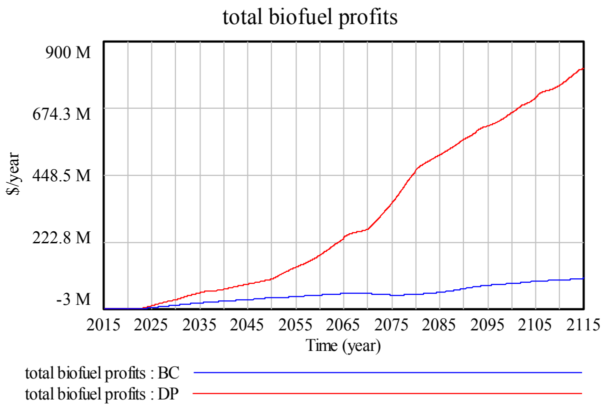


Figure 7: The total biofuel profits for DP and the BC

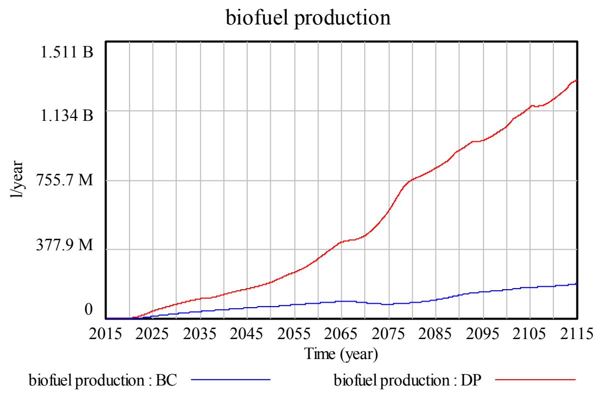


Figure 8: The total biofuel profits for DP and the BC

In terms of bio-power, DP successfully implements bio-power at a steady rate, leading to a share in the power generation of 9% in 2115 as can be seen in figure 9. Nevertheless, petrol power is still significantly present in the case of DP, although it decreases from 47% in share to around 37%. Additionally the potential to export power is present with annual potential revenues rising up to US$ 40 million.

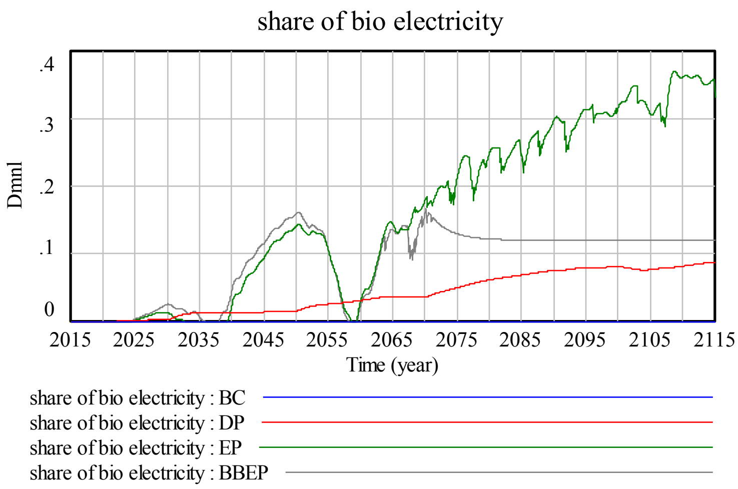


Figure 9: share of bio-power for all three strategies and the BC

The deforestation decreases towards around 6000 ha/year in 2060, whereupon it increases up to 18,000 ha/year in 2115. At the end of the simulation, in 2115, the forest coverage is equal to 13.8 million hectares or 88% of the total land area as can be seen in figure 10. Hereby the deforestation is mainly driven by the demand for settlement land, as the demand for agricultural land, in particular for sugarcane as biofuel feedstock, remains limited.

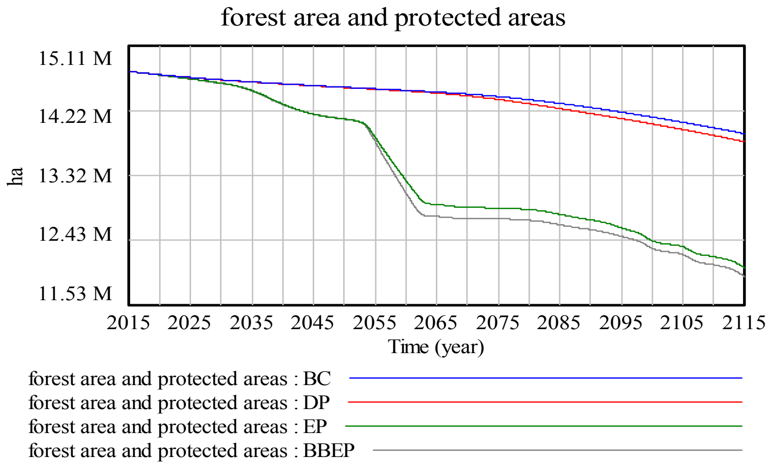


Figure 10: forest and protected areas

In terms of the total CO_2 emissions, the DP strategy is able to limit emission in 2115 to 7.5 million ton/year, as can be seen in figure 11. This despite the strong increase in transport and power generation in a growing economy. Figure 12 shows that in the transport, CO_2 emission will stabilize at around 2 million tons per year due to the blending measures and the introduction of flex-fuel vehicles, combusting high blends of carbon neutral biofuel.

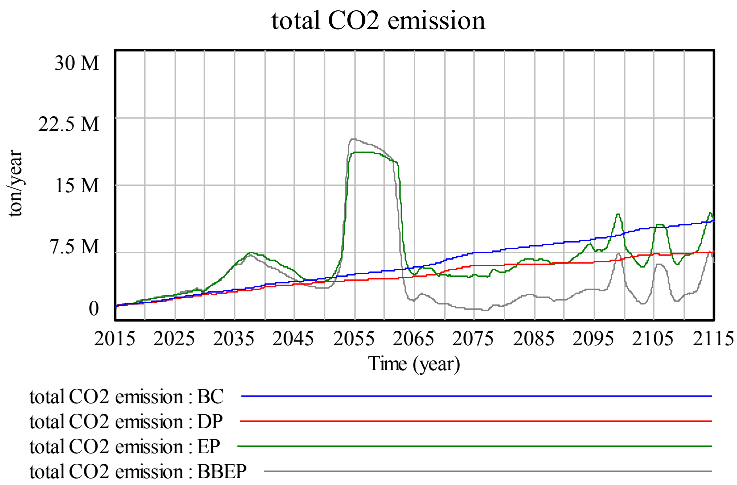


Figure 11: The total CO_2 emissions for all three strategies and BC

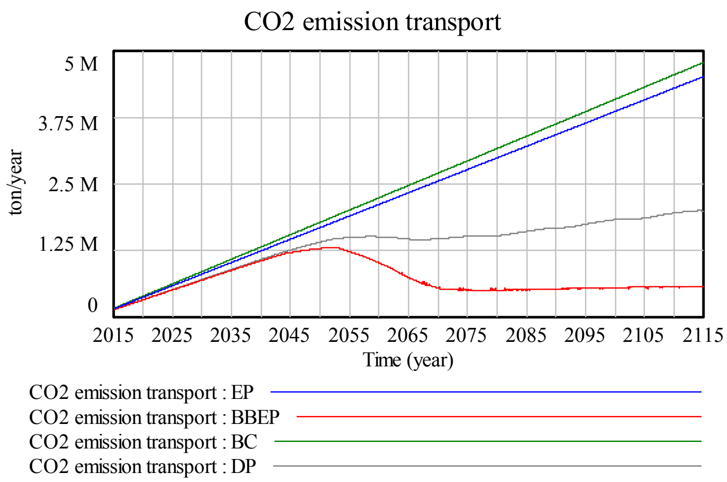


Figure 12: CO_2 by the transport

A notable observation is that the Environmental Index continues to show a decreasing trend, however less strong in comparison to the BC. This indicates a decay in the environment and possibly a lack of effective policy measures to preserve the environment by DP.

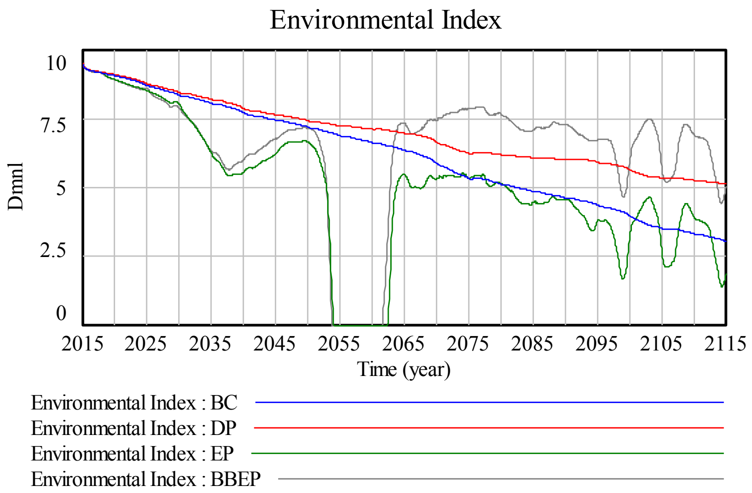


Figure 13: The EI for all three strategies and BC

4.2.2 The Export Policy strategy or EP

Regarding the EP strategy, a significant difference can be noted, relative to the BC but also DP. The biofuel production peaks at 28.24 billion liters in 2115, this is considerably more than the DP focusing on the local demand as EP focusses on the export. Figure 14 illustrates the development of the biofuel production for the EP and the BBEEP. The production for the BC and the DP is displayed separately in figure 8, because the difference is far too big to usefully display all strategies in one graph. The same holds for the biofuel profits, due to the huge difference in scale between the EP and BBEP on one hand and the BC and DP on the other hand.

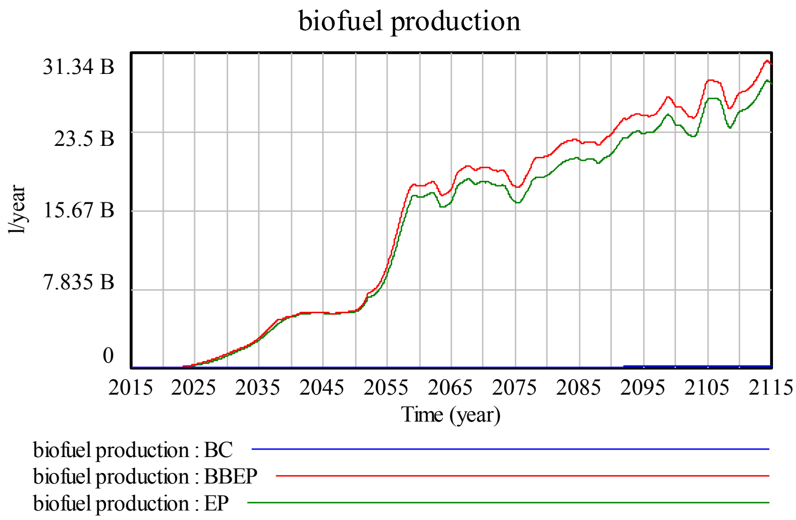


Figure 14: Biofuel production for EP, BBEP and BC

Next, the EP strategy requires major investments of up to US$ 6.7 billion in 2115. Considering the associated investments, there is a significant shortage of financial resources in the periods 2050 – 2055 and 2080 – 2115. But in general the EP is profitable after a start period of losses until around

2025. Figure 15, shows that the profits may rise up to US$ 10 billion, although with annual fluctuations. The investments shortages can thus be financed with the profits made.

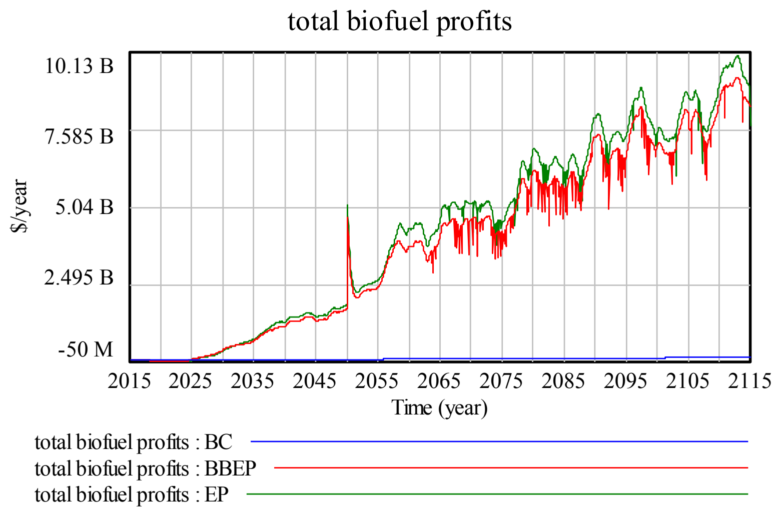


Figure 15: total biofuel profits for EP, BBEP and BC

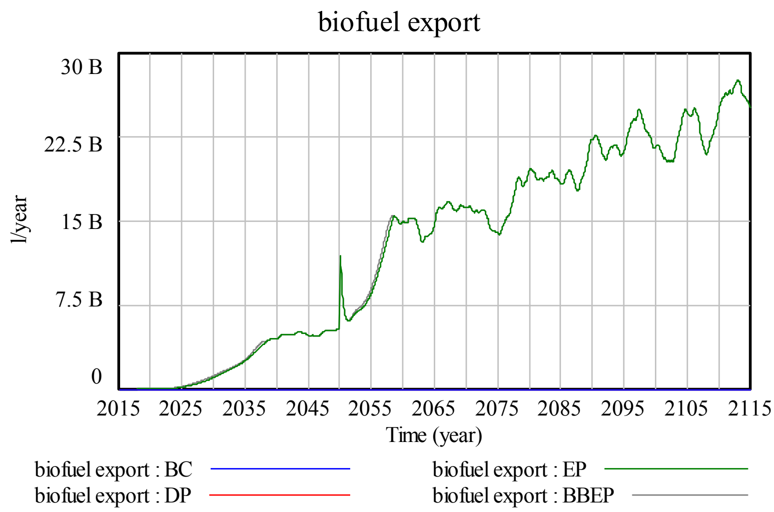


Figure 16: biofuel export for EP, BBEP and BC

The EP strategy focusses on the export of biofuel and that can be seen in figure 16. With a government quota of allowed biofuel export as a percentage of the international demand equal to 1% in 2018, 2% in 2030 and 5% in 2050; the Surinamese biofuel export increases considerably towards 25.21 billion liters in 2115. With this export the Surinamese biofuel industry will become very important in the global biofuel market. To put this export into perspective, the United States and Brazil as the world's largest bioethanol exporters, exported 3.2 billion liters and 1.5 billion liters respectively in 2014.

With the assumed learning curves, technological developments and their effect on cost reductions, biofuel total cost could drastically decrease in Suriname to an equilibrium of US$ 0.18. Even with the government taxes, Surinamese biofuel would still be very competitive on the world market where the price per liter in July 2015 was US$ 0.49 (Trading Economics, 2015). The price in Suriname can decrease to US$ 0.47 all in for EP, that is inclusive taxes and a generous profit for the industry up to US$ 0.10 per liter.

With the EP strategy bio-power can become very important for Suriname with a share of about 36% 2115, as can be seen in figure 9. This limits the share of petrol power to 14% 2115, assuming a share of hydro- and solar-power equal to 60%. The export potential of power can peak at about US$ 148.2 million per year.

Further, the impact of EP on land use is significant as the forest coverage drops from almost 95% in 2015 to 77.3% in 2115. The 77.3% is equal to 12.05 million hectares of forest covered land, according to the simulations displayed in figure 10. Consequently the carbon capture capacity of the Surinamese rainforest drops from 38.37 million ton/year to 31.33 million ton/year.

From Figure 11 it can be noticed that the total CO_2 emissions show an increasing trend towards 10.9 million ton/year. The reason behind higher emissions with EP, relative to DP can be explained by the assumption that in EP the blending obligations are lower, 15% instead of 25%, and the implementation of flex-fuel vehicles and the use of E100 is lower due to the absence of government incentives for flex-fuel vehicles.
The CO_2 emission trend shows a certain spike in the period 2050-2065, this can be explained by sudden strong increases in deforestation to clear up land for sugarcane cultivation. This deforestation significantly increases the emission via CO_2 stored in forest. This spike is horizontally limited, flattened, thanks to deforestation law which bans the stronger and more frequent deforestation in the model.

Finally the EI decreases significantly for the EP strategy, stronger than both BC and DP, mainly due to the deforestation and soil degradation as a consequence of a large scale biofuel industry. The decrease tends towards 1.8 EI points in 2115. This strategy focusses on maximal export revenue, contributing to the sustainability objectives and energy needs of other countries, while leading to an environmental deterioration in Suriname. This is an undesirable, but occurring phenomenon in many third world countries accommodating biofuel and biomass production for the developed countries. The EP strategy should contribute more towards preserving the environment, it does not facilitate sufficient environmental preservation measures to protect Suriname.

2.2.3 The Bio-bases Economy Policy strategy or BBEP

The first interesting finding on the BBEP strategy, is that in terms of the biofuel production behavior the outcome of the BBEP strategy is comparable to that of the EP strategy. This can be seen in figure 14. However there is a numerical difference of about 2 billion liters between BBEP and EP from around 2067 until 2115. This can be explained by the stronger domestic demand caused by E100 consumption via the implementation of flex-fuel vehicles, which is also the case in the DP strategy but not for EP. Regarding the biofuel export, figure 16 shows that the export is completely identical for EP and BBEP.

Second, the biofuel demand increases steadily in the national and international market, but not as strong as the production capacity in the form of new refineries. This leads to a decreasing capacity utilization from around 100% to slightly below 50% in 2115. This is the case for both EP and BBEP and is a real problem in today's biofuel industry (Soare, Bunger, Kersh, Suryana, & Udupa, n.d.). A possible explanation derived from the model is that the attractiveness of the industry remains high due to the profits made, hereby new investments are continuously made in the capacity. In the case of the BC and DP, however, the capacity utilization is mostly high at around 90%.

Next, the biofuel cost reduction observed for EP, also occurs in BBEP. Surinamese biofuel thus remains very competitive in the international market.

Due to the larger scale, the required investments are also higher, but only slightly, through scale advantages. From the modeled investments flows, a shortage in finances occurs like in EP. However the large profitability of the industry, after a start period of losses, provides the ability to finance these deficits as mentioned in EP.

Also, the BBEP strategy strongly focusses on creating a fully renewable power generation. This can be realized considering the simulations. Around 2070 the power generation can be completely carbon neutral with only hydro-, solar- and bio-power. The share of bio-power in 2115 for BBEP is 12%, as can be seen in figure 9. The rest of the power generation is covered by hydro-power. A power supply with very low operational cost can thus be established, as no expensive fuel is needed for hydro- and bio-power. Additionally the export potential for electricity is huge in this strategy. Annually the potential revenue rises, up to US$ 800 million in 2115. However this will require large investments in the relatively expensive hydro-power construction. The required investments can amount up to US$ 250 million annually. These are not considered in the "total bio-industry investments" where only the bio-power investments are considered and investment deficits already occur.

A larger scale biofuel industry in BBEP is sadly also associated with a larger scale of deforestation relative to in particular DP and the BC. The difference with EP is, however, limited. The forest coverage in 2115 is 76.5% or 11.93 million hectares. This difference is less than 1% relative to the EP strategy. Deforestation law included in the model, helps to keep the difference in deforestation compared to the BC, relatively low.

For BBEP the land under sugarcane cultivation in 2115 is equal to around 1.6 million hectares or 10.3% of the total Surinamese land. Ludena, Razo and Saucedo (2007) state that 1.96 million hectares of suitable land is available for sugar cane cultivation in Suriname.

A positive observation in figure 11, is that the total CO_2 emission can drop below the 2015 level of around 3 million ton/year. For some periods in which deforestation is stronger than normal, the emissions peaks. But in general the emission is around 3 million ton/year, due to the BBEP strategy leading to considerable CO_2 savings in the field of transport and power generation. Figure 12 shows that the emission coming from the transport tends to balance around 500,000 ton/year. This is considerably lower than in the BC where the transport related emissions can rise up to 5 million ton in 2115.

As a result of the fully renewable power generation from 2070, the CO_2 emitted by the power generation is equal to 0 ton/year from 2070 to 2115.

Hence the CO_2 emissions are primarily caused by deforestation. For example a strong deforestation spike in the 2057-2067 period is very evident in the CO_2 emissions and the EI. These low emissions together with a high carbon capture capacity via the rainforest, technically imply a negative carbon exposure for Suriname. This provides the ability for Suriname to deal in carbon credits.

Finally due to the strong emission reductions, the BBEP boasts an EI, which is around the same level as the 2015 level. This can be seen in figure 13. For BBEP the negative biofuel industry impacts on the environment can thus be compensated by the positive impacts.

4.3 System context scenarios

This sub chapter discussed the construction of three context scenarios: Bio-2, Bio-1 and Bio-0. These three scenarios will be used in the policy uncertainty analysis. In figure 17, the scenario logic is displayed. It is assumed that three driving forces are important on the global biofuel scene. These driving forces also have significant uncertainty and lend themselves to assess the policy strategies in their robustness. The driving forces assumed here are: *economic development, technological development* and *the international preference for biofuel.* A distinction is made between the extreme states in dimension for the driving forces, as can be seen at the ends of the axes.

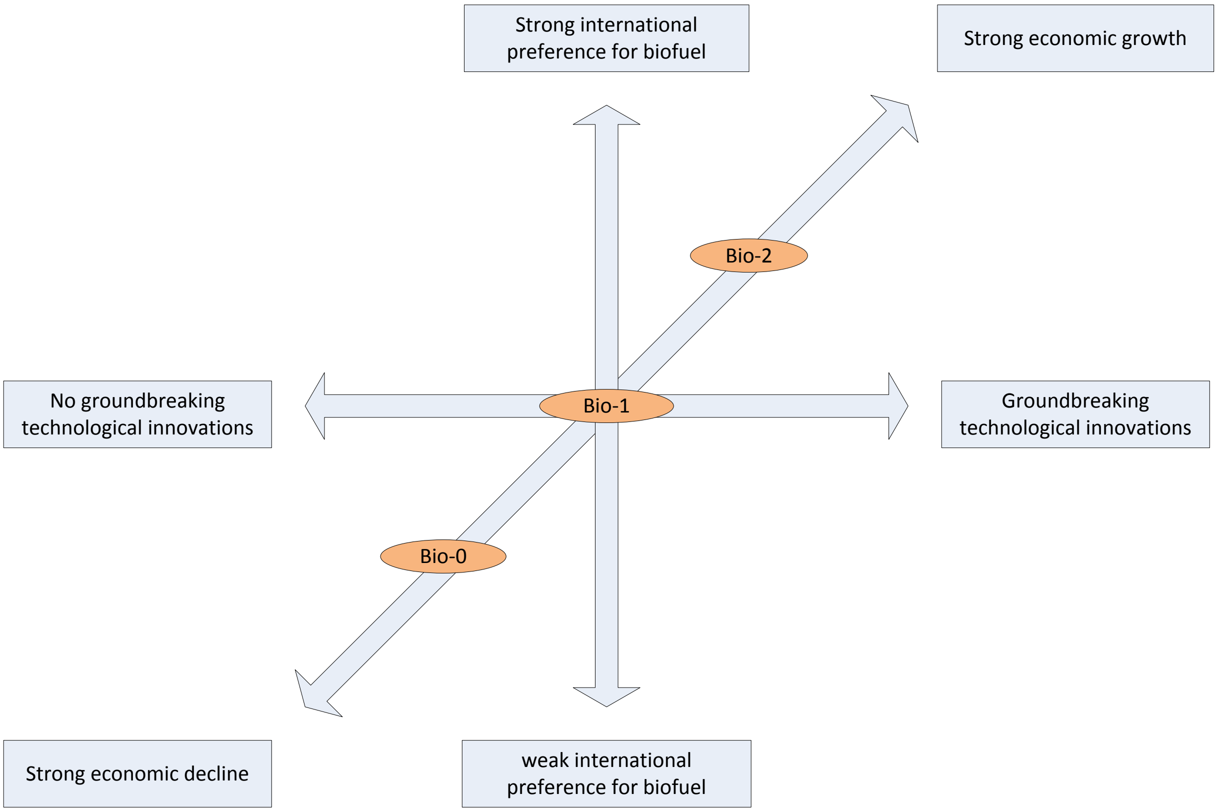


Figure 17: the scenario logic

Economic development, is relevant considering their relationship with (foreign direct) investments in the Surinamese biofuel industry. Hereby in particular the economy in the countries and regions where biofuel play an important role in the energy mix and origin countries of multinationals with an interest to invest in the Surinamese biofuel industry, are interesting to keep an eye on. It is imaginable that in times of global economic distress, not much risks will be taken to perform investments in a market like Suriname where biofuels are relatively new. However, these foreign investments will boost the Surinamese economy enabling more domestic investments and government incentives (Pettinger, 2008). A declining local economy can lead to the review of subsidies with public funds by the government. These subsidies are, however, crucial for a new biofuel industry to successfully kick-off (Barisa, Romagnoli, Blumberga, & Blumberga, 2015).

Technological development is another interesting driving force behind a successful biofuel industry to take into account. Technological development plays an important role in the biofuel supply chain from feedstock cultivation, transportation and (pre-)processing to the biofuel refinery process, storage, transportation and consumption. Especially cost reduction via higher efficiencies regarding higher yields and lower energy consumption can be realized with technology.

But also in the maturation and success of advanced biofuels (second and third generation), technological development is critical (Ziolkowska, 2014), (Coelho, Goldemberg, Lucon, & Guardabassi, 2006) and (Janssen, Turhollow, Rutz, & Mergner, 2013).

At last, technological development is important for the extent to which bagasse is being allocated towards the generation of bio-power. Generating bio-power out of bagasse, although the feedstock cost are basically the opportunity cost of bagasse (Walter & Ensinas, 2010), requires advanced technology in terms if preparation and combustion to achieve high efficiency (International Renewable Energy Agency, 2012).

The international preference for biofuel or the international biofuel policy, is the third driving force taken into account to study plausible futures. Especially with the eye on Suriname as biofuel exporter, the international biofuel policy is of major importance. International biofuel policy is determinative for the development of the international biofuel demand, next to the success of biofuel alternatives. According to the FAO (2008), biofuel policy is primarily driven by climate change concerns, energy security and the desire to support the farm sector via an increased demand for agricultural products. Some important examples of international biofuel policy are (Carter & Schaefer, 2015) (European Commission, 2012): a) the EU biofuel blending policy, but also blending policies in the USA and other non-EU countries and b) the strict EU requirements regarding the sustainability of biofuels in terms of GHG emissions, land use change, source of the biomass/feedstock etc. included in the EU Renewable Energy Directive (RED).

As can be seen in figure 17, three scenarios will be considered in the policy analysis. Hereby the study does not focus on the probability of the scenarios to occur, but rather on the plausibility. After all, it is not possible to forecast the future, as it will always be wrong. The scenarios rather have the purpose to explore the robustness of the policy strategies in this study, on plausible future developments in the context of the biofuel system (Enserink, et al., 2010). The considered scenarios are in accordance to a specific dimensional space in the scenario logic and are as follows:

Bio-2: Strong Biofuel growth

a) International growth in demand with 6%, based on data of the Renewable Fuels Association (2014) and forecast of Navigant research (2014).
b) The international biofuel policy is assumed to be 1, on a scale from 0 to 1.
c) A moderate march of biofuel alternatives like electric mobility, 4 on a scale from 1 to 10. (Renewable Fuels Association, 2014)
d) Annual assumed foreign direct investments (FDI) in the Suriname biofuel industry are in the region of US$500 million
e) The biofuel related technological development is strong.

Bio-1: Moderate Biofuel growth

a) International growth with 2%, this can be considered equal to the increase in demand for transportation fuels as suggested by Faaij, Szwarc, and Walter (2008).
b) The international biofuel policy is assumed to be 0.6, on a scale from 0 to 1.
c) A strong march of biofuel alternatives like electric mobility, 7 on a scale from 1 to 10.
d) Annual assumed foreign direct investments (FDI) in the Suriname biofuel industry are in the region of US$250 million
e) The biofuel related technological development is moderate.

Bio-0: Global shift from biofuel to alternatives like electric mobility

a) Domination by biofuel alternatives like electric mobility in the global transportation sustainability revolution. The success can be scaled a 10 on a scale from 1 to 10.
b) No international demand for biofuel.
c) The international biofuel policy is assumed to be 0, on a scale from 0 to 1.
d) No annual FDI assumed in the Surinamese biofuel industry
e) The technological development is weak.

In sub chapter 4.4 these scenarios are used to assess the robustness of the policy strategies.

4.4 Robustness of the policy strategies

To assess the robustness of the policy strategies, they are subject to an uncertainty analysis which incorporates the three contextual scenarios discussed in 4.3. First the policies are run with each scenario individually. Subsequently, for each policy strategy, 5000 runs are simulated in which the scenario parameters can take any value in the dimensional space between the parameter values of scenario Bio-2 as maximum and scenario Bio-0 as minimum.

In Appendix E, the graphs belonging to the scenario uncertainty analysis are attached for a detailed view. In this sub chapter, however, only important findings will be discussed.

4.4.1 DP scenario analysis

First, DP is a stable biofuel policy when considered under both the Bio-2 and Bio-1 scenario individually. For the Bio-0 scenario, however, DP is not able to meet local demand as investing in biofuel is not attractive under the Bio-0 conditions in terms of technological developments and cost reductions. In the Bio-0 scenario, only small marginal profits can be made from around 2040. Whereas profits occur as early as 2024 in the other scenarios.

Second, the share of bio-power is between 9% and 10% in 2115 for Bio-1 and Bio-2 and 0% for Bio-0. In Bio-0, sustainability investments and the desire for bio-power are insufficient.

At the end of the simulation, in 2115, the forest coverage remains above 90% of the total land area for all three scenarios.

Further, DP limits CO_2 emissions in 2115 to about 7.5 million ton/year in the Bio-2 and Bio-1 scenario. In the Bio-0 scenario the emission increases to 9 million ton/year, mainly due to the absence of bio-power and the higher petrol power generation.
Finally for all three scenarios, the Environmental Index decreases significantly.

The aforementioned stability of DP's performance under Bio-2 and Bio-1, is also maintained to a large extent in the full range of scenario uncertainty. No irregular change in behavior is noticed and all of the aforementioned findings for DP hold, with only numerical variations. The simulations with parameter values near those of Bio-0, indicate that although DP is a very effective policy in 95% of the 5000 runs, there are still about 250 runs in which DP is unprofitable and not able to meet its objectives. But in general DP is a very robust policy strategy.

4.4.2 EP scenario analysis

Between Bio-2, Bio-1 and Bio-0 there is a significant difference in the biofuel production, as EP is focused on the international market with a considerable amount of uncertainty. In Bio-2 the annual production peaks at around 50 billion liters in 2115, while the peak in Bio-1 is at 16.5 billion liter. The production is almost completely exported. In Bio-0 the production peaks at 45.12 million liter in 2115, while the export is negligible due to the shift to alternatives. Solemnly focusing on the international market brings along strong dependency and uncertainty driven by factors like: international biofuel policy and the success of biofuel alternatives.

Second, for both Bio-2 and Bio-1, EP is very profitable after a start period of small losses. For Bio-2 the profits increase up to US$ 17 billion and US$ 5 billion for Bio-1. However Bio-0, would be fatal for a large scale biofuel industry in Suriname due to constant losses.

Thirdly, with the EP strategy bio-power holds a 35% share for Bio-2 and 27% for Bio-1 in 2115.

The impact of EP on land use is significant as the forest coverage drops from almost 95% in 2015 to 70% and 80.5% in 2115 for Bio-2 and Bio-1 respectively.

Further, the total CO_2 emissions show a trend of increase towards 10.9, 12.1 and 10.17 million ton/year for Bio-2, Bio-1 and Bio-0 respectively.

Finally the EI decreases significantly for the EP strategy in all three scenarios, mainly due to the intensive deforestation and soil degradation. The least strong decrease is for Bio-0, in which the biofuel industry is also the smallest when compared to Bio-2 and Bio-1.

When assessing EP for robustness under the entire uncertainty range between Bio-2 and Bio-0, it can be concluded that EP is far less robust in comparison to DP, but in general still very robust in achieving its objectives. To begin there is very large numerical variation in the possible outcome of EP when exposing it to the scenario uncertainty. Especially the EI, which is not the least important KPI, shows strong uncertainty in both numerical value and behavior.

Secondly, this policy is very dependent on international biofuel demand related aspects like the biofuel policy, the growth in demand and the success of biofuel alternatives. These aspects which are considered in the scenarios, indeed have a large impact on the robustness of EP, as shown by BioSU. Also the technological development has a strong effect, as a weak technological development prevents the desired increase in agricultural yields. This leads to much more aggressive deforestation in order to cover the increasing demand and a further deterioration of the Surinamese forest and environment.

4.4.3 BBEP scenario analysis

To begin, the behavior of the biofuel production, export and the profits for the BBEP strategy is comparable to that of the EP strategy for all three scenarios with only numerical differences.

Secondly, the BBEP strategy strongly focusses on creating a fully renewable power generation. This can be realized in the case of Bio-2 and Bio-1. Around 2080 the power generation can be completely carbon neutral with only hydro-, solar- and bio-power.

The forest coverage in 2115 for BBEP is 69.42% in the case of Bio-2, 79.8% for Bio-1 and 89.10% for Bio-0.

Additionally, for both Bio-2 and Bio-1 the total CO_2 emissions can drop below the 2015 level of around 3 million ton/year.

At last, due to the strong emission reductions, the BBEP limits the EI decrease, in particular for Bio-1 and Bio-2. For Bio-0, oddly enough, the weakest EI decrease can be noticed. The low deforestation and weak biofuel industry leading to low land deterioration is a possible explanation. For Bio-2, BBEP is characterized with strong EI fluctuations as a consequence of the fluctuation in deforestation to free up land leading to fluctuating biodiversity and CO_2 emissions.

Under the full range of scenario uncertainty assumed here, the robustness of BBEP is more or less comparable to that of EP. Especially for the EI the effect of uncertainty is similar to that in the case of EP.

For BBEP, in 95% of the 5000 simulation runs, the result is a profitable biofuel industry in Suriname, including a carbon neutral power generation sector and transport with a strongly reduced carbon intensity. All 5000 simulations indicate that BBEP results in a steady increase over time of the biofuel production. But the influence of near Bio-0 situations is also clear, especially on the production and export; 50% of the 5000 simulations indicate the biofuel production not increasing higher than 15 billion liters/year. In general BBEP is also robust, however far less when compared to BP, but then again BBEP is slightly more robust than EP. For BBEP there namely also is a considerable domestic biofuel market to fall back on when the international demand collapses.

5. Conclusion and reflection

This chapter concludes the study on a large scale biofuel industry in Suriname. A reflection on the study and the BioSU model will also be discussed.

5.1 Conclusions

When considering the problem statement mentioned in the introduction, the various findings resulting from this study can be synthesized.

The first sub question derived from the problem statement is about the export potential of a Surinamese biofuel industry. After this study it can be concluded that the potential is extremely high. For the absolute maximum assumed international biofuel demand starting at 200 billion liters in 2015 and growing at a rate of 15% annually, Suriname could handle a maximum of 30% of that demand with the available resources. This would however have dramatic consequences for the Surinamese forest and environment. But when considering the policy strategies, the export of biofuel equal to 5% of the international demand is preferable in order to maintain a sustainable biofuel industry with economic profits, a maintained environment and biofuel with zero CO_2 emissions from feedstock all the way to combustion.

The second sub question is considering the impact of government policy on the biofuel production. Government incentives, both on the demand and supply side, especially in the field of blending obligations, tax exemptions and subsidies for e.g. biofuel infrastructures directly impact the demand for biofuel and the production. In the case of Suriname it is also important that government policy includes improving the investment climate to attract much more FDI, as the biofuel industry will require massive investments. Especially to start up the industry in Suriname, the government measures are crucial. Simulations without biofuel policy, resulted in almost negligible amounts of production as the incentives to use and produce biofuel are far too weak.

The third question relates to the environmental and LUC impact of a biofuel industry over time. When considering the assumed policy strategies, environmental protection law like deforestation legislation is necessary to realize a sustainable biofuel industry with minimal impact on the environment. Deforestation is inevitable with the eye on a growing population and more demand for settlement land and agricultural land for food and additionally biofuel feedstock in the form of sugarcane, but it can be minimized among others to maintain the reputation of Suriname as World's Greenest nation (Ministry of Planning and Development Cooperation, n.d.). For the biofuel part, the assumed deforestation law, leads to incentives to increase the yields on the available land. This minimizes deforestation, for sugarcane cultivation purposes, over time. And by doing so, the biodiversity is preserved and the CO_2 emission released through deforestation together with the decrease in carbon capture ability of the forest is minimized. However, this has to be realized without too much artificial and polluting chemicals and fertilizers, which could lead to other side effects e.g. land depletion and groundwater pollution.

The last sub question focusses on the influence of the international biofuel market on the Surinamese biofuel industry. Robust and effective biofuel policy has to cope with the uncertainty of the three scenarios, never knowing what will happen in the future. However indications are that biofuel will play a significant role of importance to reach the ambitious climate goals on the medium- to long-term, as alternatives for biofuels are not developing quick enough and not all countries have the conditions and resources for the alternatives (Goldemberg & Guardabassi, 2009), (Janssen, Turhollow, Rutz, & Mergner, 2013). It could be imaginable to design a Surinamese industry solemnly focusing on the export, like EP does. However, in this case a collapse of the international market would lead to a direct collapse of the own industry as suggested by the EP policy and the Bio-0 scenario. On the other hand policy like BBEP also establishes a domestic market, so that the complete industry does not collapse when the international demand decreases. Over time the industry can then recover and the policy can be transformed in a more domestic, DP like, approach. Policy which also enables a local market, also establishes local advantages. For example the BBEP policy, leads to carbon neutral power generation with bio-power and hydro-power upward of 2070 and a strongly decreased carbon intensity of the transport with limited annual emission of not more than 500,000 ton/year.

In short and considering the problem statement: developing a biofuel industry in Suriname will pay off in the future under the condition that a) enough government incentives are implemented as a catalyst in the development of a biofuel industry and local biofuel demand b) the policy not only addresses export, but also establishes a local demand to cope with the uncertainty of the international biofuel market and to also establish local CO_2 reduction and energy security advantages and c) sufficient environmental and forest preservation law is implemented with a strict control mechanism. When taking these steps in outlining biofuel policy in Suriname, the negative consequences regarding LUC (deforestation) and the environment are minimized, while the positive impacts regarding energy security, CO_2 emission reduction, agricultural development, rural development, renewable energy and economic growth and diversification are maximized.

5.2 Reflection on the study and BioSU

Although this study is carried out with the most of care, there is always room for improvements. The study is based on some fundamental assumptions in terms of boundary, structure and behavior of a biofuel system. Assumptions had to be made, as not much case related data is available and not much prior biofuel research exists for Suriname. Looking up data was a very time and energy consuming action without always achieving results. The choice was made to base the model where possible on the bioethanol system in Brazil, a case comparable to Suriname. Also the Environmental and Sustainability Impact Assessment report of the Wageningen ethanol project provided much insights regarding the Surinamese specific biofuel related characteristics. The model also take into account actual problems in Suriname like a bad investment climate among others.

Nevertheless the model and the study has some mentionable shortcomings and assumptions namely:

- Advanced biofuels are not taken into account sufficiently, while biodiesel is not taken into account at all. This, although they are gaining ground in the biofuels world.
- Although the food agricultural sector is inseparably connected to the biofuel agriculture in the case of sugarcane, however to a lesser extent relative to corn or wheat, the model does not include food security issues.
- The model contains a simplified financial sector, whereas investors and biofuel producers will want to have a very detailed elaboration of the effects of investments.
- The model assumes the biofuel industry as a whole, not taking into account competition between companies.
- The model does not incorporate a comprehensive set of sustainability criteria, whereas more aspects are of significant importance to assess the environmental impact. The chosen set is however internationally common in research.
- An important aspect which does not enjoy sufficient attention in the study, is de multi-actor aspect in terms of e.g. interests, goals and important resources.

These aspects don't make the model useless as no model is perfect and at best a simplification of the real world with many assumptions, although the assumptions need to be scientifically sound (Zeigler, Praehofer, & Gon Kim, 2000).

The mentioned shortcomings can be seen as possibilities to improve the study in the future. For future studies the writer, would like to review this model with fellow researchers and built further towards a more detailed model. A model that is a tool to test any biofuel policy, not only in the case of Suriname, but also for any other country with the ambition to develop a biofuel industry.

References

Alexandratos, N., & Bruinsma, J. (2012). *World Agriculture Towards 2030/2050: the 2012 revision.* Retrieved from http://environmentportal.in/files/file/World%20agriculture%%202030.pdf

Barisa, A., Romagnoli, F., Blumberga, A., & Blumberga, D. (2015). Future biodiesel policy designs and consumption patterns in Latvia: a system dynamics model. *Journal of Cleaner Production*, 71-82. doi:http://dx.doi.org/10.1016/j.jclepro.2014.05.067

Boerboom, H. (2014). *Suriname kampt met stroomtekort*. Retrieved from nos.nl: http://nos.nl/artikel/689428-suriname-kampt-met-stroomtekort.html

bp. (2012). *Case study: a sugarcane ethanol plant in Brazil.* Retrieved from http://www.unece.org/fileadmin/DAM/energy/se/pp/unfc/ws_RenewReserv_London_Oct2012/D1_S8_Howes.pdf

Canadian Electricity Association. (n.d.). *hydro*. Retrieved from powerforthefuture.ca: http://powerforthefuture.ca/electricity-411/electricity-fuel-source-technical-papers/hydro/

Carter, C., & Schaefer, A. (2015, May). *US biofuels policy, global food prices, and international trade obligations.* Retrieved from https://www.aei.org/wp-content/uploads/2015/05/US-biofuels-policy.pdf

Coelho, S., Goldemberg, J., Lucon, O., & Guardabassi, P. (2006). Brazilian sugarcane ethanol: lessons learned. *Energy for Sustainable Development*. Retrieved from http://www.researchgate.net/publication/271826040_Brazilian_sugarcane_ethanol_lessons_learned

de Freitas, L., & Kaneko, S. (2011). Ethanol demand under the flex-fuel technology regime in Brazil. *Energy Economics*, 1146-1154. doi:http://dx.doi.org/10.1016/j.eneco.2011.03.011

Derlagen, C., Barreiro-Hurlé, J., & Shik, O. (2013). *Agricultural Sector Support in Suriname.* Rome, Italy: IDB/FAO. Retrieved from http://www.gov.sr/media/968294/agricultural_sector_support_in_suriname.pdf

Energie Bedrijven Suriname. (n.d.). *tariefsaanpassing*. Retrieved from http://www.nvebs.com/thuis/elektriciteit/tariefsaanpassingen/

Enserink, B., Hermans, L., Kwakkel, J., Thissen, W., Koppenjan, J., & Bots, P. (2010). *Policy Analysis of Multi-Actor Systems.* Den Haag: Uitgeverij LEMMA.

ERM. (2012). *Draft Environmental and Social Impact Assessment Staatsolie Wageningen Sugarcane to Ethanol and Sugar Project.* Retrieved from http://www.staatsolie.com/press_releases/Persberichten%202012/wageningen-ethanol&sugar-project-draft-esia_nov2012.pdf

European Commission. (2012, October 12). *Indirect Land Use Change (ILUC).* MEMO, Brussel. Retrieved from http://europa.eu/rapid/press-release_MEMO-12-787_en.htm

Faaij, A., Szwarc, A., & Walter, A. (2008). Demand for bioethanol for transport. In *Sugarcane ethanol: Contributions to climate change mitigation and the environment.* The Netherlands: Wageningen Academic Publishers.

Fact Fish. (2013). *Suriname: Bananas, yield (hectogram per hectare)*. Retrieved from http://www.factfish.com/statistic-country/suriname/bananas,%20yield

FAO. (2008). *The State of Food and Agriculture 2008. Part I-BIOFUELS: prospects, risks and opportunities.* Rome: FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Retrieved from http://www.fao.org/docrep/011/i0100e/i0100e00.htm

FAO. (2013). *Crop Water Information: Citrus*. Retrieved from http://www.fao.org/nr/water/cropinfo_citrus.html

FAO. (2013). *Save and Grow: Cassava.* Rome: FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Retrieved from http://www.fao.org/docrep/018/i3278e/i3278e.pdf

Fearnside, P. (2005). Deforestation in Brazilian Amazonia: History, Rates,and Consequences. *Conservation Biology*, 680–688. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111-/j.1523-1739.2005.00697.x/pdf

Flach, B., Bendz, K., Krautgartner, R., & Lieberz, S. (2013). *EU Biofuels Annual 2013.* United States Department of Agriculture. Retrieved from http://gain.fas.usda.gov/Recent%20GAIN%-20Publications/Biofuels%20Annual_The%20Hague_EU-27_8-13-2013.pdf

Franco, C., Ochoa, M., & Flórez, A. (2009). System Dynamics Approach to Biofuels in Colombia. *Proceedings of the 27th International Conference of the System Dynamics Society.* Albuquerque, New Mexico, USA. Retrieved from http://www.systemdynamics.org/ conferences/2009/proceed/papers/P1189.pdf

Goldemberg, J., & Guardabassi, P. (2009). Are biofuels a feasible option? *Energy Policy*, 10-14. doi:10.1016/j.enpol.2008.08.031

Government of Canada. (n.d.). *Fuel Combustion*. Retrieved from http://www.ec.gc.ca/ges-ghg/default.asp?n=AC2B7641-1

Government of the Republic of Suriname. (2006). *MEERJARENONTWIKKELINGSPLAN 2006-2011 Strategie voor Duurzame Ontwikkeling.* Paramaribo, Suriname: Regering van de Republiek Suriname. Retrieved from http://www.gov.sr/media/176049/meerjaren_ontwikkelingsplan _mop__2006-2011.pdf

Hassuani, S., Leal, L., & Macedo, I. (2005). *Biomass power generation: Sugar cane bagasse and trash.* Brazil: PNUD - Programa das Nações Unidas para o Desenvolvimento and CTC - Centro de Tecnologia Canavieira. Retrieved from http://www.mct.gov.br/upd_blob/0001/1594.pdf

Henstra, T. (2013). *Water quantity division in a rice irrigation scheme in Nickerie, Suriname: Gaining insight in physical water division in order to fine-tune its managment.* Master Thesis, Wageningen University, Water Resources Management group. Retrieved from https://www.wageningenur.nl/web/file?uuid=5d9ccf84-c2be-455d-a907-3c605675b28c&owner=a5294f9e-ad90-4bfb-82e7-3d2f287e1193

Hess, R., Wright, C., & Kenney, K. (2007). Cellulosic biomass feedstocks and logistics for ethanol production. *Biofuels, Bioproducts and Biorefinery*, 181-190. doi:10.1002/bbb.26

Hilbert, J., & Galligani, S. (2014). Argentina. In B. Solomon, & R. Bailis, *Sustainable Development of Biofuels in Latin America and the Caribbean.* doi:10.1007/978-1-4614-9275-7

IDB. (2013). *Suriname's Energy Market*. Retrieved from http://blogs.iadb.org/caribbean-dev-trends/2013/11/20/surinames-energy-market/

Inter-American Development Bank. (n.d.). *DEVELOPMENT OF RENEWABLE ENERGY, ENERGY EFFICIENCY AND ELECTRIFICATION OF SURINAME.* Retrieved from http://idbdocs.iadb.org /wsdocs/getdocument.aspx?docnum=37699385

International Renewable Energy Agency. (2012). *Biomass for power generation.* IRENA Working Paper. Retrieved from https://www.irena.org/DocumentDownloads/Publications /RE_Technologies_Cost_Analysis-BIOMASS.pdf

IPCC. (2014). *IPCC Fifth Assessment Report Climate Change 2014: Impacts, Adaptation, and Vulnerability.* Retrieved from http://ipcc-wg2.gov/AR5/images/uploads/-WG2AR5 _SPM_FINAL.pdf

Janssen, R., Turhollow, A., Rutz, D., & Mergner, R. (2013). Production facilities for second-generation biofuels in the USA and the EU - Current status and future perspective. *Biofuels, Bioproducts and Biorefining*, 647-665. doi:10.1002/bbb.1451

Ludena, C., Razo, C., & Saucedo, A. (2007). Biofuels Potential in Latin America and the Caribbean: Quantitative Considerations and Policy Implications for the Agricultural Sector. *the American Association of Agricultural Economics Annual Meeting.* Portland, OR. Retrieved from https://ideas.repec.org/p/ags/aaea07/9986.html

Ministry of Planning and Development Cooperation. (n.d.). *Suriname Green economic development that leverages natural resources, while maintaining Suriname's status as the Greenest Nation on Earth.* Retrieved from https://seors.unfccc.int/seors/attachments/get_attachment?code=2LAVH67GSGE7JI1LHE4NU3WUOTFXPARN

Ministry of Trade and Industry. (2015, juli). *huidige brandstofprijzen*. Retrieved from http://gov.sr/ministerie-van-hi/huidige-brandstofprijzen.aspx

Musango, J., Brent, A., Amigun, B., Pretorius, L., & Müller, H. (2011). Technology sustainability assessment of biodiesel development in South Africa:. *Energy*, 6922-6940. doi:10.1016/j.energy.2011.09.028

Navigant research. (2014). *Biofuels for Transportation Markets.* Retrieved from http://www.navigantresearch.com/research/biofuels-for-transportation-markets

Newmont Mining Corporation. (2014). *Newmont Welcomes Suriname's Decision to Participate in the Merian Gold Project*. Retrieved from http://www.newmont.com/newsroom/newsroom-details/2014/Newmont-Welcomes-Surinames-Decision-to-Participate-in-the-Merian-Gold-Project/default.aspx

OECD. (2013). *Environment at a Glance 2013: OECD Indicators.* doi: 10.1787/9789264185715-en

Panichelli, N. (2012). *IMPACT OF BIOFUELS PRODUCTION ON LAND-USE CHANGE AND GREENHOUSE GAS EMISSIONS: Methodological framework and system dynamics modeling applied to soybean-based biodiesel production in Argentina.* Doctoral Dissertation, Ecole polytechnique federale de Lausanne, Suisse. Retrieved from http://infoscience.epfl.ch/record/174796 /files/EPFL_TH4974.pdf

Persdient kabinet van de Republiek Suriname. (2012, Maart 30). Government Take heeft minimale invloed op consumentenprijzen. *DE OVERHEID, 2*(3). Retrieved from http://www.gov.sr/media/466268/webeditie_33_de_overheid_2012_mrt_30.pdf

Pettinger, T. (2008). *Investment and Economic Growth.* Retrieved from www.economicshelp.org: http://www.economicshelp.org/blog/495/economics/investment-and-economic-growth/

Plouvier, D., Gomes, L., Verweij, P., & Verlinden, N. (2012). *Living Guianas Report 2012 State of the Guianas Drivers and pressures Towards Green Economies.* Paramaribo, Suriname: WWF Guianas.

Pruyt, E. (2013). *Small System Dynamics Models for Big Issues: Triple Jump towards Real-World Dynamic Complexity.* Delft: TU Delft Library.

Pruyt, E., & De Sitter, G. (2008). 'Food or Energy?' Is that the question? *Proceedings of the 26th International Conference of the System Dynamics Society.* Athens, Greece. Retrieved from http://www.systemdynamics.org/conferences/2008/proceed/papers/PRUYT372.pdf

Renewable Energy World Editors. (2013). *Tapping Brazilian "Bagasse" for Electricity Production*. Retrieved from http://www.renewableenergyworld.com/articles/2013/07/tapping-brazilian-bagasse-for-electricity-production.html

Renewable Fuels Association. (2014). *World Fuel Ethanol Production*. Retrieved from http://ethanolrfa.org/pages/World-Fuel-Ethanol-Production

Ros, J., Overmars, K., Stehfest, E., Prins, A., Notenboom, J., & van Oorschot, M. (2010). *Identifying the indirect effects of bio-energy production.* Retrieved from www.pbl.nl/sites/-default/files/cms/.../500143003.pdf

Sandvik, S. (2008). *IMPACTS OF PEAK OIL AND FOOD BASED BIOFUEL PRODUCTION ON LONG-TERM FOOD SECURITY: A DYNAMIC POLICY MODEL.* Bergen: University of Bergen. Retrieved from https://bora.uib.no/bitstream/handle/1956/3308/47529210.pdf?sequence=1

Shah, K., Philippidis, G., Dulal, B., & Brodnig, G. (2012). Developing biofuels industry in small economies: Policy experiences and lessons from the caribbean basin initiative. *Mitigation and Adaptation Strategies for Global Change*. doi:10.1007/s11027-012-9437-8

Smeets, E., Achterbosch, T., van Berkum, S., Broens, D. F., Meijrink, G., & van Meijl, H. (2013). *De invloed van biobrandstoffen op de volatiliteit van prijzen van agrarische grondstoffen.* Retrieved from http://www.rijksoverheid.nl/documenten-en-publicaties/publicaties/2013/02/01-/issue-paper-de-invloed-van-biobrandstoffen-op-de-volatiliteit-van-prijzen-van-agrarische-grondstoffen.html

Soare, A., Bunger, M., Kersh, K., Suryana, N., & Udupa, S. (n.d.). *Nations Race to Build Alternative-Fuel Capacity.* Retrieved from http://web.luxresearchinc.com/hs-fs/hub/86611/file-440631717-pdf/AF__2014__SMR_sample.pdf

Sterman, J. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World.* New York: McGraw-Hill.

Stichting Peakoil Nederland. (n.d.). *Wat is peakoil?* Retrieved from http://www.peakoil.nl/wat-is-peakoil/

Szczesniak, A. (2000). *THE MINERAL INDUSTRY OF SURINAME.* Retrieved from http://minerals.usgs.gov/minerals/pubs/country/2000/9520000.pdf

The Transnational Institute. (n.d.). *Flex Crops.* Retrieved from http://www.google.nl/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&cad=rja&uact=8&ved=0CE8QFjAF&url=http%3A%2F%2Fwww.tni.org%2Fsites%2Fwww.tni.org%2Ffiles%2Fdownload%2Fflexcrops04.pdf&ei=y-6CVdOuKcSyswHSkraAAw&usg=AFQjCNEDQVGTmrLscuHOCeoE-F3dYrX7eQ&bvm=bv.9604

Tidball, L., Bluestein, J., Rodriquez, N., & Knoke, S. (2010). *Cost and Performance Assumptions for Modeling Electricity Generation Technologies.* Retrieved from http://www.nrel.gov/docs/fy11osti/48595.pdf

Trading Economics. (2015, July). *Ethanol*. Retrieved from www.tradingeconomics.com: http://www.tradingeconomics.com/commodity/ethanol

U.S. Department of Agriculture. (2006). *THE ECONOMIC FEASIBILITY OF ETHANOL PRODUCTION FROM SUGAR IN THE UNITED STATES.* Retrieved from http://www.usda.gov/oce/reports/energy/EthanolSugarFeasibilityReport3.pdf

U.S. Environmental Protection Agency. (n.d.). *Calculations and References*. Retrieved from http://www.epa.gov/cleanenergy/energy-resources/refs.html

United Nation Statistics Division [UNSD]. (n.d.). *UNSD Environmental Indicators.* Retrieved from http://unstats.un.org/unsd/environment/qindicators.htm

UNICA-Brazilian Sugarcane Industry Association. (2015). *Sugarcane Best Cultivation Practices*. Retrieved from http://sugarcane.org/sustainability/best-practices

van Roekel, A. (2014). *Wanneer is de olie op?* Retrieved from http://www.kennislink.nl/publicaties-/wanneer-is-de-olie-op

Velasco, J. (2013). *Brazilian Sugarcane.* Retrieved from http://www.eia.gov/: http://www.eia.gov/biofuels/workshop/presentations/2013/pdf/presentation-08-020113.pdf

Vimmerstedt, L., Bush, B., & Peterson, S. (2012). Ethanol Distribution, Dispensing, and Use: Analysis of a Portion of the Biomass-to-Biofuels Supply Chain Using System Dynamics. *PLoS ONE*. doi:10.1371/journal.pone.0035082

Vimmerstedt, L., Bush, B., Hsu, D., Inman, D., & Peterson, S. (2014). Maturation of biomass-to-biofuels conversion technology pathways for rapid expansion of biofuels production: a system dynamics perspective. *Biofuels, Bioproduction and Biorefining*, 158-176. doi:10.1002/bbb.1515

vin2food. (n.d.). *Vinasse for cultivating Artemia and zooplankton, as well as for producing microalgae*. Retrieved from http://www.vin2food.org/vin2food_en_ansatz_prozess.php

Walter, A., & Ensinas, A. (2010). Combined production of second-generation biofuels and electricity from sugarcane residues. *Energy*, 874–879. doi:10.1016/j.energy.2009.07.032

Warner, E., Inman, D., Kunstman, D., Bush, B., Vimmerstedt, L., Peterson, S., Macknick, J., & Zhang,

Y. (2013). Modeling biofuel expansion effects on land use change dynamics. *ENVIRONMENTAL RESEARCH LETTERS*. doi:10.1088/1748-9326/8/1/015003

World Bank. (2014). *Population, total*. Retrieved from http://data.worldbank.org/indicator/SP.POP.TOTL/countries/SR?display=graph

World Bank. (2015, April 1). *Suriname overview*. Retrieved from http://www.worldbank.org/en/country/suriname/overview

World Bank. (n.d.). *Cereal yield (kg per hectare)*. Retrieved from http://data.worldbank.org/indicator/AG.YLD.CREL.KG/countries

World Bank. (2015). *Plant species (higher), threatened*. Retrieved from http://data.worldbank.org/indicator/EN.HPT.THRD.NO/countries/SR-XJ-XT?display=graph

Zeigler, B., Praehofer, H., & Gon Kim, T. (2000). *Theory of Modeling and Simulation: Integrating Discrete Event and Continuous Complex Dynamic Systems.* United States of America: 1976 Elsevier Science.

Ziolkowska, J. (2014). Optimizing biofuels production in an uncertain decision environment: conventional vs. advanced technologies. *Applied Energy*, 366-376. doi:10.1016/j.apenergy.2013.09.060

Appendices

Appendix A. Model diagrams

A.1 The bulls-eye diagram

The bulls-eye diagram, see figure 18, has the purpose to schematically provide an overview of all the factors which are considered during this study and to what extent they are taken into account (Pruyt, 2013). The factors are categorized as either a *thoroughly modelled internal factor, a superficially modelled internal factor, an external factor or an excluded (deliberately omitted) factor.* The categorization is realized based on the scope of the study and the resources available e.g. data, knowledge and time.

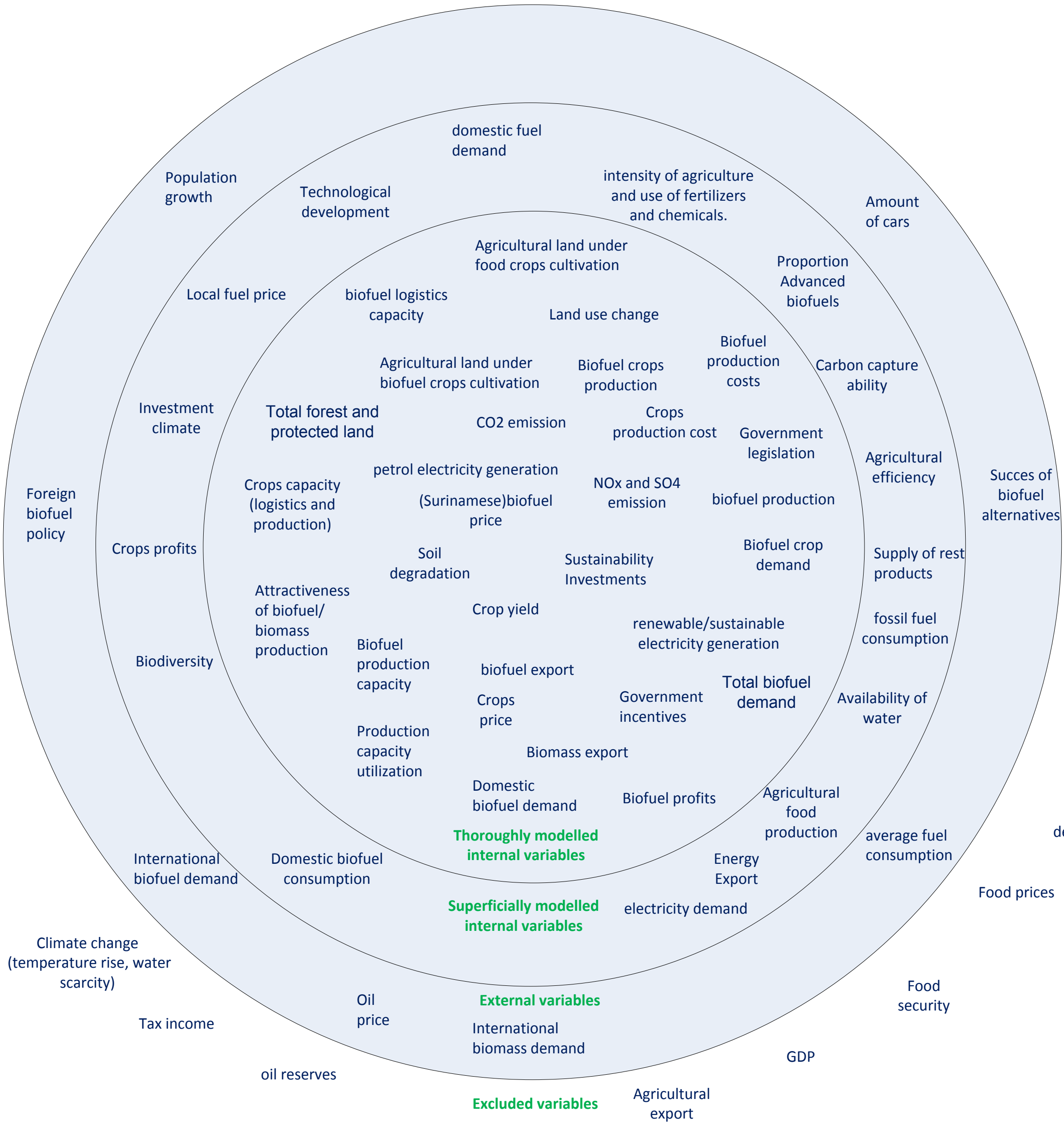


Figure 18: The bulls-eye diagram

The *thoroughly modelled internal factors* are considered to be the core of the biofuel system and will be modelled in detail. These factors are predominantly directly linked to the biofuel supply-chain.

The *superficially modelled internal factors* are also considered an integral part of the biofuel system but are on a lower level on a scale of importance relative to the thoroughly modelled factors, so to speak. Hence they are modelled to a lesser extent of detail to keep the model from becoming too large. These factors are predominantly in fields which are on a higher level of aggregation for example fuel and electricity demands, various environmental aspects which are dependent of much more factors than considered in the biofuel system, agricultural production and technological developments of which the modelling is often very difficult and highly uncertain.

The *external factors* cannot be influenced by the stakeholders in the biofuel system, however, they are inevitable to successfully understand and study biofuel systems. They have a significant influence on the system as a whole and thus the outcome of biofuel policy. The external factors are mainly in the field of international developments in technology and biofuel alternatives, biofuel policy and the subsequent effect on biofuel demand. It may be possible that some external factors can be influenced by stakeholders, but because they fall outside the scope of this study, they are considered as an externality. Their inclusion as internal factors would make the model to large and uncontrollable for the modeler. Subsequently the risk that the model loses its credibility and usefulness for the aim of the study could occur.

Finally there are is excluded or intentionally omitted factors to keep the model manageable and fit for the study. These are factors which are outside the scope of the study and in the field of food security and food prices, taking into account the assumption that food supply will always have first priority over biofuels so the food security will not be jeopardized by the biofuel industry. Furthermore factors like oil reserves are left out. Even in the worst case scenario that the Surinamese oil reserves are completely depleted and no new commercially exploitable reserves are found, long term agreements like the Petro-Caribe agreement with Venezuela make it fairly easy to import oil from nearby. This limits the risk of shortages in oil supply for the timespan considered by this study. Besides, including the oil market in the model would make the model far too large and partially shift the focus away from biofuels. The GDP and fiscal system are also not modelled as specific factors, however the effect of the GDP has been taken into account to determine for example the demand for electricity, food and fuels.

Note that certain excluded factors are illustrated in the causal and sector diagram, with the purpose to give an overview of how these factors are situated in the biofuel system although they are omitted in the dynamic simulation model BioSU.

A.2 The Causal Diagram

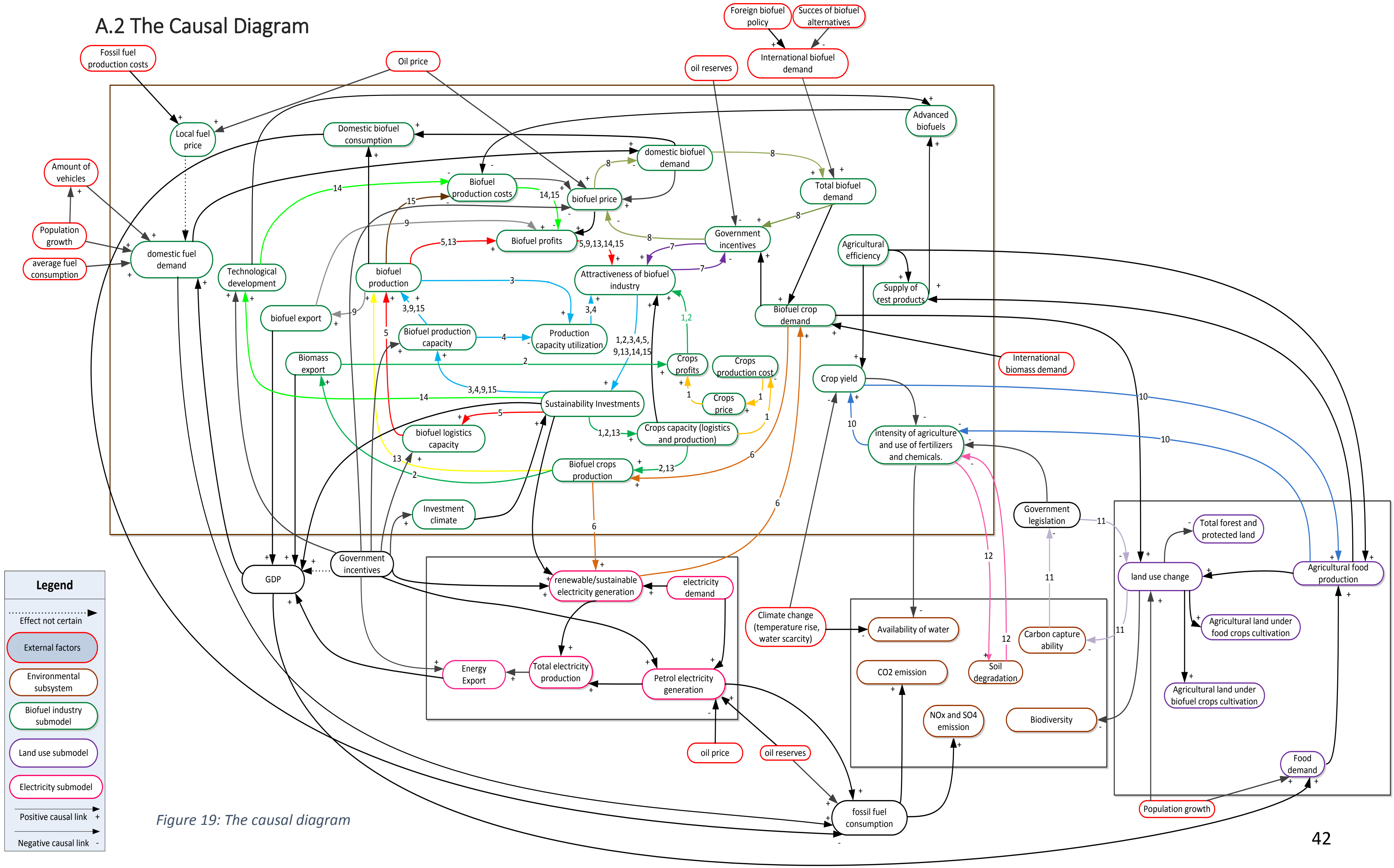


Figure 19: The causal diagram

The causal diagram is a functional tool, which provides a detailed overview of all factors in a biofuel system relevant to this study and the causal relations between them. The goal is to provide the modeler and the public with a better understanding in the composition of a biofuel system and not less important, the interaction and relationship between the factors. The diagram is thus useful for qualitative "what if?" analysis, by providing understanding in the influence of changes in factors on other factors and subsequently on the system as a whole (Enserink, et al., 2010). Furthermore interesting relations, effects and important feedback loops can be identified and studied. This forms a firm basis for quantitative system modeling and simulation for the purpose of policy analysis through the System Dynamics methodology. The causal diagram is on a higher level of aggregation, relative to the BioSU model. Factors in the causal diagram are modelled in more detail in the BioSU model. Nevertheless, general mechanisms and aspects of the biofuel system are all covered in the causal diagram. The causal diagram is displayed in figure 19.

In the causal diagram a distinction can be made between *internal factors* (both the thoroughly and superficially modeled factors from the bulls-eye diagram) and *external factors.* Internal factors can be described as factors which are within the sphere of influence of stakeholder within the biofuel system. They can be influenced directly or indirectly, hence they form important parameters to base policy upon. These factors can be identified as oval figures in the causal diagram, with a line color associated to the sub-model to which the factor can be attributed to. The color associations are illustrated in the legend of the causal diagram. *External factors* are distinguished by a red line color. *External factors,* as mentioned before, cannot be influenced by the stakeholders in the biofuel system, however, they are inevitable to successfully understand and study biofuel systems. They have a significant influence on the system as a whole and thus the outcome of biofuel policy. These external factors are discussed in section A.2.1.

One can also notice that certain causal links have a particular color and number. These attributes are associated with feedback loops identified in the biofuel system. For the discussion of these feedback loops, please see section A.2.2 on the feedback loops where they are displayed and discussed individually.

The causal relations between the factors are represented via one-sided arrows between the factors. Each causal relation is associated with a "+" or "-" sign, which represents the type of causal relationship. A causal relation between factor A and B, marked with a "+", implies that an increase in the value of factor A, will lead to an increase in the value of B (or a decrease of B in the case of a decrease of A). On the other hand a causal relation between factors A and B marked "-", implies that an increase of A leads to a decrease of B (or an increase of B in case of a decrease of A) (Enserink, et al., 2010).

A.2.1 external factors

The (international) ***price of oil*** has a large effect on the price of biofuels, in addition to the obvious impact on the local gasoline price. This is because an increase in the price of oil increases the demand for biofuel, causing the price of biofuels to also increasing (Smeets, et al., 2013). The price of oil also has direct impact on the price of agricultural products. According to Smeets, et al. (2013), this relationship works via two mechanisms. First, the oil price has a large share in the production cost of agricultural commodities, in particular via the costs for fertilizers. For the period 1996 to 2004, approximately 20% of the production costs for corn in the United States can be accounted for by energy cost, in which oil plays the most important role. This share increased up to 32% in 2007-2008 as a result of high oil prices (Flach, Bendz, Krautgartner, & Lieberz, 2013). Secondly, an increase in the biofuel demand when oil prices rise, leads to an increase in the price of agricultural products as feedstock for the conventional biofuels. These conventional biofuels are now dominant in the biofuel production compared to advanced biofuels. The volatility of food prices under the influence of the oil price is thus enhanced by biofuel production (Smeets et al., 2013). However, the second mechanism is not relevant in this study as food prices are excluded and the assumption is made that food agriculture and affordable food has priority over biofuels at all times.

Additionally the oil price has an immediate impact on the electricity market if fossil oil products have an important role in the power generation. Increasing the role of hydro-power and introducing bio-power could decrease the risk of an increasing electricity price as a consequence of increasing oil prices.

The ***oil reserves*** are also important in the success of biofuel. Biofuel in Suriname, is an alternative to fossil fuels. The oil reserve is divided into the "easy-oil", which are easy and inexpensive to exploit and "complex-oil", which are more expensive and harder to exploit. An example of "complex oil" is the oil from shale rock in the United States. The oil price is mainly determined by the extent to which complex-oil is exploited (Stichting Peakoil Nederland, n.d.). The price of oil which is subject to many (geo)-political, technological and the market issues, is now kept artificially low to keep production high. This makes the operation of complex oil at a price of between US$60 and US$75 unprofitable.

According to oil and gas specialist at TNO, Cyril Widdershoven, oil reserves will be depleted in about eighty years given a price per barrel of US$ 100 and the currently known reserves. If the oil becomes more expensive because of scarcity, when the peak in oil production is over, we can perhaps extend the oil era to 260 years (van Roekel, 2014). This is because at higher oil prices the exploitation of complex-oil becomes economically attractive. But as things are looking at the moment with the price per barrel at about US$50, many analysts suggest that the increase in price will not occur soon or as strong as desired by the complex-oil industry.

However, it is suggested that the discovery of new oil reserves in Suriname may lead to an increase in the fossil fuel consumption in Suriname. The energy vision of many consecutive administrations in Suriname indicates that the support and preference is very much placed on a fossil based economy. The recent construction of a US$ 1 billion oil refinery by Staatsolie, the expansion of the petrol based power generation capacity and the cancellation of the biofuel plans are clear examples of the vision. So the discovery of more oil, especially off shore where there are high hopes to encounter large reserves of oil, most probably won't work in the favor of a biofuel industry. The government will most likely allocate resources towards the further development of the fossil based economy, instead of incentives for a biofuel industry.

Poor access to oil reserves globally and to a lesser extent in Suriname, in particular complex oil due to low oil prices, highlights the demand for alternative fuels such as biofuels. The emergence of other alternatives to fossil fuels, such as electric- and hydrogen based transport will grow stronger with high oil prices, scarcity or poor access to oil reserves. Note that these ***alternatives are also competitors for biofuels***. However an increase in electric driving and driving on hydrogen also has consequences for the security of fuel supply, especially as technological development is not at the desired rate. The high costs and the energy intensity with which the hydrogen production is coupled, the low energy density and the limited supply of hydrogen filling stations are major causes behind the risk of a worsening security of supply according to Ball and Wietschel (2009).

The ***food demand*** will naturally grow with the growing world population, and that is no exception in Suriname. According to the FAO, in the period 2006-2050, the demand for food will globally increase by over 60% in line with the current trend, of which nearly 40% is the direct result of the growth in population (Alexandratos & Bruinsma, 2012). This increase in food demand leads directly to an increase in the price of food, especially when food supply cannot keep up with the rate at which the food demand is growing due to various causes such as water scarcity and other adverse weather conditions, high energy prices and a heavy competition with biofuel feedstock.

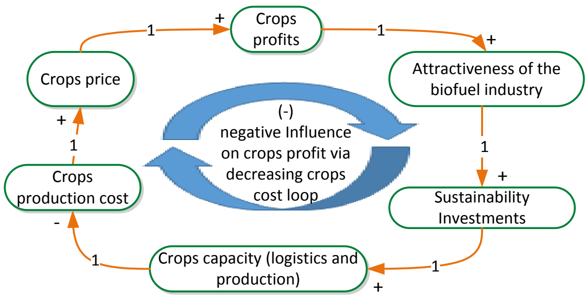
With increasing economic activity and a growing population in Suriname, the expectation is that the ***amount of vehicles*** will also increase. This has a direct influence on the domestic fuel demand. How strong this increase is, is partially dependent on the technological development in terms of the fuel efficiency of the vehicles.

An interesting relationship in the causal diagram is the relationship between ***climate change***, in particular temperature rise, and the agricultural yield. According to the Fifth Assessment Report Climate Change 2014: Impacts, Adaptation and Vulnerability of the IPCC, high temperatures and drought caused by climate change will lead to decreasing agricultural yields at an average decrease of two per cent each decade (IPCC, 2014). This, while the food demand increases with about ten percent per decade, causing a huge threat to the food supply. The decreasing yields will also have a significant impact on the biofuel industry.

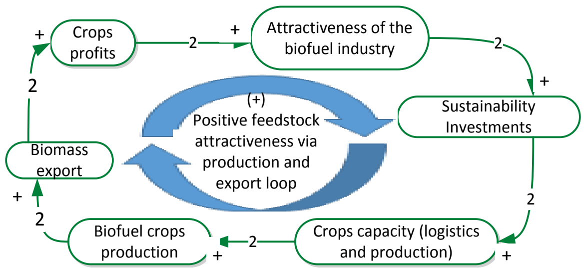
The ***population growth*** is also considered as an important external factor with a direct impact on various sub-models. First of all, as mentioned in the paragraphs above, the increase in food demand, the amount of vehicles and subsequently the local fuel demand is strongly correlated with the population growth. Additionally a growing population also leads to an increase in the electricity demand via the residential consumption but also a growing industry to keep up with the demand for goods by the growing population. Worth mentioning is that population growth also has a significant influence in the land use changes. This occurs via an increase in settlement land for various civilization activities and an increase in agricultural land to facilitate the increased food demand. This could have an impact on the deforestation rate in Suriname.

Finally ***international biofuel policy*** is of major importance in particular with the eye on Suriname as biofuel exporter. International biofuel policy is leading in the development of the international biofuel demand in addition to the success of biofuel alternatives. With international biofuel policy some important examples are: a) the EU biofuel blending policy, but also blending policies in the USA and other non-EU countries and b) the strict EU demands regarding the sustainability of biofuels in terms of GHG emissions, source of the biomass/feedstock etc. included in the EU Renewable Energy Directive (RED).

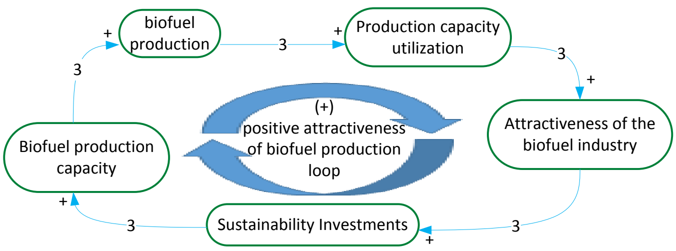
A.2.2 Feedback loops



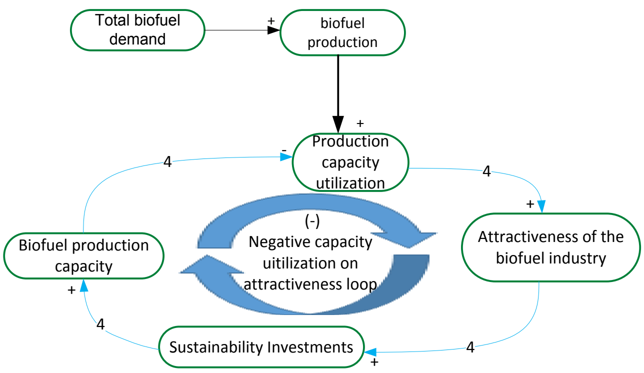
Negative influence on crops profit via decreasing crops cost loop: The first feedback loop discussed is situated in the biofuel industry sub model. This feedback loop implies the fact that increasing crops profits, leads to a larger attractiveness of the industry. Subsequently investments in the industry will increase leading to higher capacities in the field of feedstock production. The increasing capacity and the associated scale advantages (economies of scale), make it possible that the crops production cost can decrease. On the other hand lower production cost can lead to a lower crops price, which may decrease the profits. The loop is thus balancing in time. This loop may be influenced if the crops prices are regulated. The prices may stay at a higher level, which can lead to increasing profits in time. This could shift the loop from a balancing loop to a positive, reinforcing loop.



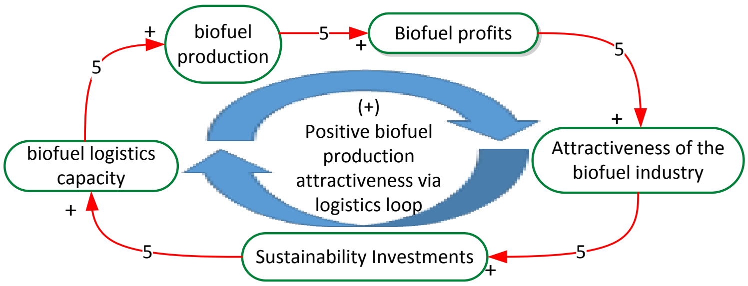
Positive feedstock attractiveness via production and export loop: This loop is also located in the biofuel industry sub model and represents the reinforcing effect of crops production and export on the attractiveness of the industry. The more sugarcane is produces as bioethanol feedstock, the more of that sugarcane or sugarcane products can be exported. Subsequently an increase in the export, leads to higher profits and an increase in the industries attractiveness.



Positive attractiveness of biofuel production loop: This loop is located in the biofuel industry sub model and indicates the reinforcing mechanism of a high capacity utilization on the attractiveness of the industry and the subsequent investments leading to capacity expansion and thus more production. However, this loop is strongly dependent on the demand for biofuel and its influence in the biofuel production. A combination of decreasing demand and subsequently decreasing production, with capacity expansion, leads to lower capacity utilization. The consequence is a decrease in the attractiveness of the industry, the investments and thus the capacity expansion. This implies a rather balancing or negative loop as can be seen below as the *negative capacity utilization on attractiveness loop.*

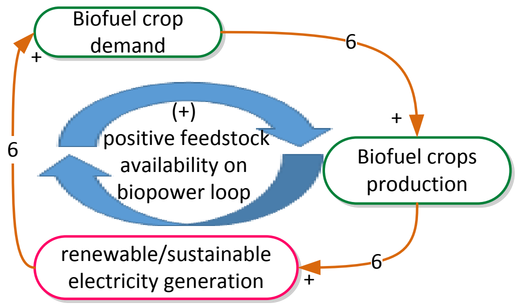


This loop thus functions as a mechanism which tries to restore the balance between the biofuel production and the production capacity via the capacity utilization.

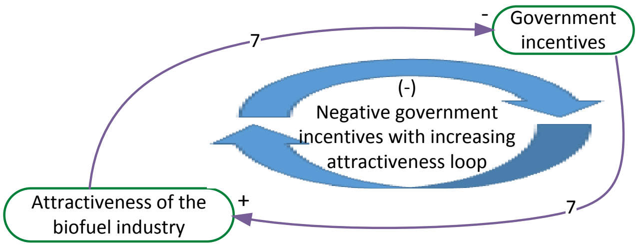


Positive biofuel production attractiveness via logistics loop: this loop and its effect are very similar to the *Positive attractiveness of biofuel production loop*. However, this loop focusses on the biofuel logistics capacity rather than the production capacity. In time an increased logistics capacity increases the profits and attractiveness of the industry systematically just like the production capacity. Via the attractiveness, the investments are attracted to further expand the logistics capacity in order to facilitate even more biofuel. Being able to facilitate more biofuel in the logistics part of the supply chain, is an incentive for the industry to increase production as logistics shortcomings are being resolved.

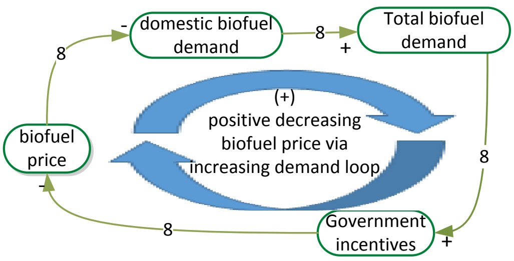
In the biofuel industry, logistics capacity is not less important relative to the production capacity, because distribution is a prominent part of the biofuel supply chain (Vimmerstedt, Bush, & Peterson, 2012). The term logistics capacity covers the whole range of biofuel transportation, storage and distribution. Hereby, facilities like pipelines, trucks and storage vessels are involved (Hess, Wright, & Kenney, 2007). Biofuel has to be transported from the temporary storage facilities of the biofuel refinery to: a) the oil refineries for blending with gasoline, b) the local gas stations in the case of E100, eventually via centralized distribution centers and c) the port for export purposes.



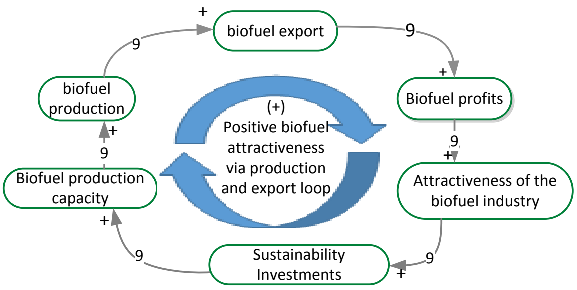
Positive feedstock availability on bio-power loop: this loop is the first inter-sub model loop which will be discussed, meaning that the loop involves factors from more than one sub model. The two sub model which are relevant in this loop is the *biofuel industry sub model* and the *electricity sub model*. This loops indicates that increasing biofuel crops demand, due to increasing biofuel demand, will lead to increasing biofuel production and subsequently to more renewable electricity generation, more specifically bio-power. Incentives will become stronger to invest in bio-power when the biofuel production is increasing because: a) due to bio-power the refineries can cut on electricity costs and b) more biofuel production, means more sugarcane is crushed, hence more bagasse is produced and the industry will look for options to efficiently get rid of the bagasse and ideally reuse them to some extent for example in the form of feedstock for bio-power. The increase in bio-power capacity will subsequently also lead to an increase in the demand for bagasse via sugarcane as feedstock for biofuels.



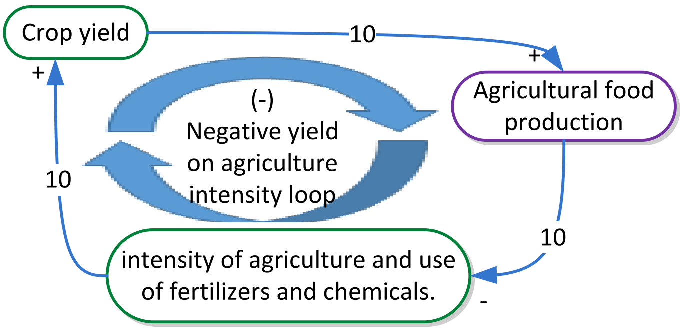
Negative government incentives with increasing attractiveness loop: this loop is located in the biofuel industry sub model. Government incentives in the biofuel industry in the form of tax exemptions, subsidies or other means lead to an increased attractiveness of the biofuel industry. The effect of the increased attractiveness is that more investments will be attracted towards the further development of the Surinamese biofuel industry. But as the attractiveness increases, the government may withdraw or decrease the intensity of certain incentive measures. This especially holds for incentive measures which are implemented to initially create the biofuel industry in Suriname as a new industry with high potential, such as subsidies in the field of refinery facilities and blending requirements (Franco, Ochoa, & Flórez, 2009). But then again, if the attractiveness begins to decrease due to a lack of incentives, then this will lead to restore or even increase the intensity of the government incentives in order to increase the attractiveness and attract more investments.



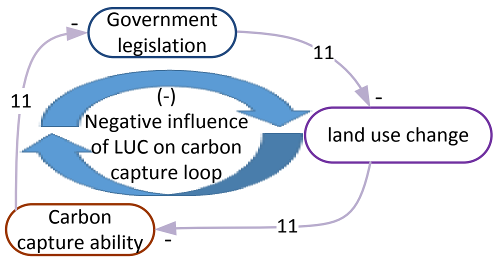
Positive decreasing biofuel price via increasing demand loop: Located in the biofuel industry sub model, this loop emphasizes the influence of the increasing demand for biofuel on the biofuel price. As the demand for biofuel increases, the market will indicate that the supply has to increase to fulfill this demand. In addition the government may try to implement measures in order to support the sector to facilitate this demand increase via for example tax exemptions. These measures, however, may lead to decreasing biofuel prices and subsequently a further increase in the domestic and thus total biofuel demand. The further increase in demand will further intensify the government incentives and this clarifies the enforcing loop.



Positive biofuel attractiveness via production and export loop: this loop is located in the biofuel industry sub model and shows large resemblance with the *Positive feedstock attractiveness via production and export loop.* However, this loop focusses on the biofuel production and its influence on the attractiveness, rather than sugarcane as feedstock. In short, this loop indicates that an increasing biofuel production and export has a positive influence on the profits and thus the attractiveness of the industry. This increased attractiveness, will attract more investments and consequently enable production capacity expansion. The capacity expansion, on its turn, enables an increase in the biofuel production, the export and again the profits and attractiveness. This effect is thus enforcing itself.

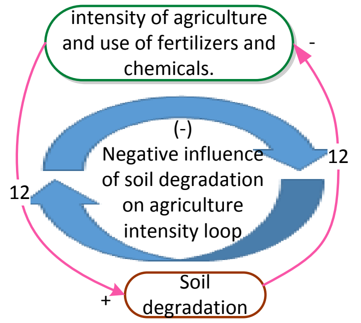


Negative yield on agriculture intensity loop: this loop is the second inter-sub model loop including both the *biofuel industry sub model* and the *land use sub model* wherein the agricultural food production is situated as a factor. In order for higher agricultural productions, the intensity of agriculture and the use of fertilizers and chemical will increase in order to increase the yield per hectare. An increasing yield on its turn realizes a higher agricultural production. If after some time and continual increase in the intensity, the production suffices the demand, a decrease in the agricultural intensity may occur as no yield increase is needed. In time this loop thus balances the intensity of agriculture via sufficient yield and production. The same holds as in the case of food agriculture holds for biofuel crops.

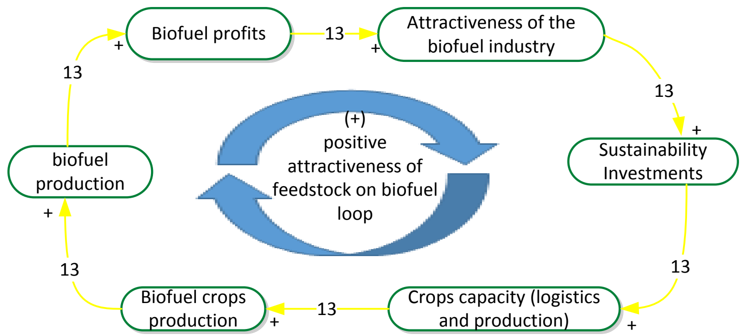


Negative influence of LUC on carbon capture loop: this loop is also inter-sub model including both the *land use sub model* and the *environmental sub model*. Government legislation, e.g. in the form of deforestation restricting law, can be a very important and effective measure to prevent major negative land use changes as a consequence of the biofuel industry. Of course only if it is implemented well, with an associated control authority and the required legislation penalties. By limiting negative land use change, in particular deforestation, the carbon capture ability of the Surinamese rainforest can be maintained and even increased. However high percentages of forest and thus a large carbon capture ability, may lead the government to easing the deforestation legislation in order to allow more land use change for various purposes including biofuel production.

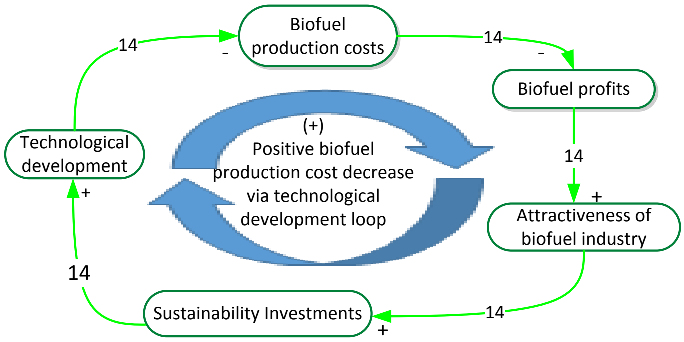
This easing of the legislation thus enables more deforestation and a decrease in the carbon capture ability. The loop is thus balancing deforestation via legislation in time.



Negative influence of soil degradation on agriculture intensity loop: this loop involves both the *biofuel industry sub model* and the *environmental sub model*. It implies that the degradation of soil (e.g. erosion and desertification) increases, when the intensity of the agriculture, in terms of the use of chemicals and fertilizers, increases. The prevention or limitation of soil degradation is an important environmental objective, so subsequently this degradation should lead to a decrease in the agriculture intensity in order to achieve the objective. It is imaginable that this negative causal link between the soil degradation and the agricultural intensity, should be supported or enforced by government policy and legislation. Leaving the intensity control over to the corporate part of the biofuel industry may lead to uncontrolled increasing of the intensity in order to achieve maximum revenue and profits via maximum yield, without seriously taking into account the environment and in particular soil degradation.

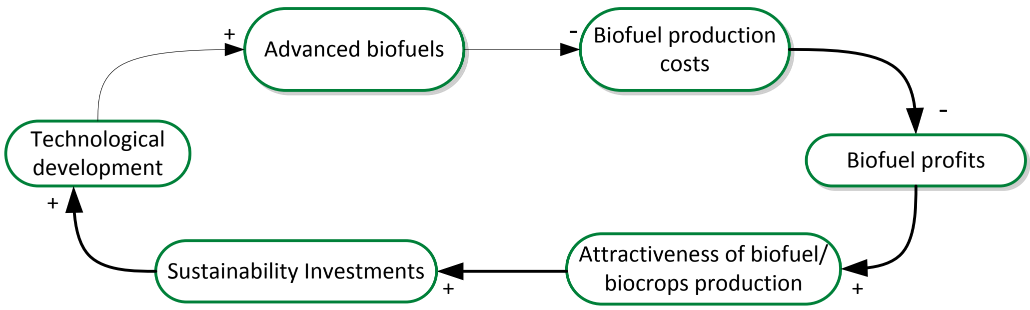


Positive attractiveness of feedstock in biofuel loop: this feedback loop simply implies the looped reinforcing influence of increasing investments in crops capacity on the biofuel production and profits. As investments are conducted in the crops capacity, more crops can be produced and subsequently more biofuel can be produced. An increasing biofuel production can lead to increasing profits and thus a higher attractiveness and again more investments as the loops repeats itself.



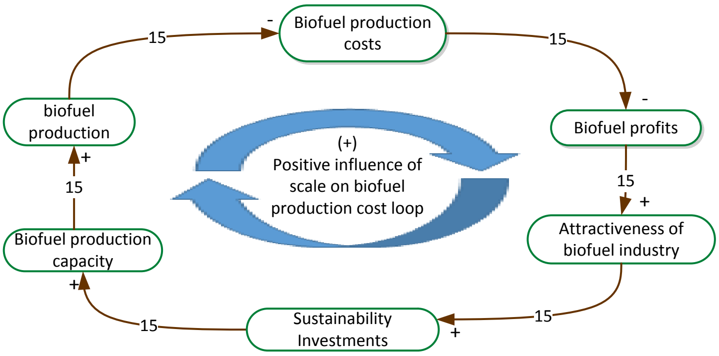
Positive biofuel production cost decrease via technological development loop: technological development plays an important role in the biofuel supply chain, especially in terms of cost reduction via higher efficiencies regarding higher yields and lower energy consumption.

But also in the advancement and success of advanced biofuels (second and third generation), technological development is critical (Ziolkowska, 2014), (Coelho, Goldemberg, Lucon, & Guardabassi, 2006) and (Janssen, Turhollow, Rutz, & Mergner, 2013). For the BioSU model which only focusses on sugarcane as input feedstock, advanced biofuels out of bagasse are a realistic and promising option. According to Walter and Ensinas (2010), this is possible via additional facilities which can be constructed annex to the excisting conventional ethanol plants. The additional facilties should be able to produce biofuel via either: a) hydrolysis for the production of ethanol or b) gasification combined with the Fischer-Tropsch conversion process for the production of not only ethanol but also biodiesel (Walter & Ensinas, 2010).



At last, technological development is important for the extent to which bagasse is being allocated towards the generation of bio-power. Generating bio-power out of bagasse, although the feedstock cost are basically the opportunity cost of bagasse (Walter & Ensinas, 2010), requires advanced technology in terms if preparation and combustion to achieve high efficiency (International Renewable Energy Agency, 2012).

The loop indicates that investments in R&D will support the rate of the technological development in time, leading to a decrease in the biofuel production cost. As mentioned before the decrease can be accounted for by various efficiency improvements and advanced biofuels. The decrease in production cost can increase the profit and higher profits imply an increase in the industries attractiveness. The increased attractiveness closes the enforcing loop by again enabling more investments in R&D to trigger technological development.



Positive influence of scale on biofuel production cost loop: this loop is located in the biofuel industry sub model. In addition to technological development, biofuel production cost can also be decreased via the economies of scale principle. Biofuel refineries are typical examples of infrastructures where this principle applies (Goldemberg & Guardabassi, 2009), (U.S. Department of Agriculture, 2006), (Vimmerstedt, Bush, Hsu, Inman, & Peterson, 2014). The loop implies, that in time, the reduction of biofuel production cost via scale advantages, boosts profits and the industries attractiveness. An attractive industry will attract more investments. These investments enable production capacity expansion, while the infrastructural economies of scale enable lower costs in terms of e.g. exponentially decreasing cost for machinery. The expansion of the capacity results in the ability to not only produce more biofuel, but also at even lower cost due to scale advantages in terms of production such as large scale feedstock purchase cost, energy consumption and efficiency.

Note that these feedback loops can differ to the ones operationalized in the BioSU SD model. The BioSU model is on a higher level of detail, relative to the causal diagram from where these causal feedback loops originate. Because of this difference in the level of detail, the feedback loops may contain more factors in the BioSU model, as more general factors of the causal diagram are modelled in several more detailed variables.

A.4 The sector diagram

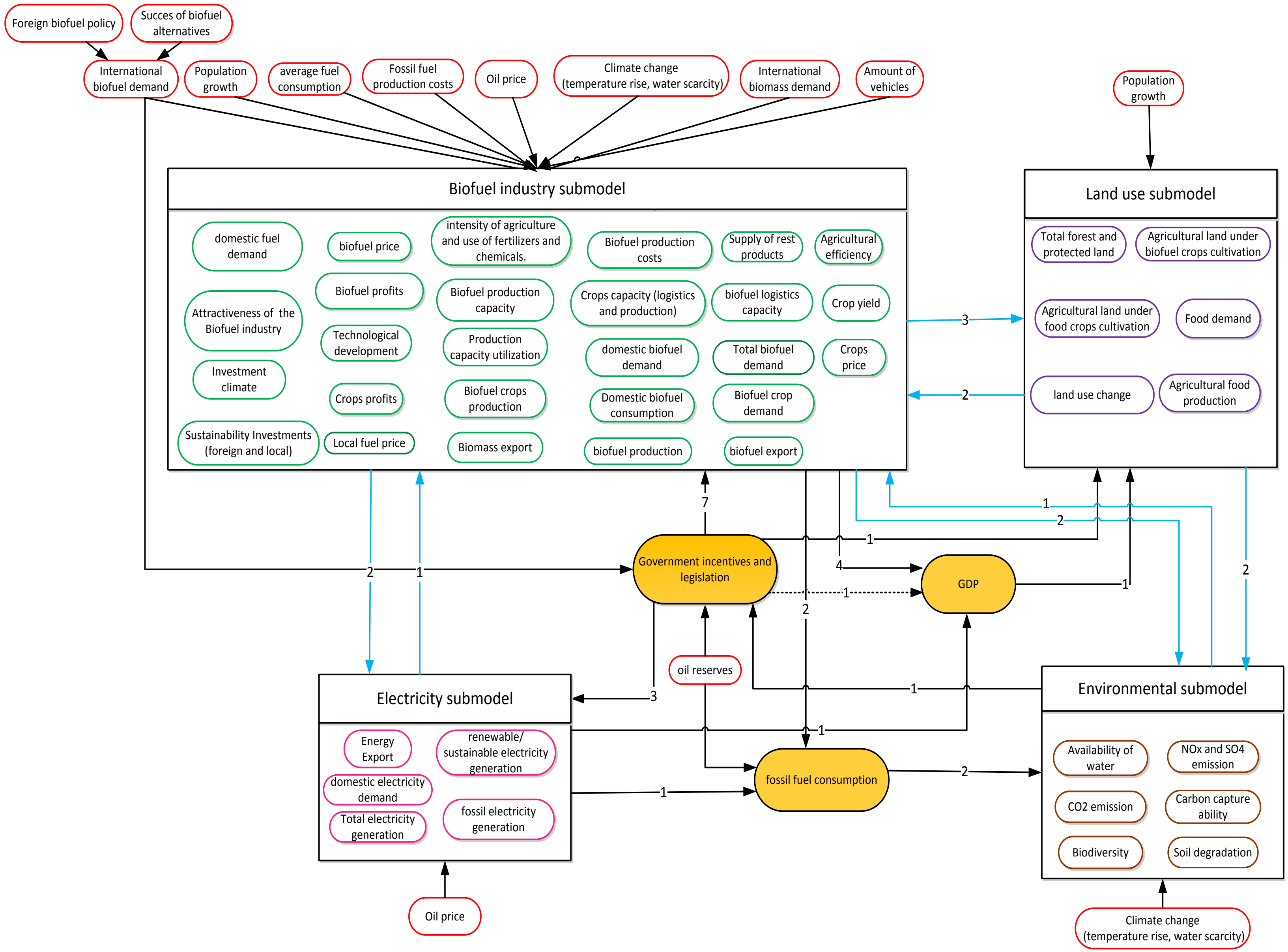


Figure 20: The sector diagram enlarged

The sector diagram provides a less detailed view of the biofuel system, as the focus is on the various sub models and the relations between them. The sector diagram thus leaves out the internal relationships between factors in the sub models and only focusses on the interaction between the sub models (Pruyt, 2013). The sector diagram, illustrated in figure 20, provides a clear big picture overview of the biofuel system to the extent that the causal diagram fails in that purpose due to its detail.

It can be noticed that in the sector diagram there are three factors that aren't part of one particular sub model, but rather they are part of more if not all four sub models. These factors are the *GDP*, *Government Incentives and Legislation*, and the *fossil fuel consumption*. The connected vectors indicate their relationship with the sub models, external factor and each other. These vectors are colored black and marked with a number, this number indicates the precise amount of relations there are, in accordance with the causal diagram.

The seven relationship links between the *Government Incentives and Legislation* and the *biofuel industry sub model are:*

1. the positive causal link between *government incentives* and *the investment climate*
2. the positive causal link between *government incentives* and *biofuel logistics capacity*
3. the positive causal link between *government incentives* and *biofuel price*
4. the positive causal link between *government incentives* and *technological development*
5. the causal link between *government incentives* and *GDP*
6. the positive causal link between *government incentives* and *biofuel production capacity*
7. the negative causal link between *government legislation* and *the intensity of agriculture and use of fertilizers and chemicals*

The three relationship links between the *Government Incentives and Legislation* and the *electricity are:*

1. the positive causal link between *government incentives* and *the renewable/sustainable electricity generation*
2. the positive causal link between *government incentives* and *the petrol electricity generation*
3. the positive causal link between *government incentives* and *the energy export*

The relationship link between the *Government Incentives and Legislation* and the *land use sub model is:*

1. the negative causal link between *government legislation* and *the land use change*

The relationship link between the *environmental sub model* and the *Government Incentives and Legislation is:*

1. the negative causal link between *the carbon capture ability* and the *government legislation*

Additionally there is a causal link between the *government incentives and legislation* and the *GDP*, of which the effect is not completely clear. Government incentives requiring financial resources have a negative effect on the GDP, however the effect of the incentives can lead to an increase in the GDP in terms of industrial activity and economic growth. The external factors *oil reserves* and *International biofuel demand* also have an effect on the government incentives and legislation measures.

There is one relationship link between the *electricity sub model and the fossil fuel consumption,* namely:

1. the positive causal link between the *petrol electricity generation* and the *fossil fuel consumption*

The two relationship links between the *biofuel industry sub model and the fossil fuel consumption are:*

1. the positive causal link between the *domestic fuel demand* and the *fossil fuel consumption*
2. the negative causal link between the local biofuel consumption and the *fossil fuel consumption*

The two relationship links between *the fossil fuel consumption* and the *environmental sub model are:*

1. the positive causal link between the *fossil fuel consumption* and the *CO_2 emission*
2. the positive causal link between the *fossil fuel consumption* and the *NO_x and SO_4 emission*

Additionally there is an effect between the oil reserves and the fossil fuel consumption, the more oil reserves are discovered the larger the tendency will be towards a fossil fuel based economy.

The four relationship links between the *biofuel industry sub model* and the GDP *are:*

1. the positive causal link between the *sustainability investments* and the *GDP*
2. the positive causal link between the *biomass export* and the *GDP*
3. the positive causal link between the *biofuel export* and the *GDP*
4. the positive causal link between the *GDP* and the domestic fuel demand

The relationship link between the *land use sub model* and the *GDP is:*

1. the positive causal link between the GDP and the food demand

The relationship link between the *electricity sub model* and the *GDP* is*:*

1. the positive causal link between the *energy export and the GDP*

In the sector diagram the links between the sub models are illustrated with blue vectors. These relationship links are also marked with a number, indicating the precise amount of causal relationships between sub models represented in each inter-sub model link, according to the causal diagram.

Between the *biofuel industry sub model* and the *land use sub model* there are five links in total. These are:

1. the positive causal link between *agricultural efficiency* and *agricultural food production*
2. the positive causal link between *crops yield* and *agricultural food production*
3. the positive causal link between *biofuel crops demand* and *land use change*
4. the positive causal link between *agricultural food production* and *supply of rest products*
5. the negative causal link between *agricultural food production* and *the intensity of agriculture and use of fertilizers and chemicals*

Between the *land use sub model* and the *Environmental sub model* there are two links in total. These are:

1. the negative causal link between *land use change* and *biodiversity*
2. the negative causal link between *land use change* and *carbon capture ability*

Between the *Electricity sub model* and the *Biofuel industry sub model,* there are three links in total, namely:

1. the positive causal link between *renewable/sustainable electricity generation* and *biofuel crop demand*
2. the positive causal link between the *biofuel crops production* and the *renewable/sustainable electricity generation*
3. the positive causal link between the *sustainability investments* and the *renewable/sustainable electricity generation*

Between the *Biofuel industry sub model* and the *Environmental sub model,* three links can be identified. These are:

1. the positive causal link between *the intensity of agriculture and use of fertilizers and chemicals* and *soil degradation*
2. the negative causal link between *the intensity of agriculture and use of fertilizers and chemicals* and *availability of water*
3. the positive causal link between *soil degradation and the intensity of agriculture and use of fertilizers and chemicals*

Appendix B. BioSU structure

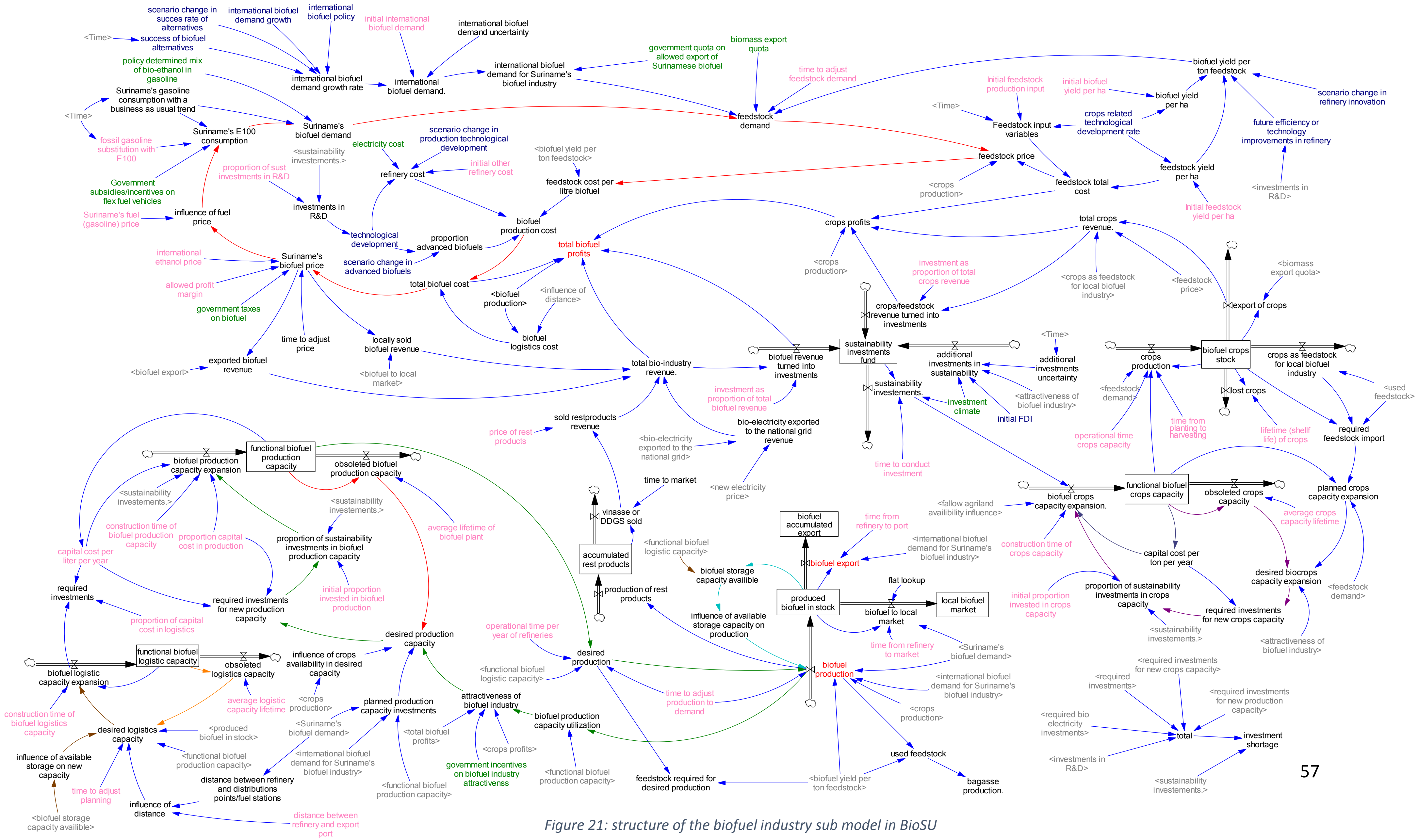


Figure 21: structure of the biofuel industry sub model in BioSU

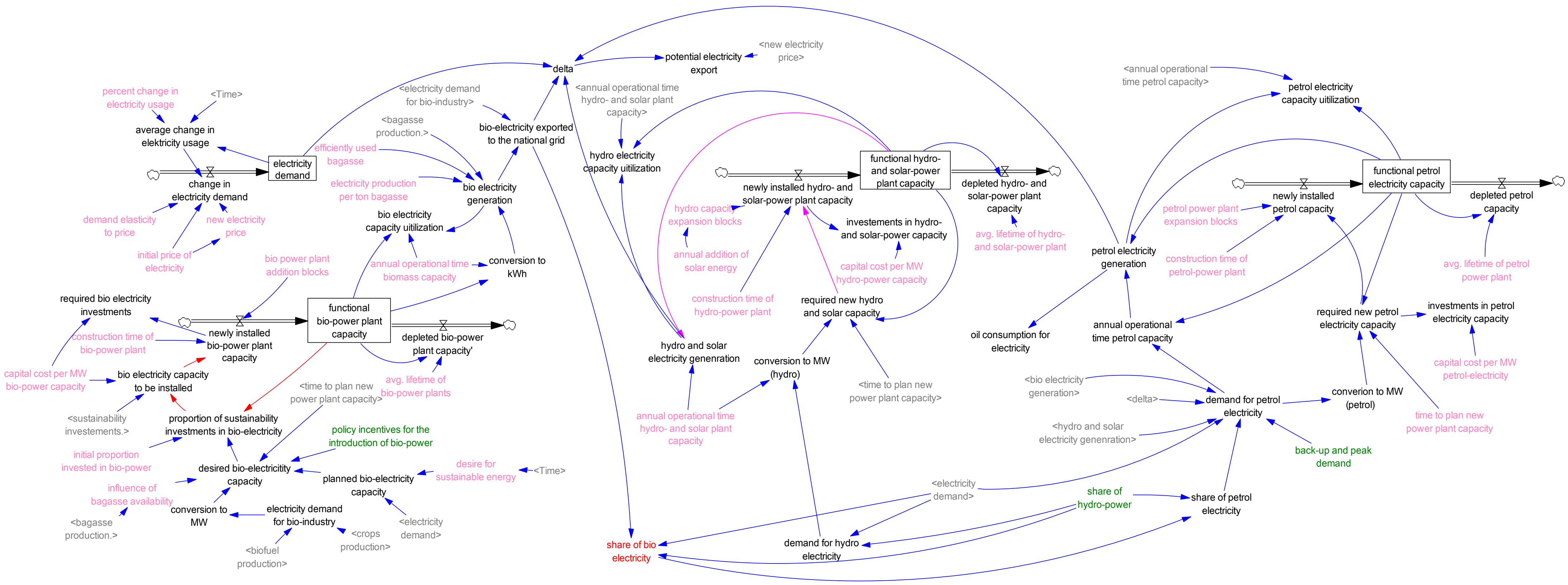


Figure 22: structure of the electricity sub model in BioSU

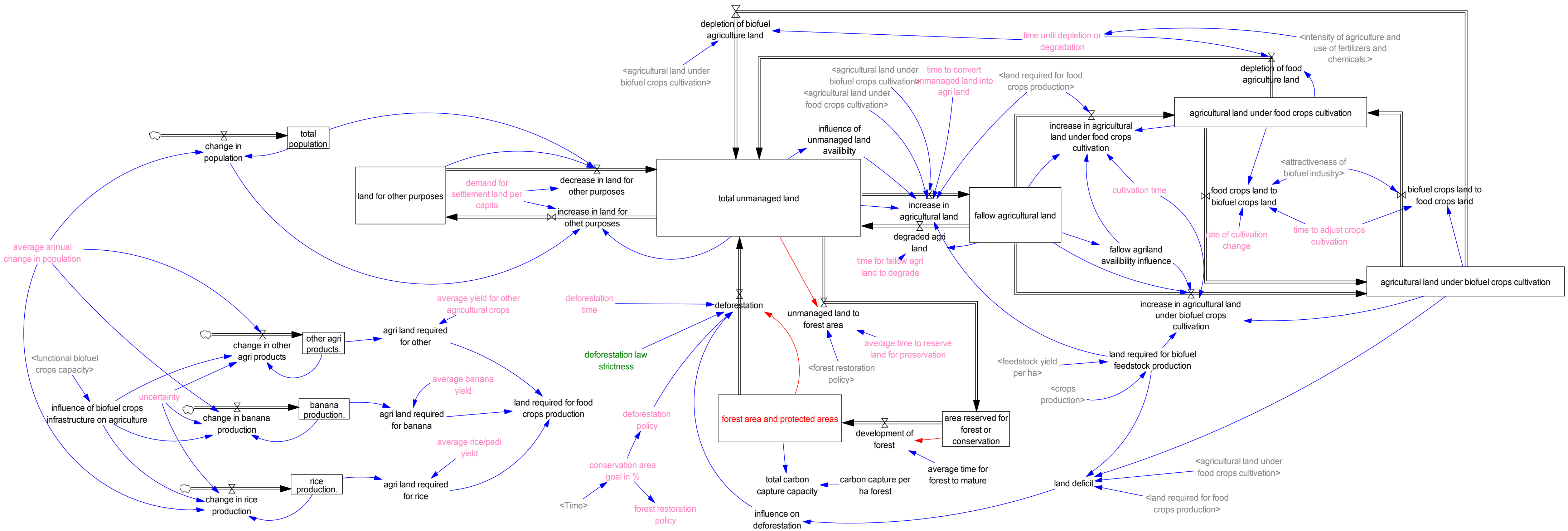


Figure 23: structure of the land use sub model in BioSU

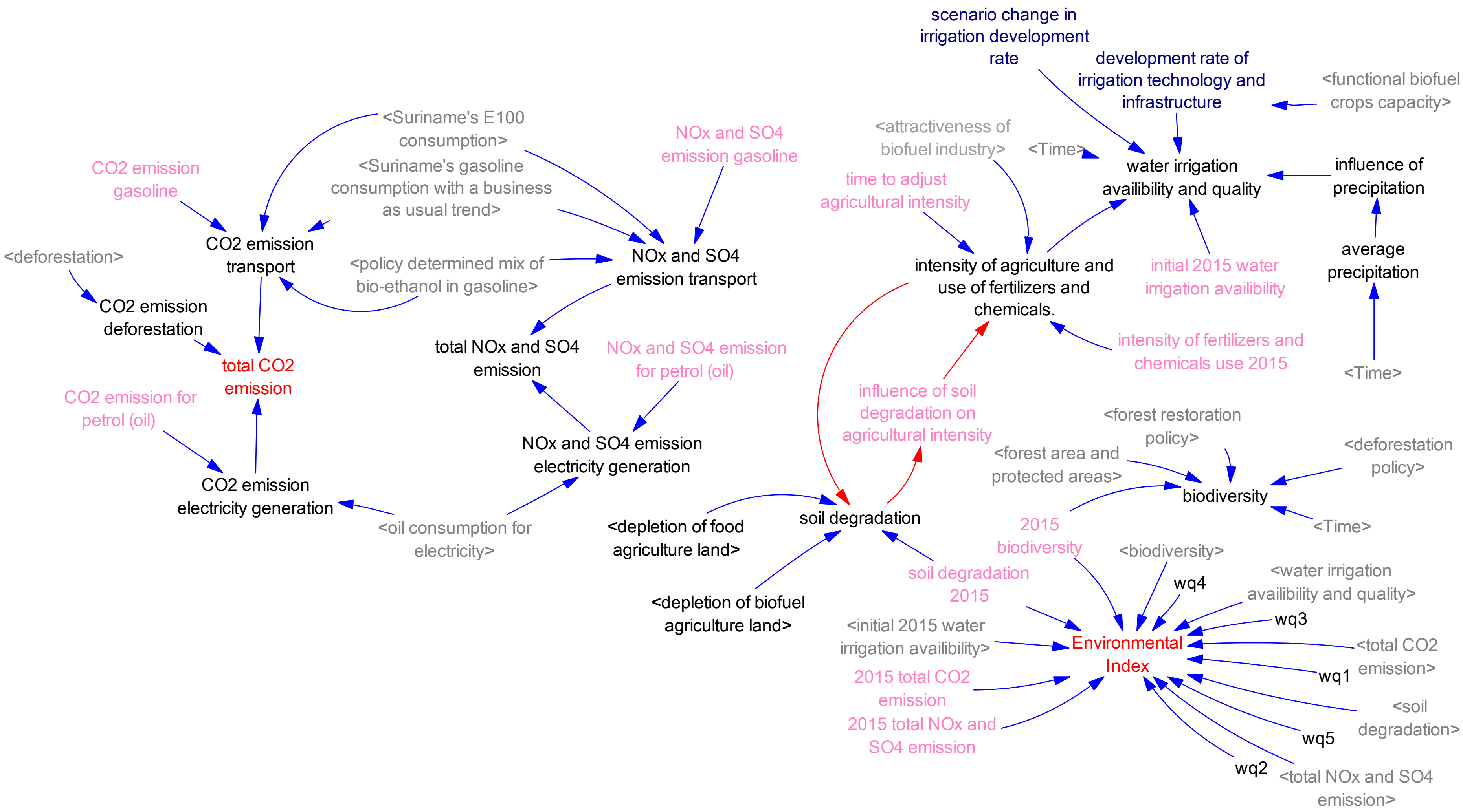
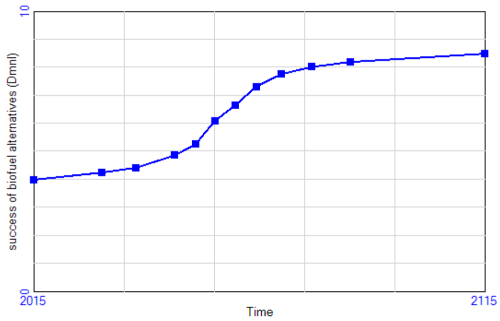
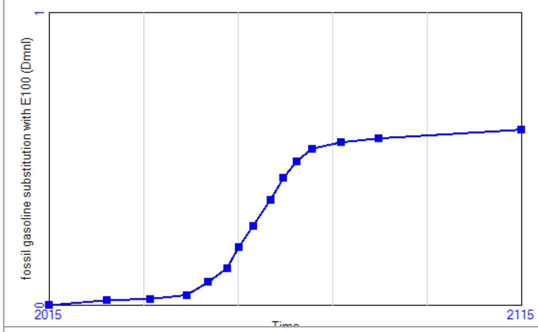
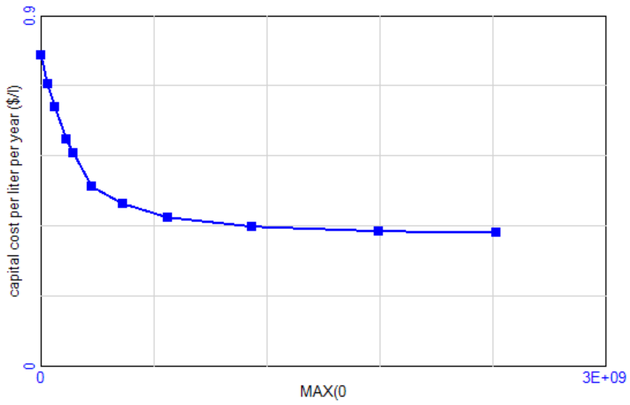


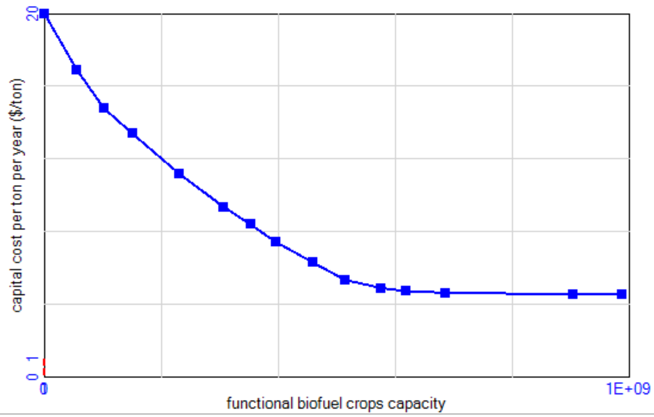
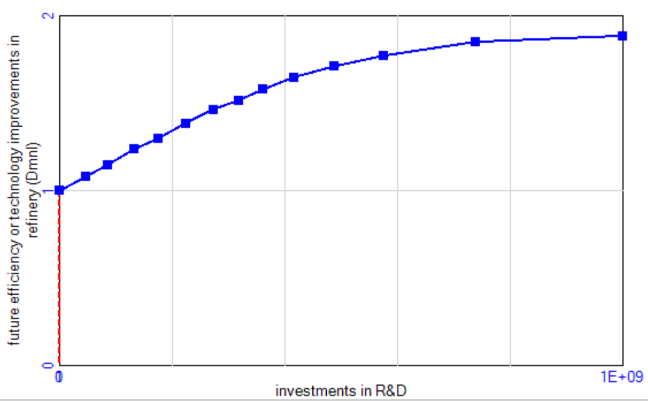
Figure 24: structure of the environmental sub model in BioSU

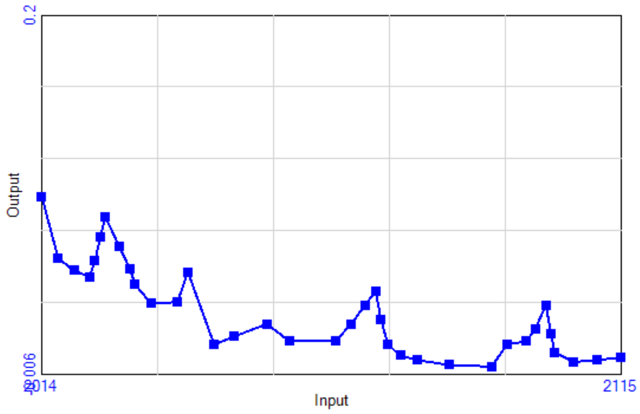
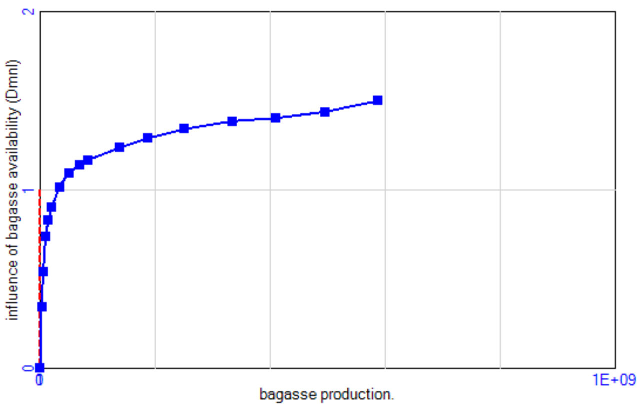
Appendix C. Parameter and factor values and assumptions

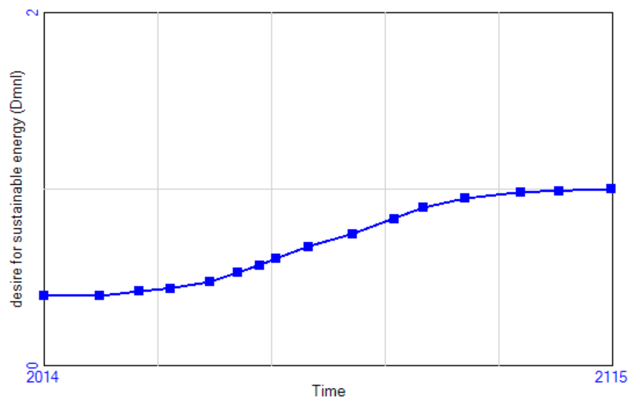
Table 3: Table with parameter and factor values and assumptions

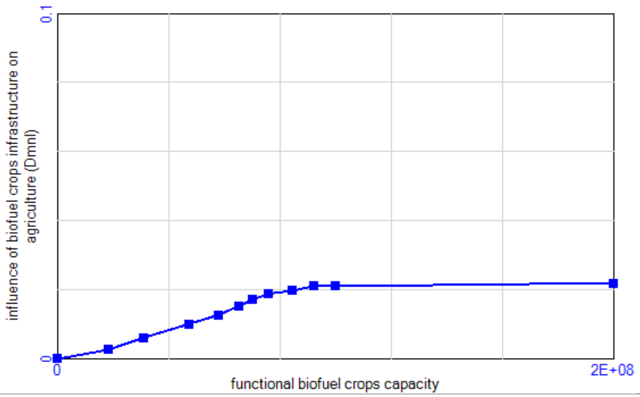
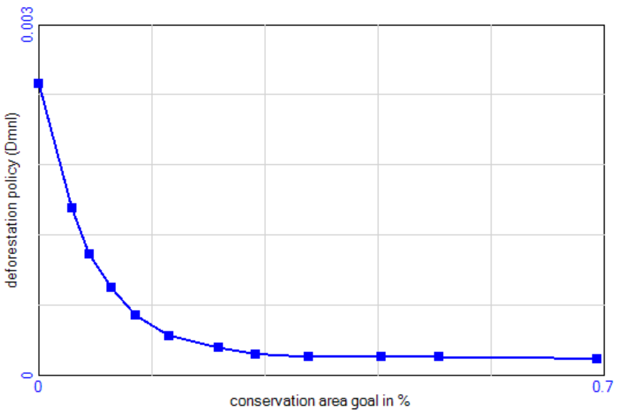
variable	Source	Sub-model
International biofuel demand growth rate Bio-2: 7% Bio-1: 2% Bio-0: 0%	(Renewable Fuels Association, 2015) (Navigant Research, 2014) (Faaij, Szwarc, & Walter, 2008)	Biofuel industry Sub-model
Success of biofuel alternatives  	Assumption (Faaij, Szwarc, & Walter, 2008) (Navigant research, 2014) (FAO, 2008) Assumption (FAO, 2013) (FAO, 2013) (World Bank, 2015)	
Initial international biofuel demand 92,000,000,000 liter/year (2015)	(Renewable Fuels Association, 2015)	
International biofuel policy BC: 0.7	assumption	
fossil gasoline substitution with E100  	Assumption based on typical technological developments	
Proportion of sustainability investments in R&D 10%	Assumption	
"Suriname's fuel (gasoline) price" 1.2 $/l	(Ministry of Trade and Industry, 2015)	
International ethanol price 0.49$/l	(Trading Economics, 2015)	
Allowed profit margin 0.1$/l	assumption	
Price of rest products (Vinasse and DDGS or Distiller's Dried Grains with Solubles, which can be used as fertilizer or kettle feed) 200 $/ton	(vin2food, n.d.)	
Construction time of biofuel logistics capacity 2 years	Assumption	
Construction time of biofuel production capacity 4 years	Assumption based on (ERM, 2012)	
Proportion of capital cost in logistics	Assumption	

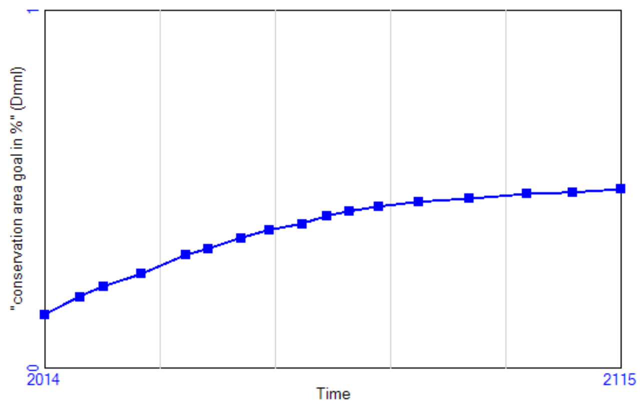
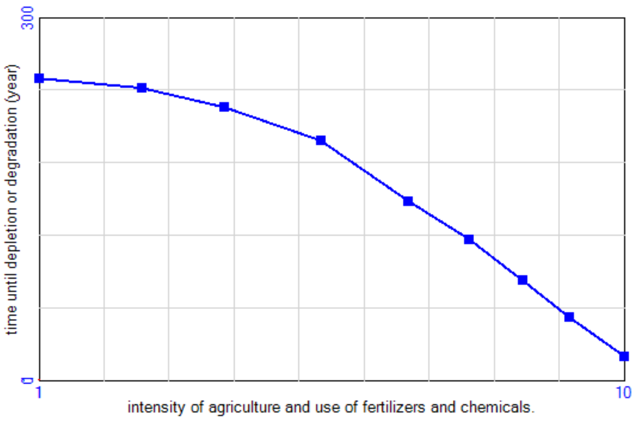
0.3	
Distance between refinery and port 200 km	Average distance to Port Nieuwe Haven in Suriname's Capital Paramaribo, from the various potential biofuel refinery sites
Capital cost per liter per year  	Based on scale of capacity to be installed. (Coelho, Goldemberg, Lucon, & Guardabassi, 2006)
Average logistics capacity lifetime 20 years	assumption
Proportion of capital cost in production 0.7	assumption
proposed proportion invested in biofuel production 0.35	assumption
Proposed proportion invested in crops capacity 0.25	assumption
operational time per year of refineries 345 days	assumption
average lifetime of biofuel plant 30 years	(bp, 2012)
Time from refinery to market 1 day	Assumption
Time from refinery to port 3 days	Assumption
investment as proportion of total biofuel revenue 20%	Assumption
investment as proportion of total crops revenue 5%	Assumption
Time to conduct investment 1 year	Assumption
construction time of crops capacity 2 years	assumption
average crops capacity lifetime 20 years	assumption
Capital cost per ton per year	assumption

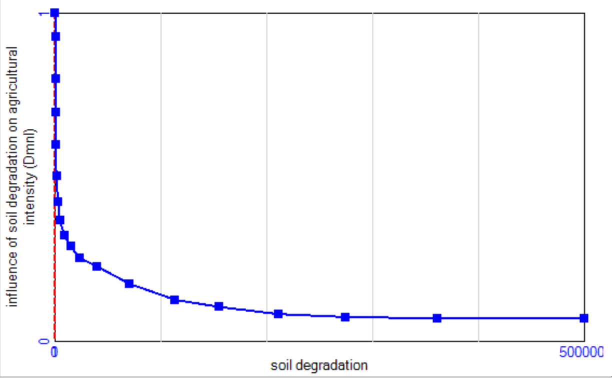
	
initial other refinery cost 0.12 $/l	(Coelho, Goldemberg, Lucon, & Guardabassi, 2006)
Electricity cost demand per liter: 0.19 kWh 0.05 $/l	(bp, 2012)
Initial feedstock yield per ha 85 ton/ha	(Velasco, 2013) (UNICA-Brazilian Sugarcane Industry Association, 2015)
initial biofuel yield per ha 6272.45 l/ha	(ERM, 2012)
Future efficiency or technology improvement in refinery 	assumption
Crops related technological development rate Bio-2: 0.30 Bio-1: 0.26 Bio-0: 0.1	(The Transnational Institute, n.d.)
Initial feedstock production input 1010.45 $/ha	(Hess, Wright, & Kenney, 2007)
Time from planting to harvesting 5 months	(USDA, n.d.)
Lifetime (shelf life) of crops 1 year	assumption
Government incentives on biofuel industry attractiveness 0.1	assumption
Time to adjust planning 6 months	assumption
Time to adjust biofuel production to demand 3.5 months	assumption
Government taxes on biofuel 0.5 $/l	assumption
Government subsidies/incentives on flex fuel vehicles	assumption

0		
policy determined mix of bio-ethanol in gasoline 10%	assumption	
Portion of international demand for Suriname's biofuel industry (How much of the international demand will Suriname supply in) 0%	assumption	
international biomass demand 0 ton/year	assumption	
Investment climate 0.8	assumption	
Percent change in electricity usage  	Assumption based on recent power demand developments in Suriname	Electricity sub-model
Initial price of electricity 0.22 $/kWh	(Energie Bedrijven Suriname, n.d.)	
Demand elasticity to price 1.3	Assumption	
Construction time of bio-power plant 1 year	Assumption	
Capital cost per MW bio-power capacity 3,280,000 $/MW	(International Renewable Energy Agency, 2012)	
Proposed proportion invested in bio-power plants 0.15	Assumption	
Influence of bagasse availability  	Assumption	
Desire for sustainable energy	assumption	

	
Avg. lifetime of bio-power plants 45 years	(Tidball, Bluestein, Rodriquez, & Knoke, 2010)
annual operational time biomass capacity 7920 hours	assumption
Electricity production per ton bagasse 450 kWh/ton	(Renewable Energy World Editors, 2013)
Efficiently used bagasse 2018 – 25% 2030 -55% 2050 – 75% 2070 – 90%	Assumption
bio power plant addition blocks 20MW	(International Renewable Energy Agency, 2012)
Annual operational time hydro and solar power plants 6132 hours	Assumption
Capital cost per MW hydro-power capacity 2,936,000 $/MW	(Tidball, Bluestein, Rodriquez, & Knoke, 2010)
Construction time of hydro capacity 4 years	Assumption
Avg. lifetime of hydro- and solar plant 75 years	(Canadian Electricity Association, n.d.)
annual addition of solar energy 5MW	Assumption
Share of hydro-power 53%	Assumption
capital cost per MW petrol-power capacity 2,167,000 $/MW	Based on SPCS expansion
"avg. lifetime of petrol power plant" 50 years	(Tidball, Bluestein, Rodriquez, & Knoke, 2010)
construction time of petrol-power plant 2 years	Assumption
petrol power plant expansion blocks 10MW	Assumption
Hydro-power plant expansion blocks 30MW	Assumption
back-up and peak demand 2015- 60,000,000 kWh, 20130-140,000,000 kWh, 2050-230,000,000 kWh 2080-330,000,000 kWh	Assumption
time to plan new power plant capacity 6 months	Assumption
"policy based introduction of bio-power" 0	Assumption

average annual change in population 0.96% - average change determined based on world bank population data up to 2014 and extrapolated to 2015 as base year.	(World Bank, 2014)	Land-use sub-model
Influence of biofuel crops infrastructure on agriculture 	assumption	
demand for settlement land per capita (This is land required for various urbanization activities both residential and industrial, but also activities like e.g. mining.) 1 ha/capita	assumption	
average yield for other agricultural crops (Cassava, citrus etc.) 31 ton/ha	(FAO, 2013) (FAO, 2013)	
average banana yield 39.4 ton/ha	(Fact Fish, 2013)	
Average rice yield 4.5 ton/ha	(World Bank, n.d.)	
deforestation time 3 months	assumption	
initial agri land 2015 120,000 ha	(Derlagen, Barreiro-Hurlé, & Shik, 2013)	
Deforestation policy 	Assumption based on (Plouvier, Gomes, Verweij, & Verlinden, 2012)	
Conservation area goal in %	(Plouvier, Gomes, Verweij, & Verlinden, 2012)	

		
average time to reserve land for preservation 6 months	assumption	
rate of cultivation change 0.2%	Assumption	
time to adjust crops cultivation 3 months	assumption	
cultivation time 2.5 months	assumption	
time for fallow agri land to degrade 2 years	Assumption	
time to convert unmanaged land into agri land 3.5 months	Assumption	
Time until depletion/degradation 	(UNICA-Brazilian Sugarcane Industry Association, 2015)	
deforestation law strictness 100	Assumption	
CO_2 emission gasoline 0.00235 ton/l	(U.S. Environmental Protection Agency, n.d.)	Environmental sub-model
"CO2 emission for petrol (oil)" average for diesel and heavy stoke oil used in electricity generators 0.00286 ton/l heavy fuel oil: 0.0031 ton/l diesel: 0.0026 ton/l	(Government of Canada, n.d.)	
NOx and SO4 emission gasoline 0.000000921 ton/l	(Government of Canada, n.d.)	
"NOx and SO4 emission for petrol (oil)"	(Government of Canada, n.d.)	

0.00000148 ton/l	
time to adjust intensity 5 months	Assumption
initial 2015 water irrigation availability 55188 m^3/ha/year	Assumption based on the Nickerie area (in which Wageningen from the WSESP project is located) as important agricultural area with the important-for-irrigation Nani Creek (Henstra, 2013).
intensity of fertilizers and chemicals use 2015 3	Assumption
influence of soil degradation on agricultural intensity  	Assumption
2015 biodiversity 35 species/1000ha	(World Bank, 2015)
soil degradation 2015 100 ha	Assumption
2015 total CO2 emission 292683 ton/year (average) 183464.5 ton due to gasoline combustion in 2015 292500 ton due to diesel and heavy fuel oil combustion for electricity generation	Based on Surinamese fuel consumption in the considered sectors
2015 total NOx and SO_4 emission 299.74 ton/year (average) 115.54 ton due to gasoline combustion in 2015 184.20 ton due to diesel and heavy fuel oil combustion for electricity generation	Based on Surinamese fuel consumption in the considered sectors

Appendix D. Model Verification & Validation

This appendix covers the model verification and validation. This part of the study is important in order to have the model fit for the purpose at hand. The purpose is to study the impact and possibilities of a developed bioenergy industry in Suriname.

D.1 Model Verification

Model verification consist of various actions in order to get the model running properly and eliminate errors with regard to structure, equations and assumptions in the model. During the process of multiple iterations in building the model, the coding was done as careful and well-thought as possible to prevent errors. This kept the errors at a minimum.

First all equations and structures in the model, all sub models, were checked for the occurrence of coding errors. The structures and equations were compared to the causal diagram and literature in order to find out if the relations and equations were coded correctly. In the used model all equation and structure errors are eliminated.

Secondly a numeric simulation check was conducted to check which integration method and time step was most suitable for simulation. At first a fixed Runge-Kutta numerical integration method, which is ideal for continuous equations and arguments, was applied. But due the fact that the model also contains numerous discrete functions, for example the addition of power plant capacity which takes place in blocks, a test was also run with a method more fitted for discrete functions namely the Euler method. The conclusion was that the difference between the two methods was minimal with the difference being limited to small numerical differences and no change in behavior. The time step with which the model runs most smoothly is 0.0625. A larger time step leads to larger differences between the two integration methods and more discrete results. At last the choice was made for the fixed Runge-Kutta method and a time step of 0.0625.

Finally the dimensional consistency with regards to unit consistency was tested in order to get all units correct. After enduring improvements of units, a few errors still occur but those have no influence on the results of the model, hence they form no imminent problem.

D.2 Model Validation

The goal of model validation as mentioned by Sterman (2000) is to test whether the model fits and is useful for the purpose of the study. This study as mentioned before is to test future policy and development of an advanced biofuel industry in Suriname and the subsequent impact on the energy supply, environment and economy. The model is considered from the base year of 2015 and further. Due to the purpose of the model to explore plausible futures and policies and to get a better understanding of the behavior of the bio industry system as a whole, it is not the main goal that the model reproduces past real-data very accurately. Also the fact that a biofuel industry will be new for Suriname, no past real data in this field is available. The tests conducted are in the field of direct structure tests and structure-oriented behavior tests.

D.2.1 Structure test

In the direct boundary adequacy test, the boundaries of the model are tested, whether they are set correctly instead of to narrow or wide. The boundaries of the model are set in accordance with the boundary of the study, mentioned in sub-chapter 1.3.

It can be concluded that the boundaries are set adequately to study a system of an advanced biofuel industry with its influences on the electricity generation, land use and environment. Factors of emission are considered from source to the atmosphere. In the biofuel supply chain the boundaries are set not to wide. The whole supply chain from production to transport to the port or distribution points is considered. This creates the ability for the study to focus on the Surinamese biofuel industry, without congestion created by unnecessary factors.

Furthermore a direct structure assessment test is conducted, whereby it can be concluded that the model structure is in accordance with the explored causal relations based on the real world.

D.2.2 Structure-oriented behavior test

First of all a sensitivity analysis (SA) is conducted. Small 10 percent changes, relative to the base case, are implemented in the value of parameters to test the sensitivity of important model factors. The base case can be described as:

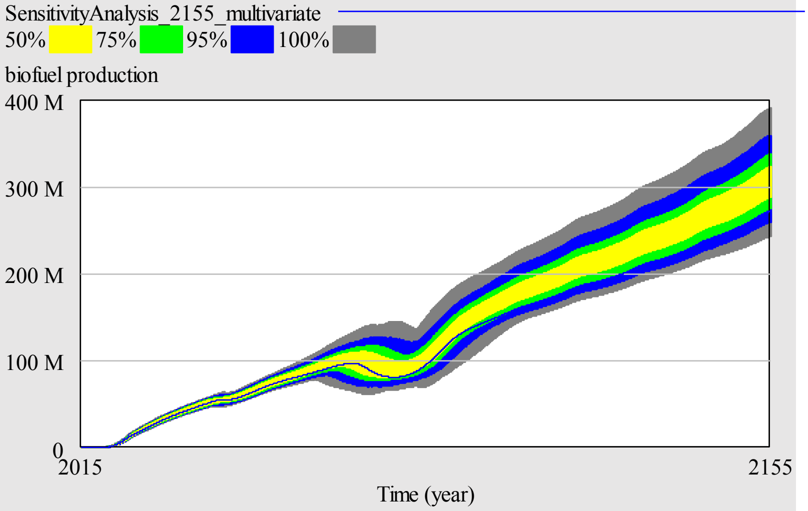
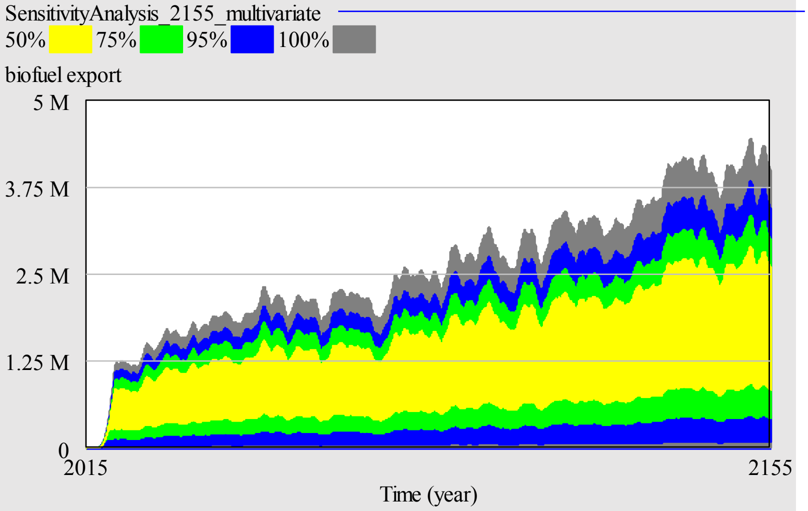
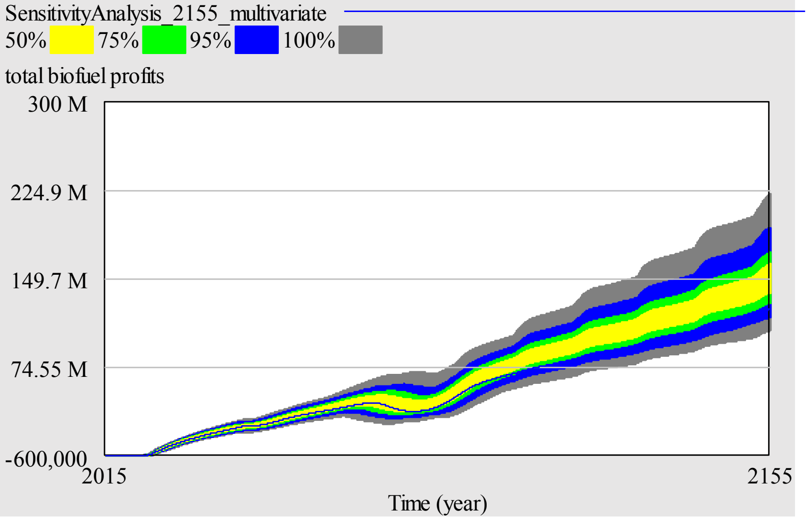
A small biofuel industry, comparable to WSESP, with domestic E10 obligations and no bio-power and biofuel export. The biofuel industry grows to merely supply the local demand. The investment climate is bad, according to the real situation (0.8 on a scale from 0 to 1 with a lower grade indicating a better investment climate). Additionally the situation can be described by an international growth in biofuel demand equal to 4% (Goldemberg & Guardabassi, 2009) and a relatively strong preference for biofuel in the international biofuel policy. Biofuel alternatives have a success rate of 5.5 on a scale from 0 to 10, with a higher grade indicating higher success. Finally annual FDI equal to US$ 375 million and a relatively strong technological development in all biofuel related fields are assumed.

The SA is conducted using multivariate sampling, within 1000 simulation runs. Furthermore the SA is conducted with an expanded timespan, namely 2015-2155, instead of the timespan of the study from the base year 2015, until 2115. Considering the purpose of the model, to explore plausible futures and policies and to get a better understanding of the behavior of the bio industry system as a whole, it is not the main goal that the model reproduces past real-data very accurately. Also the fact that a biofuel industry is new for Suriname, no past real data in this field is available. However for the validation the timespan is extended to 2155 to also study whether the chosen timespan is appropriate considering the purpose of the model. Also, eventual irregularities in the model after 2115 can be detected and corrected in the case the model will be used for longer timespans in the future.

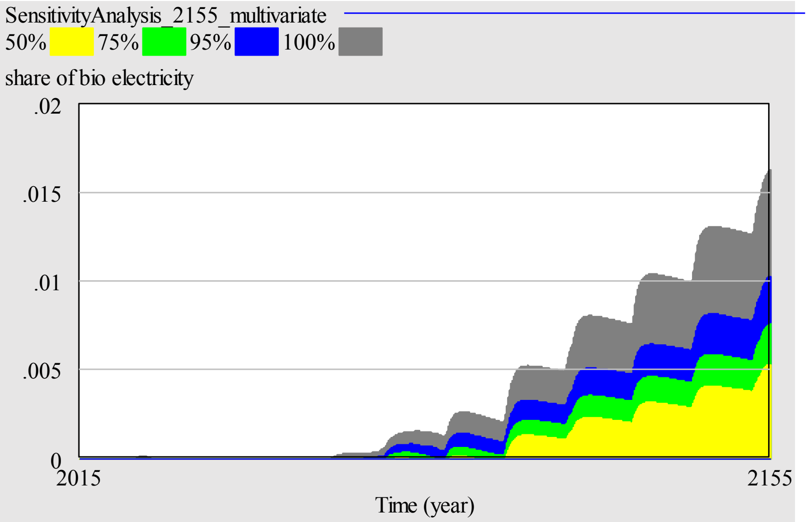
In table 4 an overview is given in the changes of the KPI's, following the 10% changes in model parameters. The graphs of the KPI's are accompanied by short text on the interpretation and elaboration of the KPI's behaviors. These KPI's are: biofuel production, biofuel export, total biofuel profits, share of bio-power, the total CO_2 emissions and the EI. Additionally table 5 provides an overview of some other model factors, complementing the KPI's in monitoring the system performance and behavior.

The legend of the KPI SA graphs, in table 4 and 5, indicate the use of four colors. To elaborate: the yellow band implies that 50% of the 1000 runs are within the yellow range. Meanwhile 75% of the runs are in the green range, 95% in the blue range and 100% or all of the runs are in the grey range.

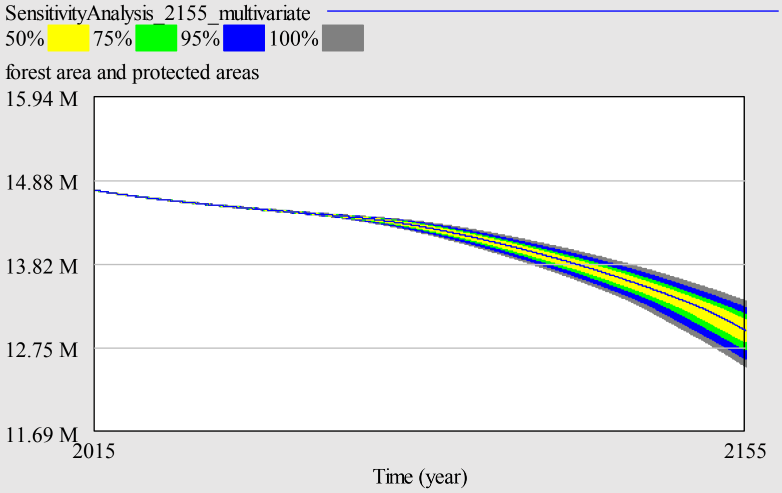
Table 4: Behavior of the KPI's in the SA

In general a rising trend can be observed in the biofuel production. However, the dip in the production in the period 2070-2090 is notable. Further research on the cause behind this dip can be traced back to a similar dip in the crops capacity and production in the period 2070-2090.	
Due to the uncertainty in the international biofuel demand, included in the model, fluctuations can be noticed in the export of biofuel. Although the base case does not focus on the export of biofuel, small amounts are still exported e.g. in the form of productions surplus.	
Also the biofuel profits show a positive trend, but with the earlier mentioned dip in the period 2070-2090. Notably, in the first years of production the industry will have to cope with losses.	

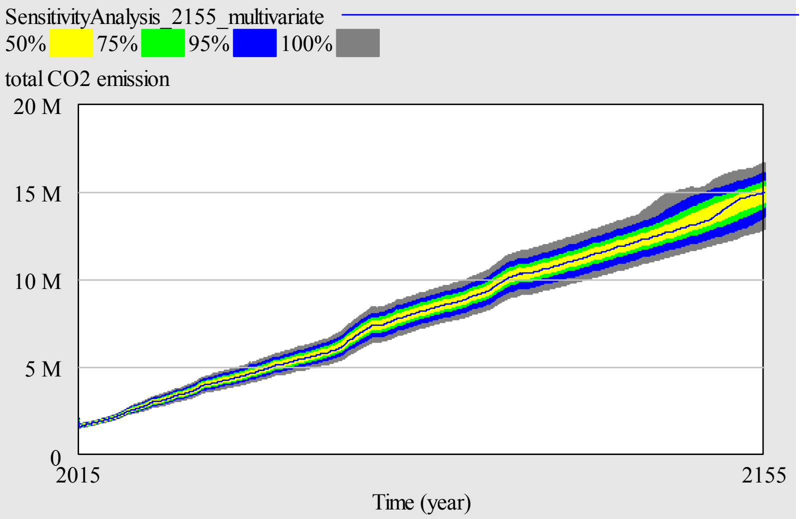
As expected the share of bio-power in the base case will be very low to negligible as bio-power is not yet introduced on a large scale.



Even in the base case, the forest covered area will decrease. This is not only caused by the biofuel industry, but also a growth in population leading to a larger demand for settlement land for various residential and industrial purposes.



A steady increase in the CO_2 emissions can be noticed as a consequence of increased transport and power generation, in particular petrol based. Also deforestation is a mentionable contributor to the CO_2 emissions. A possible CO_2 reduction realized by implementing E10 in the transport, can thus be overturned by an increase in deforestation. It is a mechanism to reckon with, when making policy to increase the role of biofuel in the economy.



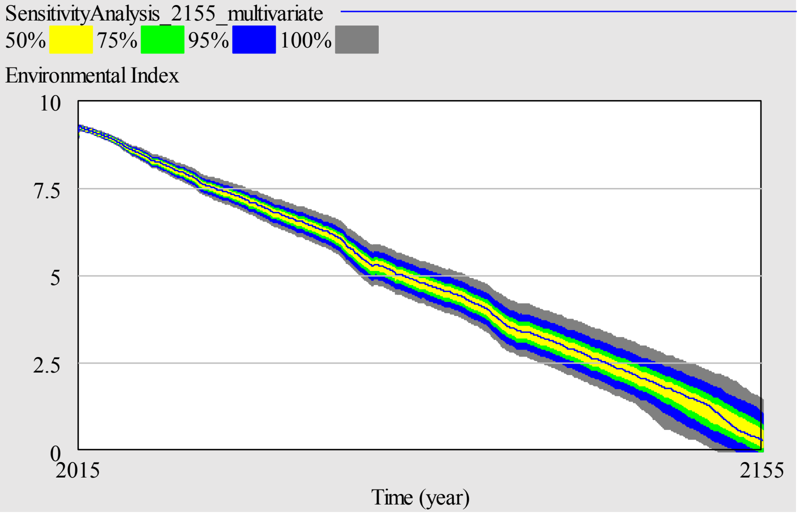
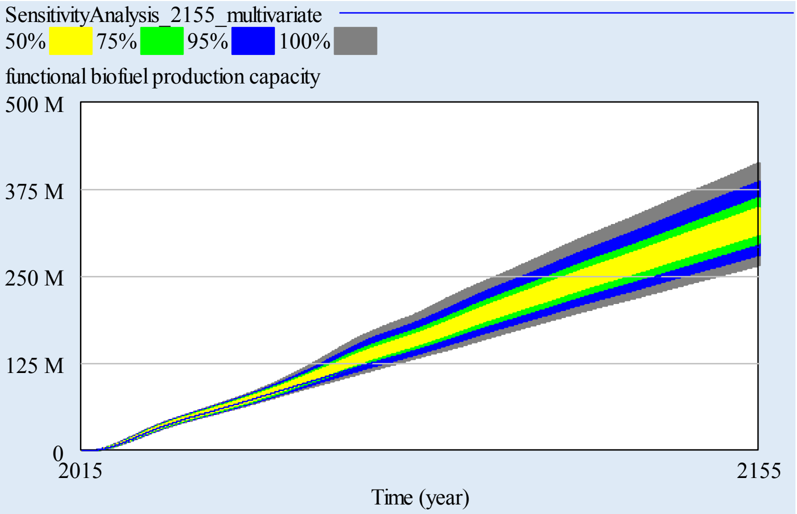
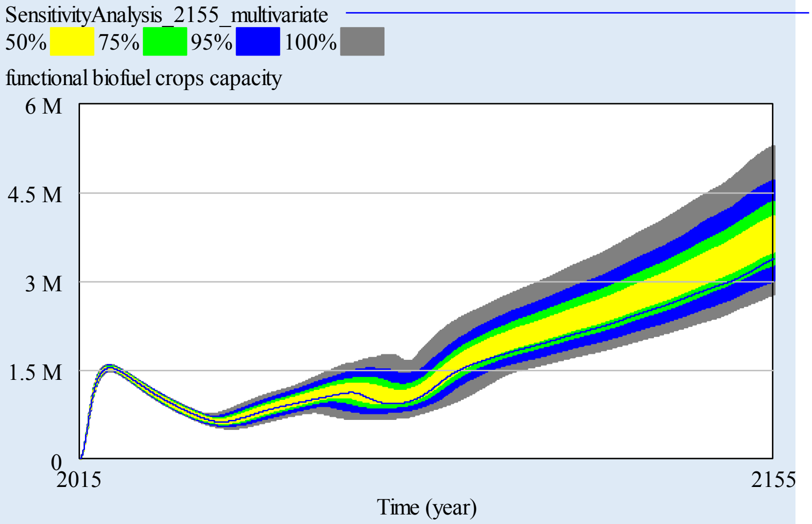
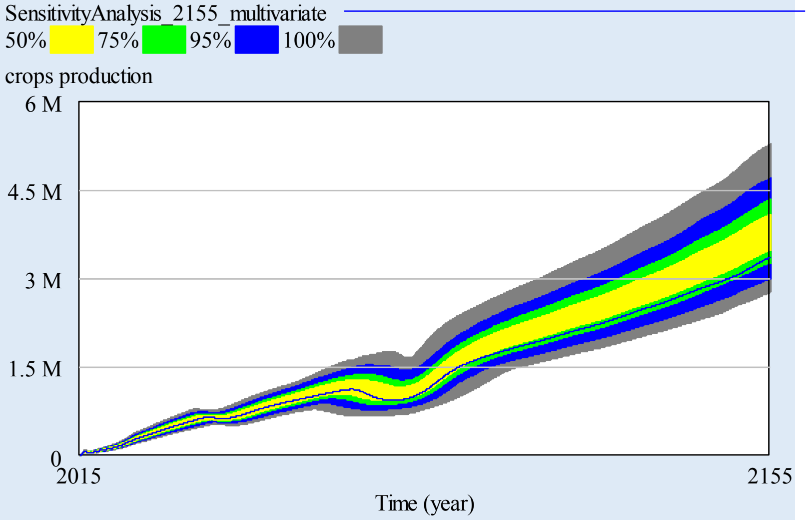
A worrying observation is that even with small changes to the base case, a negative trend of the EI can be noticed. So policy is required in order to preserve the environment.	

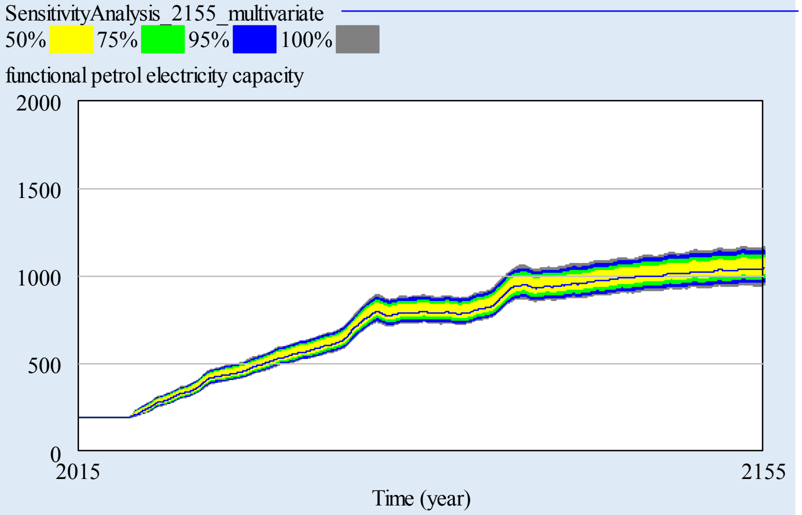
Table 5: Some other interesting model factors in the SA

An increasing biofuel production capacity to supply in the local demand. No irregularities can be noticed.	
A strong peak in the capacity expansion in the beginning, will lead to capacity surplus and subsequently low expansion rates until about 2040. This can be noticed in the decreasing capacity. However, after 2040 the capacity surplus turns into a capacity shortage leading to a steady increase in the capacity. In the period 2070-2090 a dip can be noticed in the capacity. Research about this gap, revealed that a shortage in agricultural land strongly contributes to this dip.	

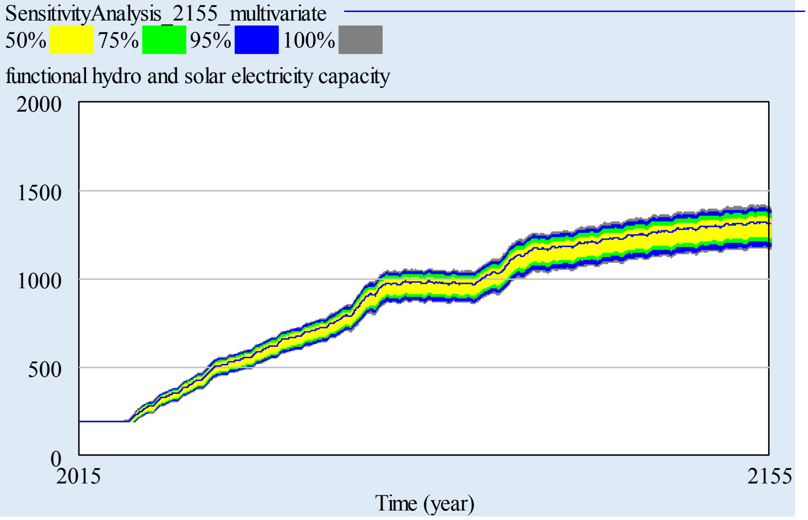
The decreasing crops capacity in the period 2020-2040 cannot be noticed in the crops production as there was a capacity surplus with no consequences on the production. The dip in the period 2070-2090 can, however, be noticed in the crops production as there was no capacity surplus. The dip in capacity, thus had a significant influence on the capacity.



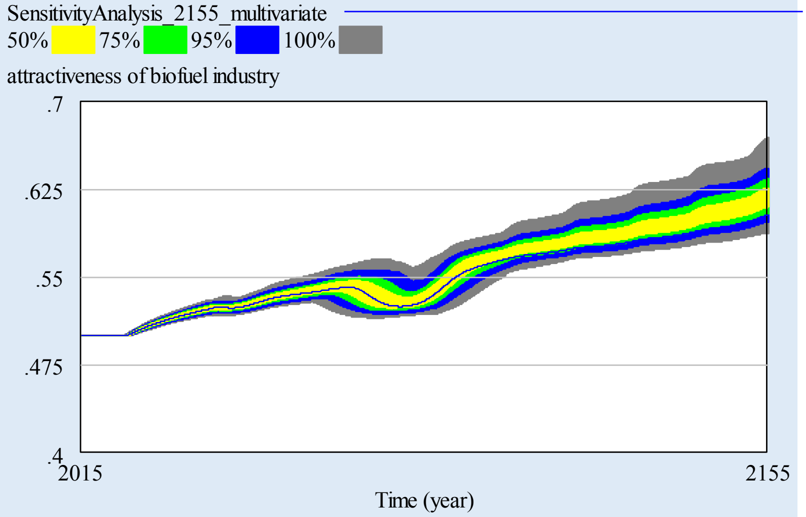
The petrol power capacity, increases according to the electricity demand. No irregularities.



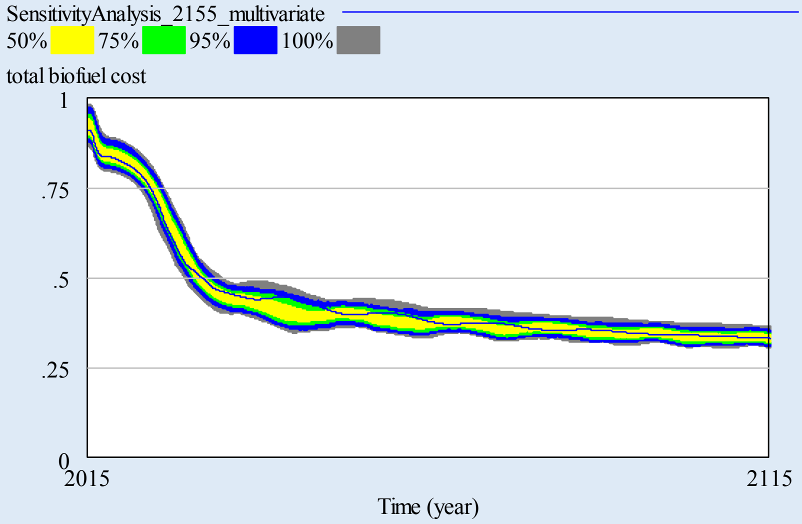
The hydro power capacity, increases according to the electricity demand and the assumed share in the total power generation. No irregularities.



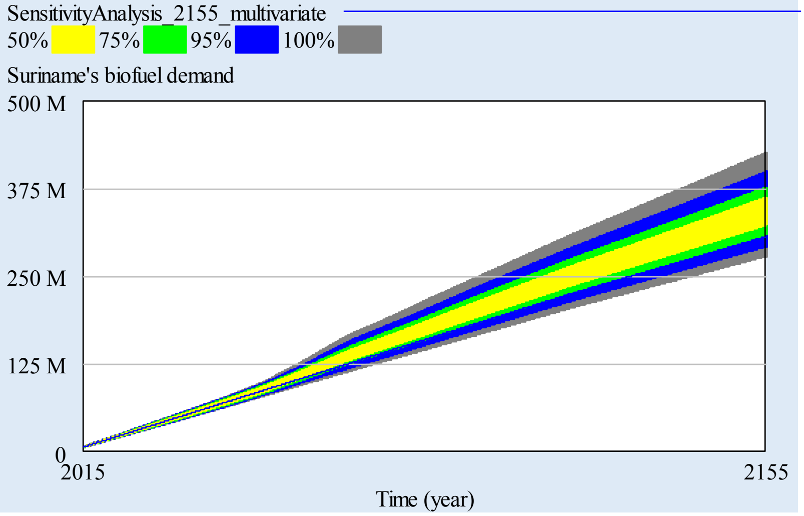
The dip in the period 2070-2090 can also be clearly noticed in the attractiveness of the biofuel industry



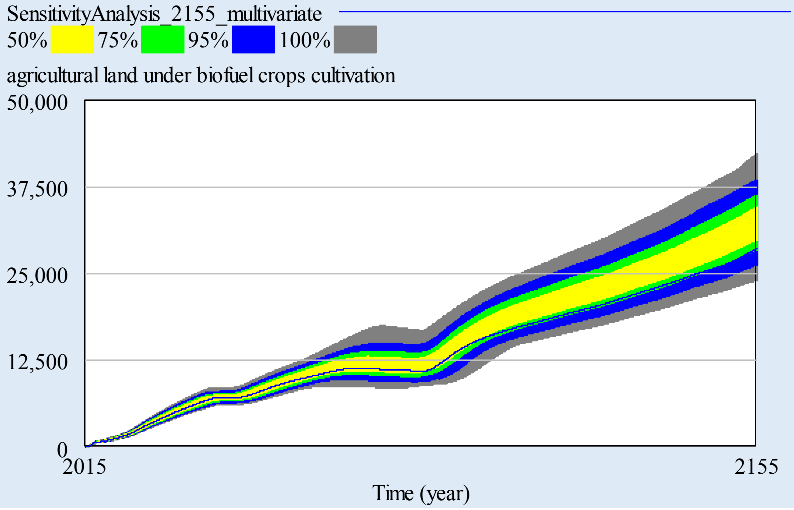
A strong decrease in costs, once the industry is established as scale and technological development have pressing influence on the cost. The cost per liter stabilizes around the US$0.30 ultimately.



Also a steady increase, corresponding to the assumed linear increase in transportation and fuel demand in Suriname. But as time goes on, more uncertainty is attached to the numerical value of the biofuel demand.



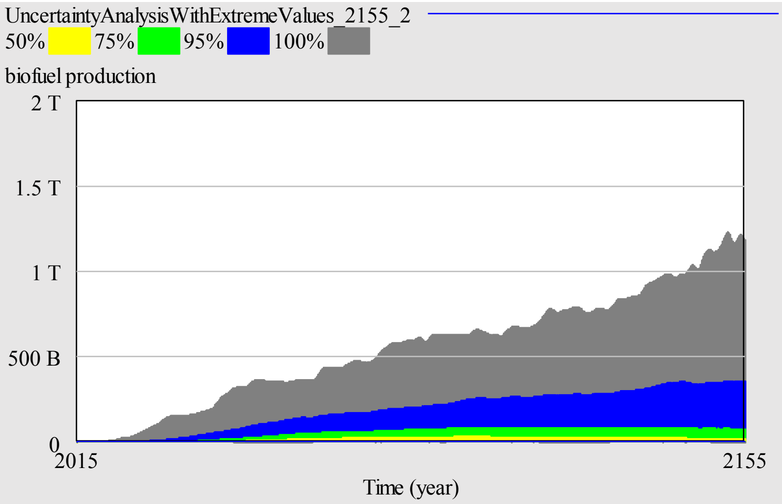
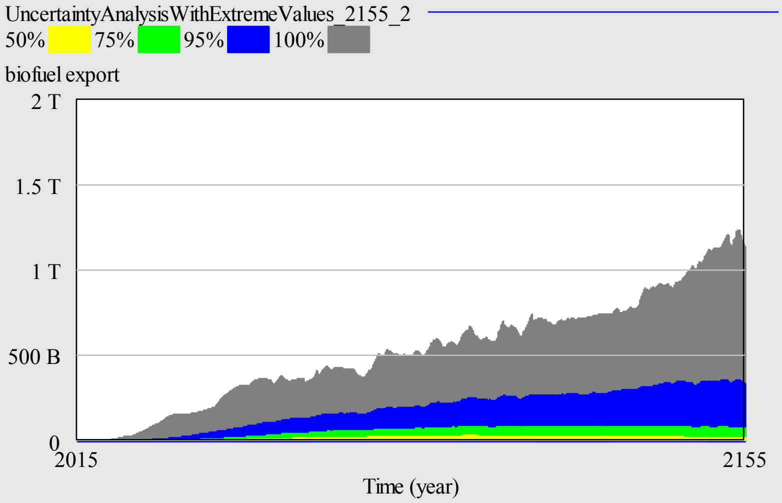
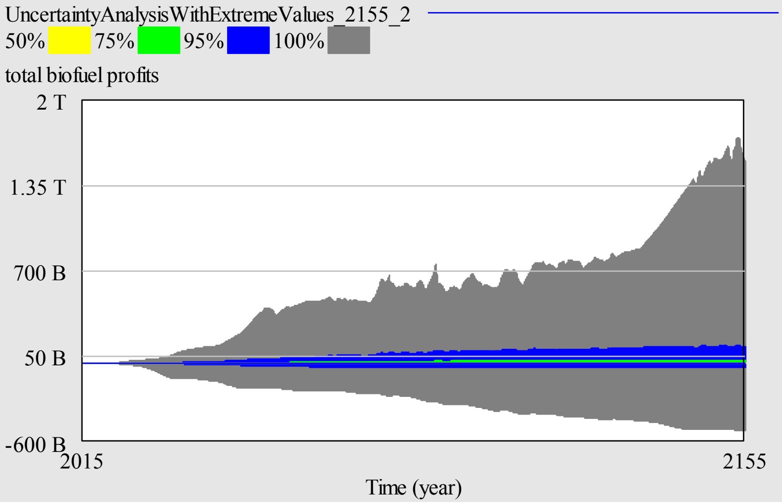
According to the increase in biofuel production, with an increase in the demand for sugarcane, the land under sugar cane cultivation for biofuel purposes also increases.



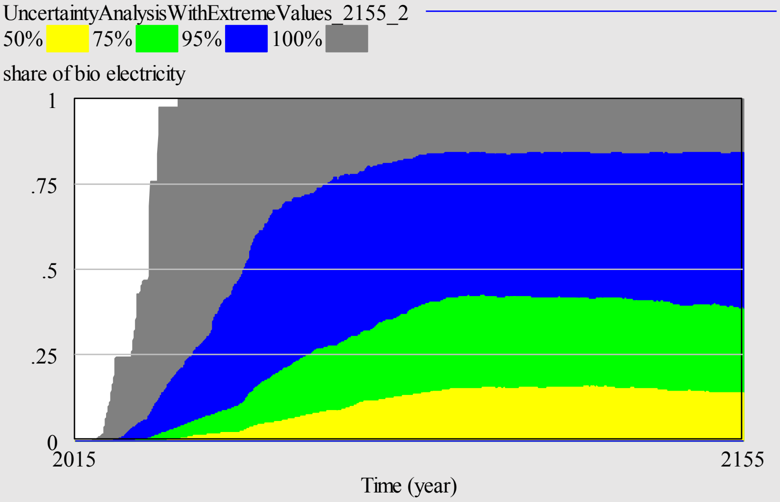
It can be concluded that the KPI's are behaviorally non-sensitive to small changes in parameters. On the other hand they are numerically-sensitive to the small changes in the parameters. The KPI's have wide ranges of numerical differences in the 1000 runs conducted for the SA. The small differences in parameters can thus have significant influence on how a Surinamese biofuel industry will perform. This is taken into account when creating and testing policy and scenarios. A worrying observation is that even with small changes to the base case, which represents a medium development of the biofuel industry comparable to the WSESP project, a negative trend of the EI can be noticed. So policy is required in order to preserve the environment.

Additionally, as part of the validation process, an uncertainty analysis (UA) is conducted in which the whole plausible uncertainty space is considered including extreme values. It is thus a hybrid uncertainty and extreme values test. This test should expose to which extend the model is still useful under extreme values and uncertainty. For the UA 5000 simulation runs are conducted using the Latin Hypercube sampling process with a timespan similar to the SA of 2015-2155. In table 6 an overview is given on the behavior of the KPI's. As is the case with the SA, also in the UA the KPI's are complemented with some other interesting or related model factors. These are displayed in table 7.

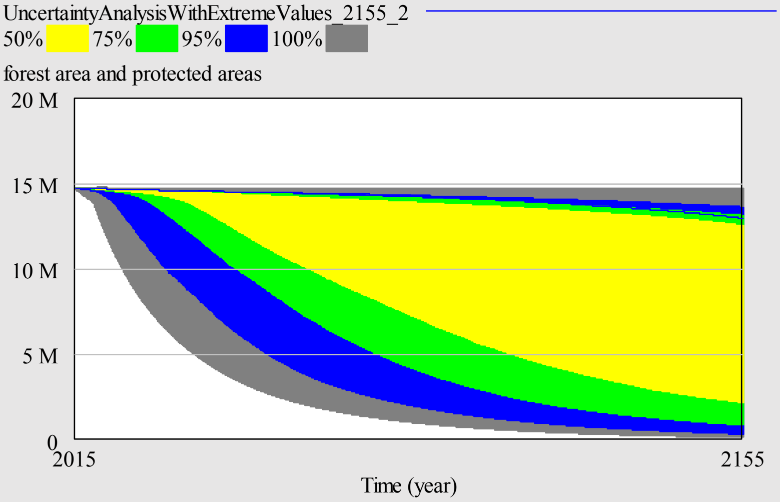
Table 6: Behavior of the KPI's in the UA

The biofuel production shows no irregular behavior, however the numerical differences are immense. This is mainly caused by how the international biofuel demand develops and to what extent Suriname will supply in that demand.	
The same as with the biofuel production can be said for the export. It is clear that that the graphs of the production and the export are show much resemblance.	
The biofuel profits show a striking trend. The inability of the model to handle more than 50% of the world demand, among others, is observable in this graph. Further test suggest that the model can properly handle up to 30% of the international demand, assuming the extreme maximum of an initial demand in 2015 equal to 200 billion liters growing at an average annual rate of 15%.	

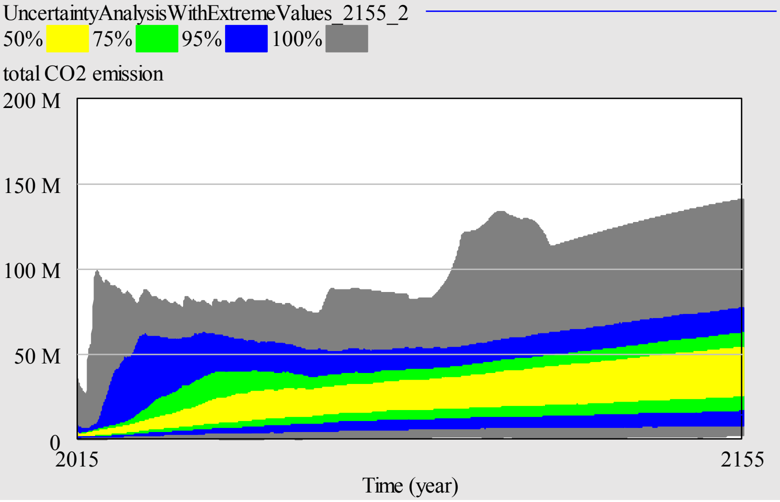
The share of bio-power can vary between 0 and 100%, according to the assumed range of 0 to 1. The share of bio-power can thus substitute the share of petrol and hydro-power completely.



With assumed extreme conditions the decrease in forest area is very striking. The forest area can, in the worst case, drop at an intense rate; all the way to 0 hectares in 2155. In the worst case very high deforestation rates of up to 10% per year and an extremely low deforestation time is assumed. This in order to free up land for the maximum assumed biofuel production and the required sugar cane.



The elimination of CO_2 emissions through biofuel in the transport and bio-power can be turned into an increasing emission trend, caused by the extreme deforestation emitting the trapped CO_2. The eyed sustainability objectives for the biofuel industry, in particular in terms of CO_2 emissions, can thus be entirely eliminated if policy is not protecting the forest.



A biofuel industry getting out of hand in terms of scale and the associated land use changes, especially in terms of deforestation can lead to abrupt decrease of the EI. Other causes are the land degradation due to intensive agriculture and the intensive use of irrigation water. However, the graph also shows that the EI can be maintained at more acceptable levels. It is critical to align policy with the goal to maintain the environment and not get carried away by the success of the biofuel industry.

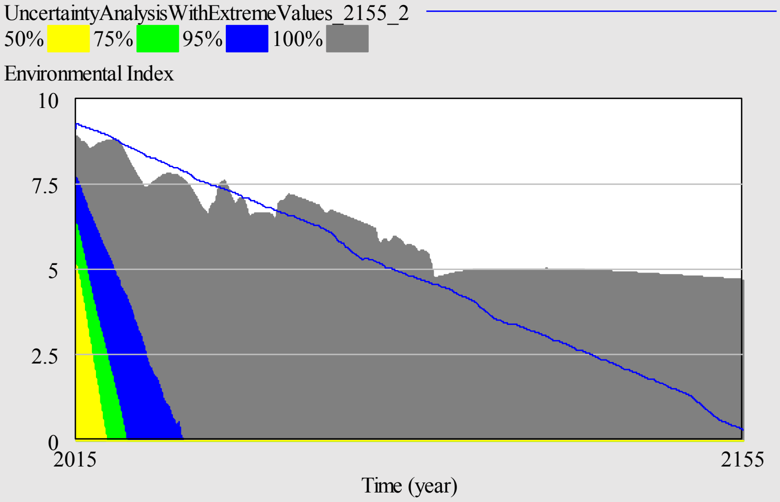
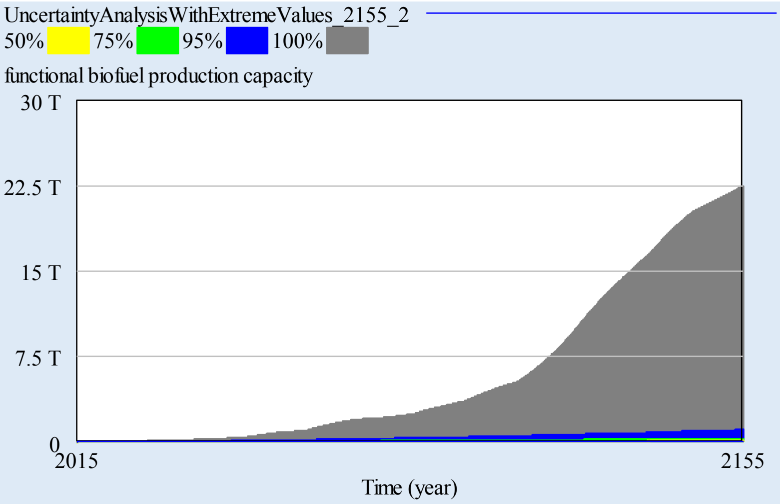
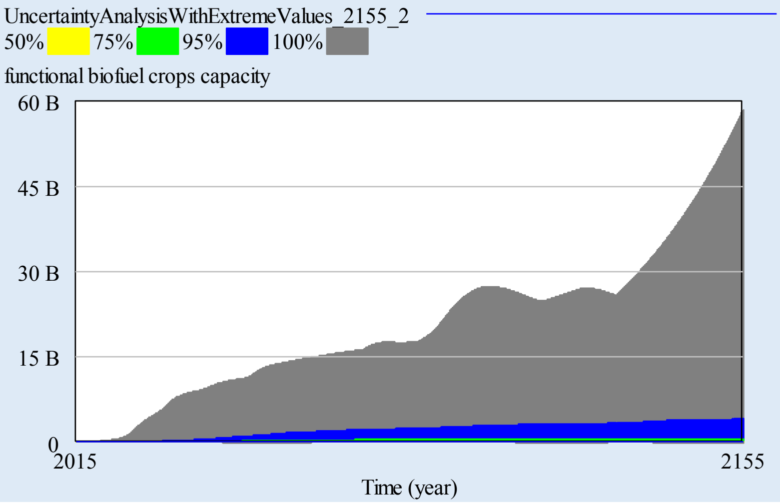


Table 7: Some other interesting model factors in the UA

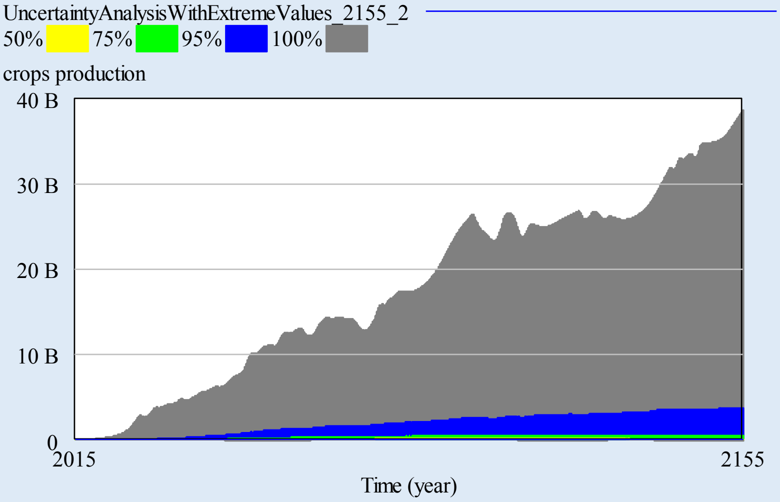
An inexplicable strong increase in the biofuel production capacity occurs when the model is exposed to a far too high demand, as assumed in the extreme maximum. The maximum biofuel production resulting from the UA is only 1.5 trillion liters. The maximum capacity of 22.5 trillion liters, would imply a capacity utilization of only 6%.



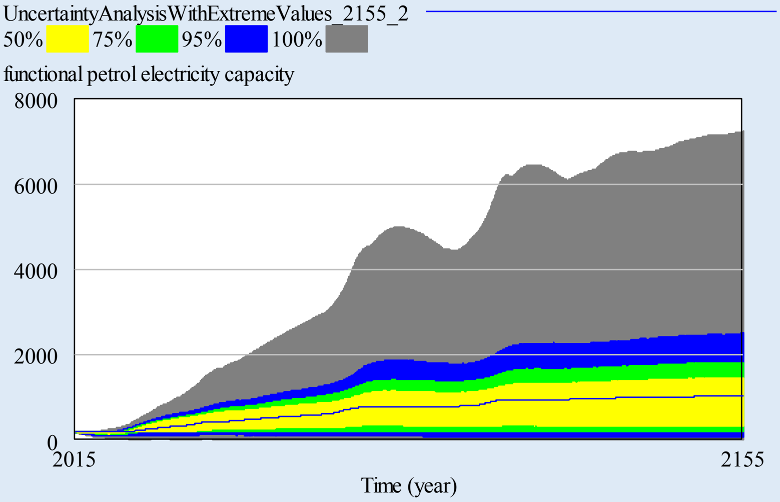
The same as for the production capacity holds for the crops capacity.



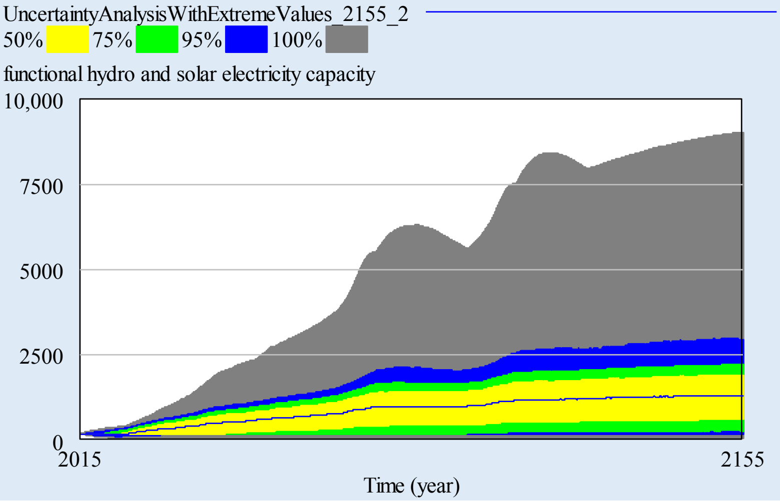
Also the crops production can get immensely high is 5% of the 5000 runs.



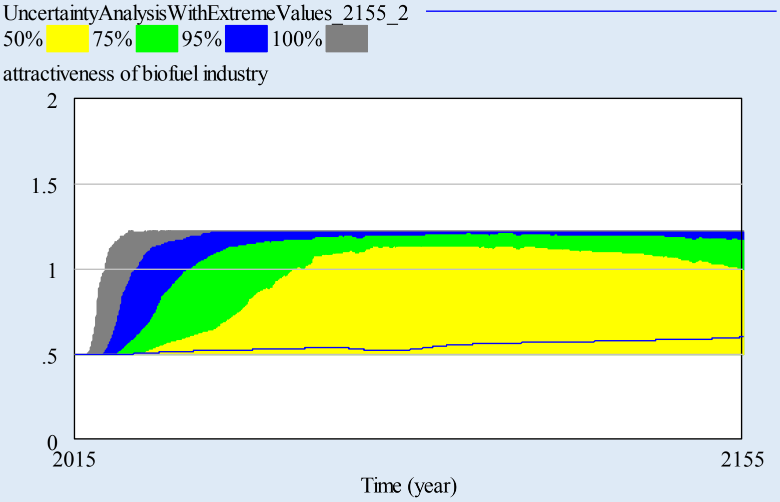
The maximum petrol capacity of about 7000MW, indicate scenarios where the Surinamese power generation will primarily be based on petrol.
Combinations of various power generation types, with petrol having a less dominating role, are however very likely in 95% of the 5000 runs.



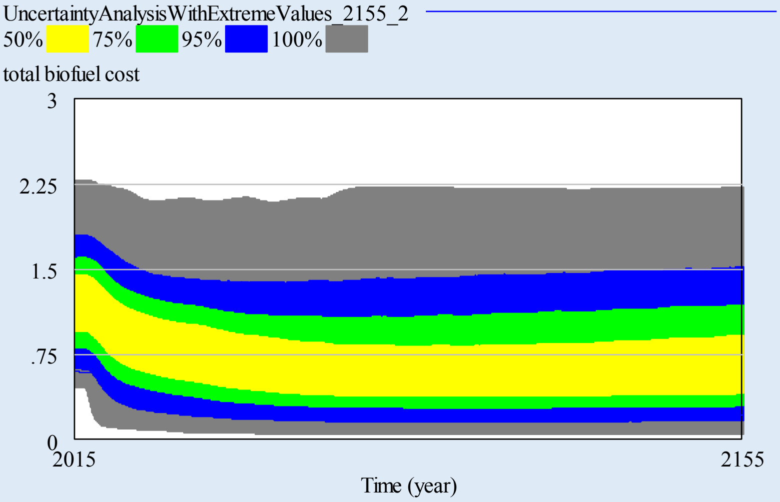
The maximum hydro capacity of about 9000 MW, implies that the Surinamese power generation will almost completely be based on hydro-power.
Combinations of various power generation types, with hydro-power having a less dominating role, are however very likely in 95% of the 5000 runs.



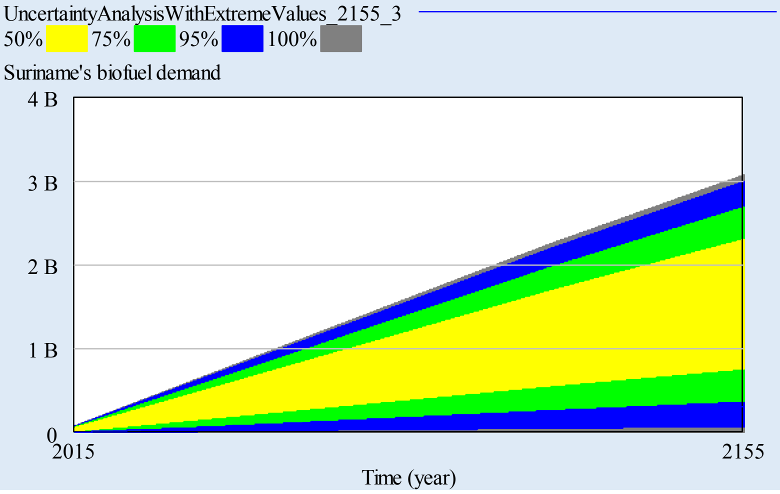
The attractiveness of the biofuel industry can be very high attracting foreign investments, especially in the case the forest and environment is not protected by government policy and legislation. Also government incentives in the biofuel industry, directly influence the attractiveness.



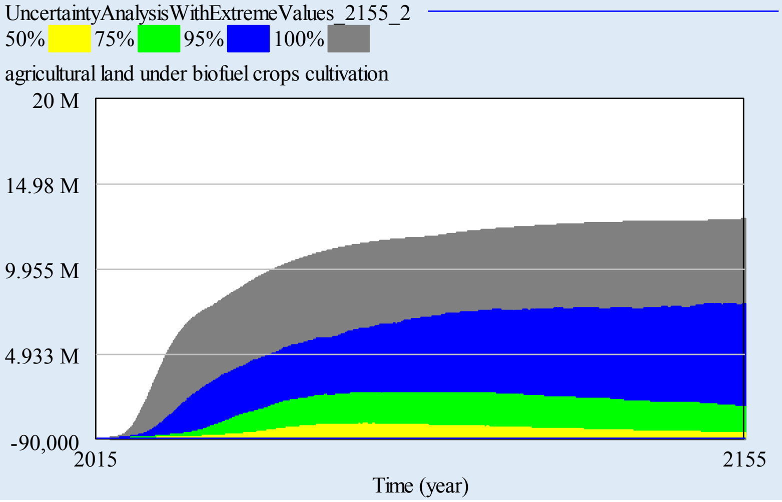
The biofuel cost has very large uncertainty regarding the numerical value, when considering the entire dimension of possibilities for the factors determining the biofuel costs.



Also the Surinamese biofuel demand has large uncertainty. This is primarily driven by the governmental biofuel blending obligations and the incentives leading to more flex-fuel vehicles and E100-E85 demand.

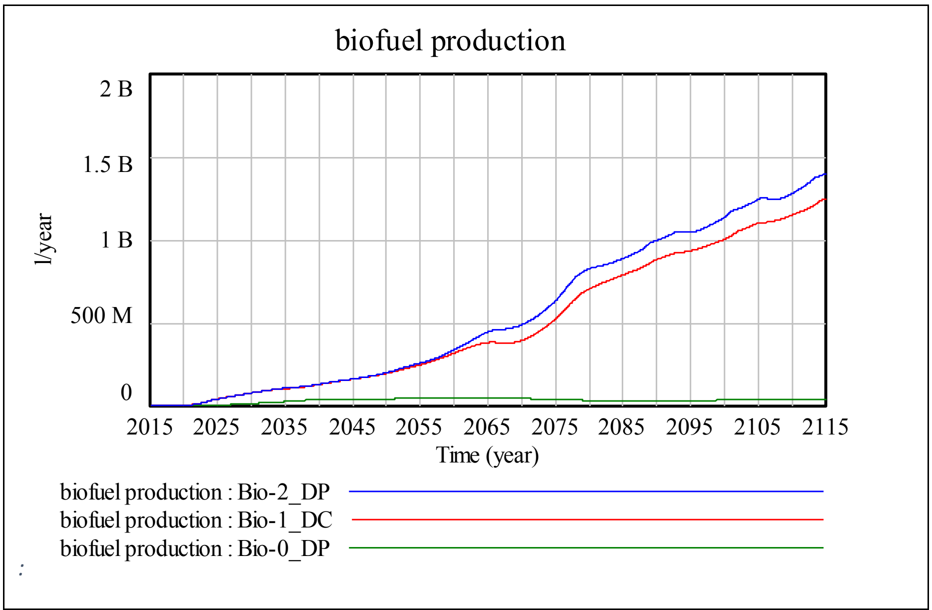


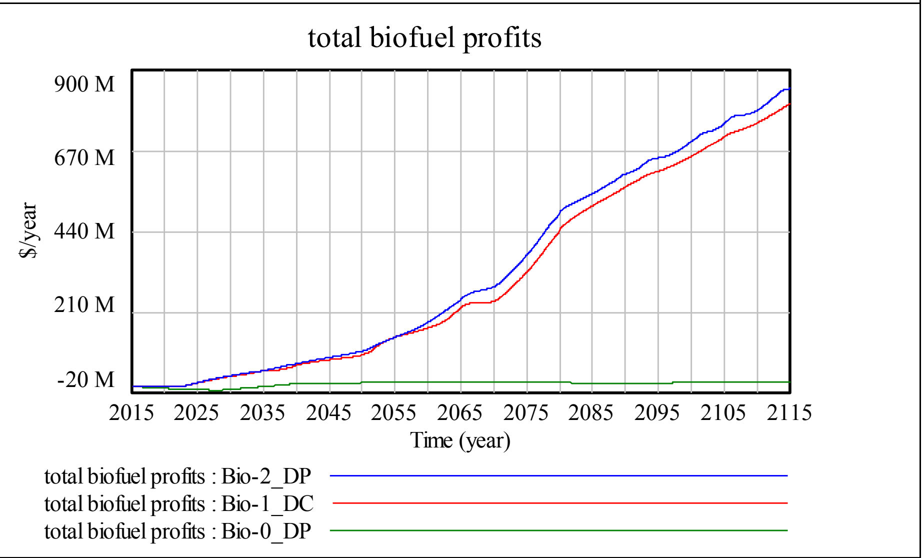
According to the biofuel demand and the extent to which the Surinamese industry is supplying demand, the land under sugar cane cultivation can also largely vary. In the most extreme situation, the land covered under sugar cane cultivation is almost equal to the current forest covered area.

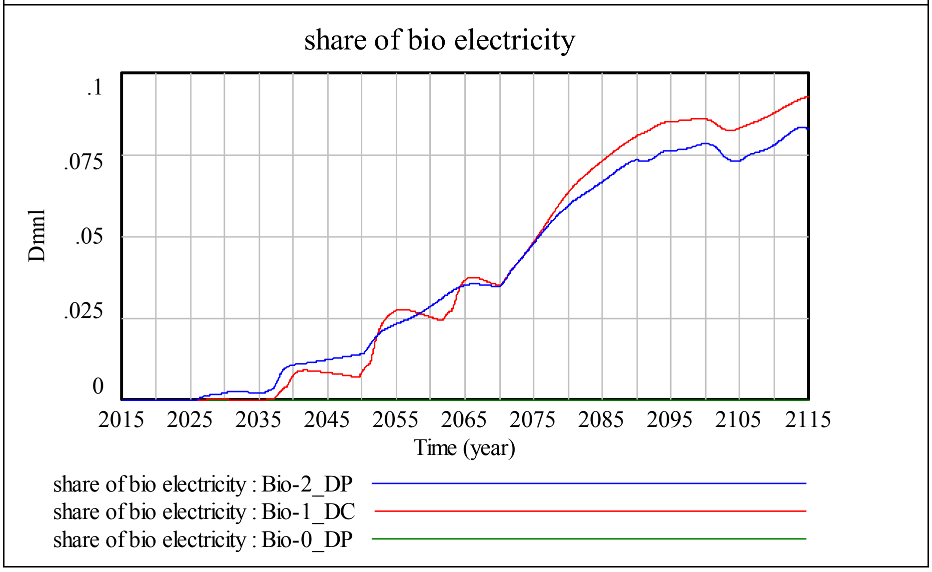


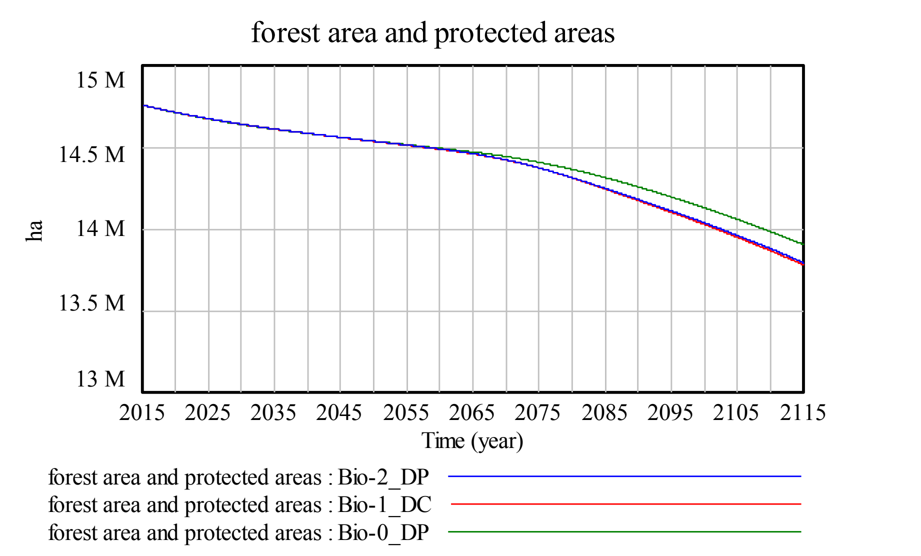
Appendix E. KPI graphs for Policy Scenario Analysis

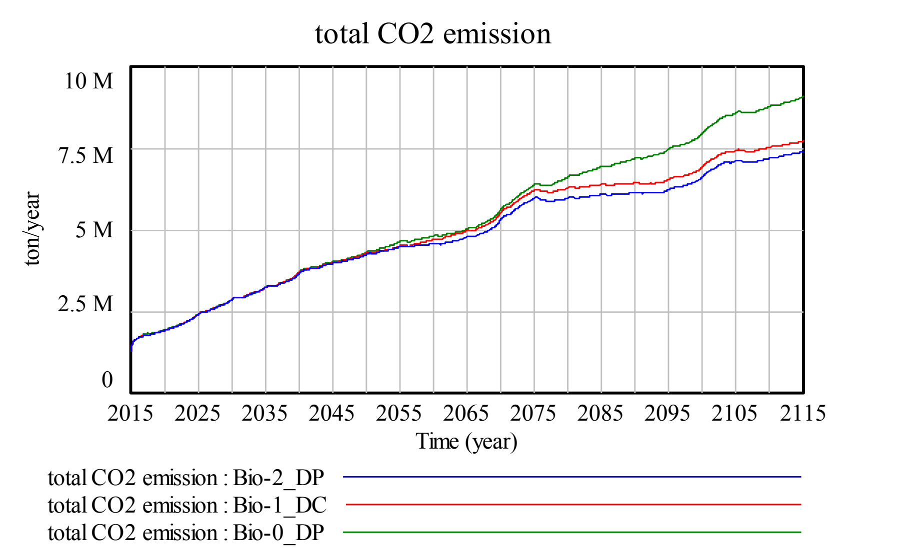
Table 8: the graphs for the KPI's when implementing DP under all three scenarios individually








forest area and protected areas
15 M
14.5 M
14 M
13.5 M
13 M
ha
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
forest area and protected areas : Bio-2_DP
forest area and protected areas : Bio-1_DC
forest area and protected areas : Bio-0_DP


total CO2 emission
10 M
7.5 M
5 M
2.5 M
0
ton/year
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
total CO2 emission : Bio-2_DP
total CO2 emission : Bio-1_DC
total CO2 emission : Bio-0_DP

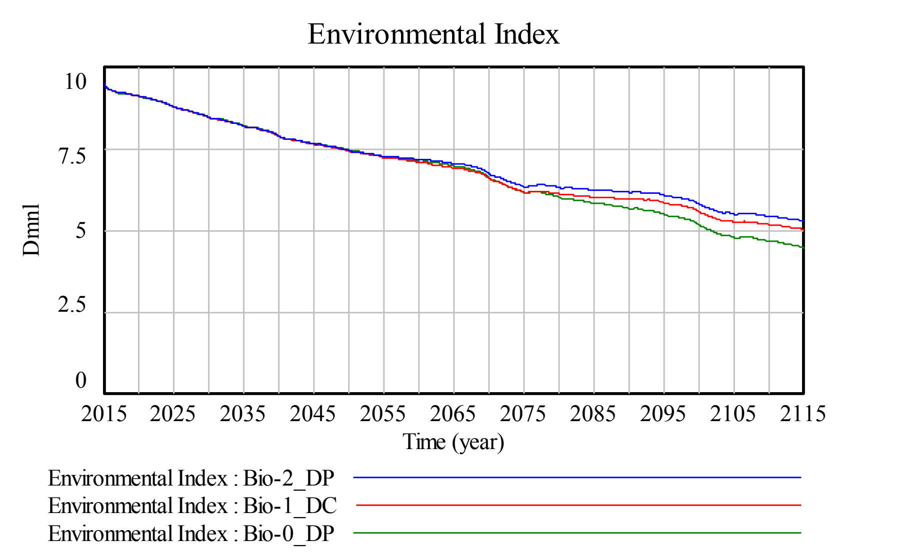
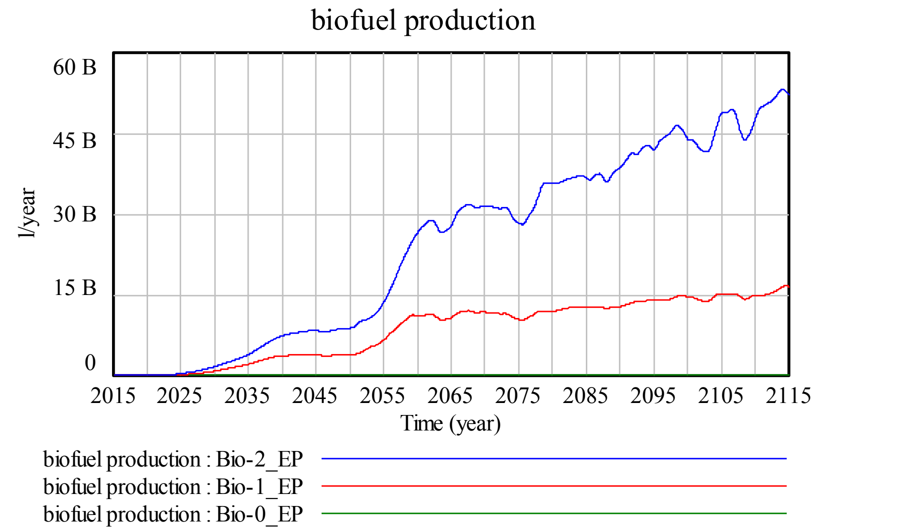
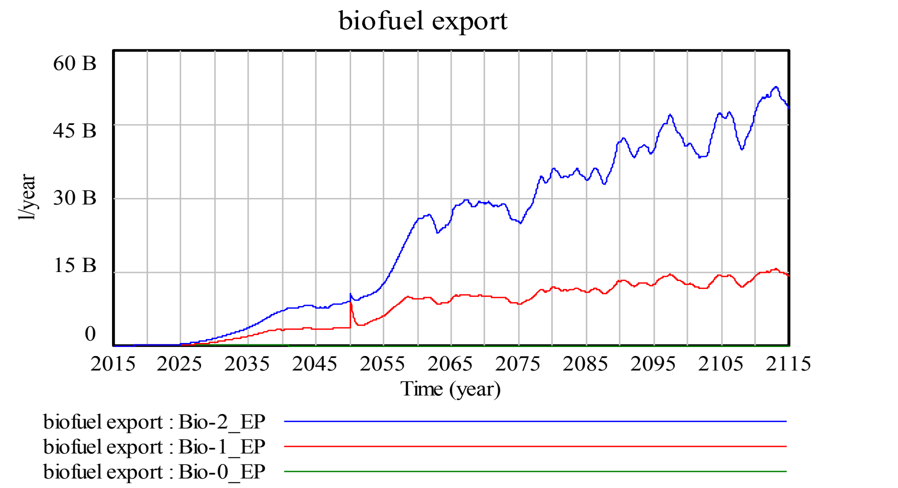
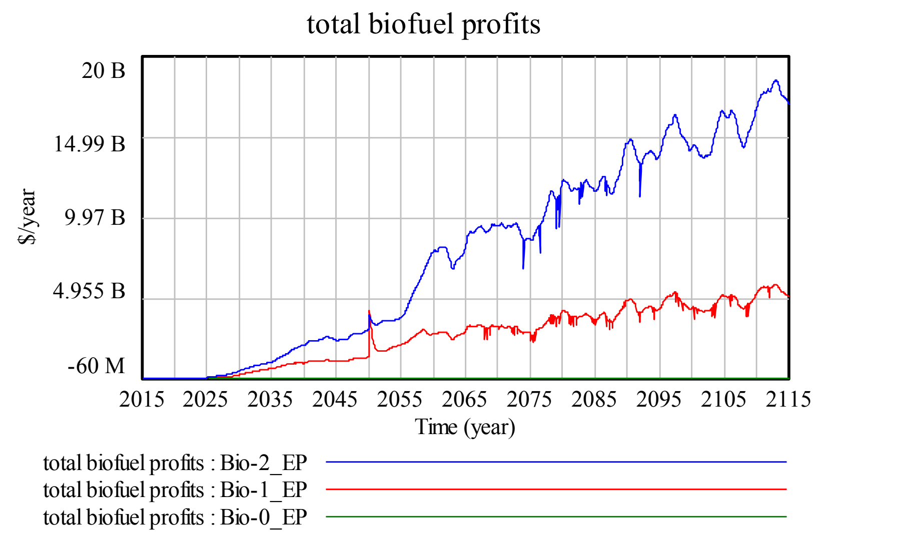
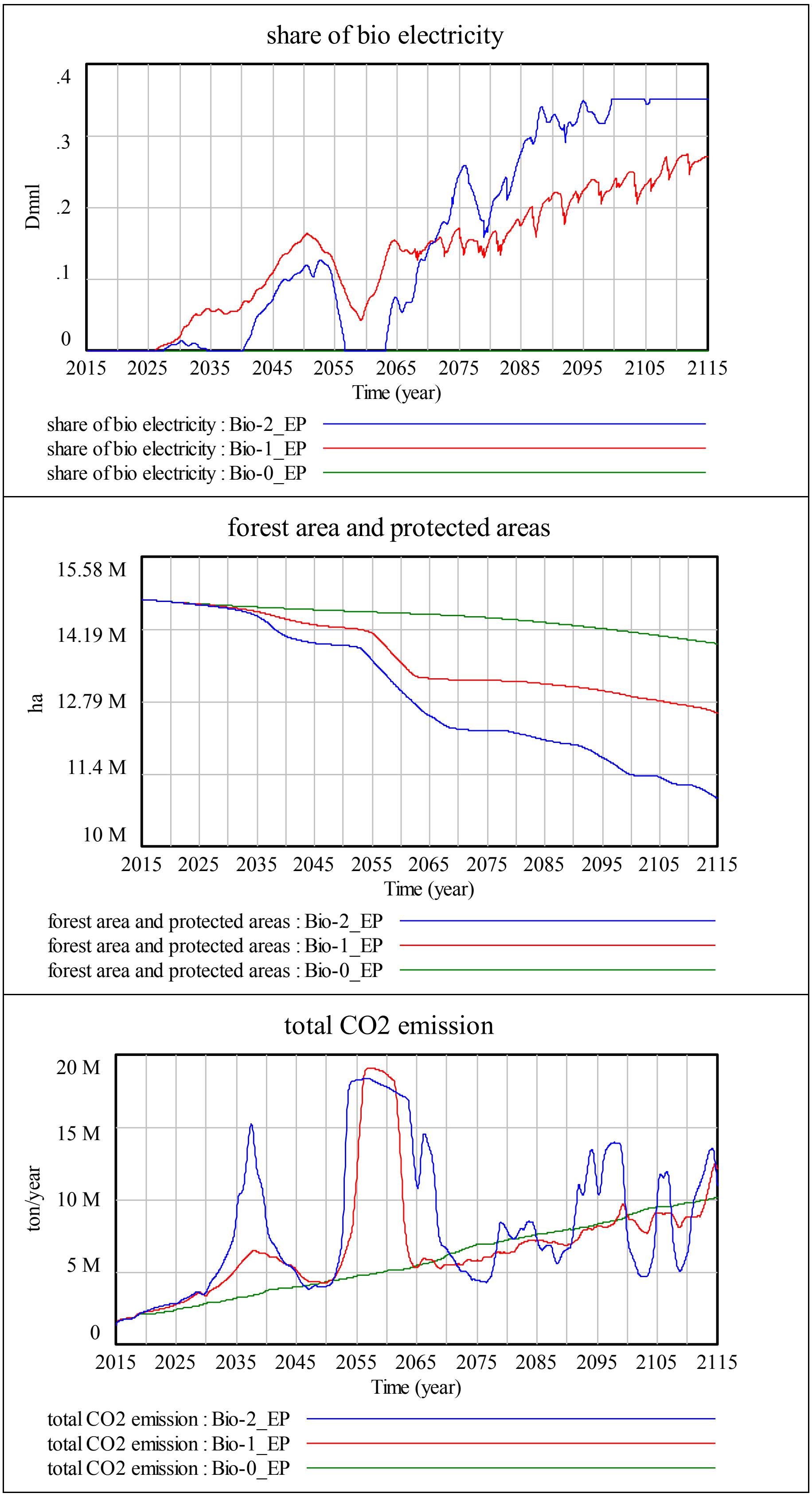

Environmental Index
10
7.5
5
2.5
0
Dmnl
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
Environmental Index : Bio-2_DP
Environmental Index : Bio-1_DC
Environmental Index : Bio-0_DP

Table 9: the graphs for the KPI's when implementing EP under all three scenarios individually








share of bio electricity
Dmnl
.4
.3
.2
.1
0
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
share of bio electricity : Bio-2_EP
share of bio electricity : Bio-1_EP
share of bio electricity : Bio-0_EP
forest area and protected areas
ha
15.58 M
14.19 M
12.79 M
11.4 M
10 M
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
forest area and protected areas : Bio-2_EP
forest area and protected areas : Bio-1_EP
forest area and protected areas : Bio-0_EP
total CO2 emission
ton/year
20 M
15 M
10 M
5 M
0
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
total CO2 emission : Bio-2_EP
total CO2 emission : Bio-1_EP
total CO2 emission : Bio-0_EP

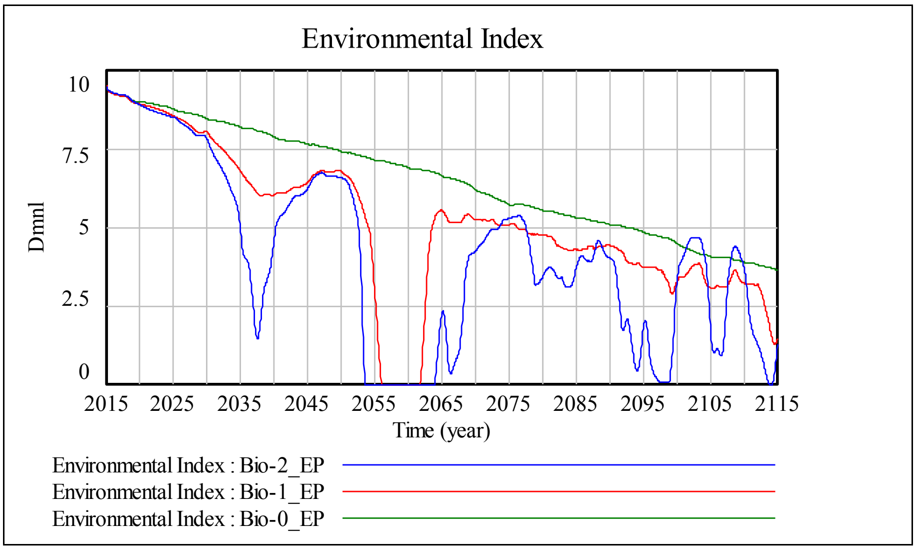
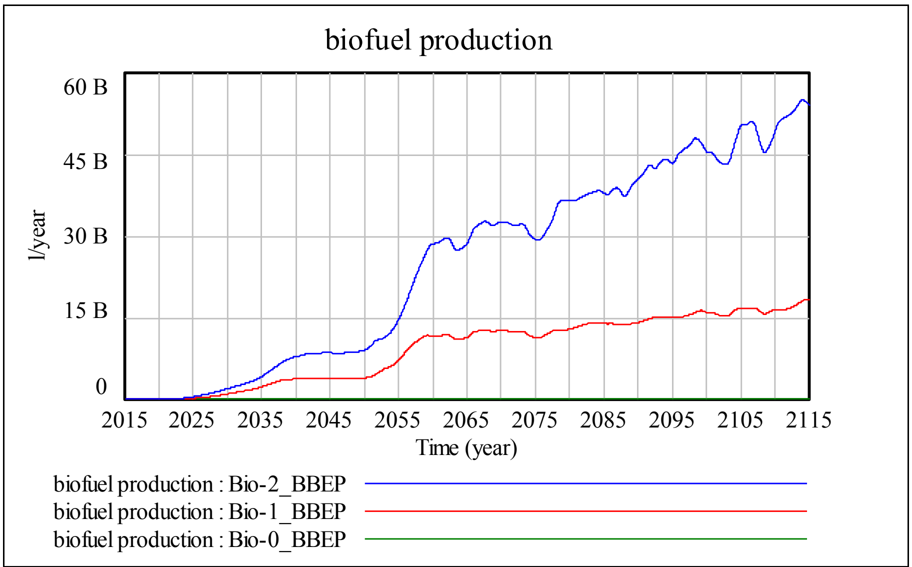
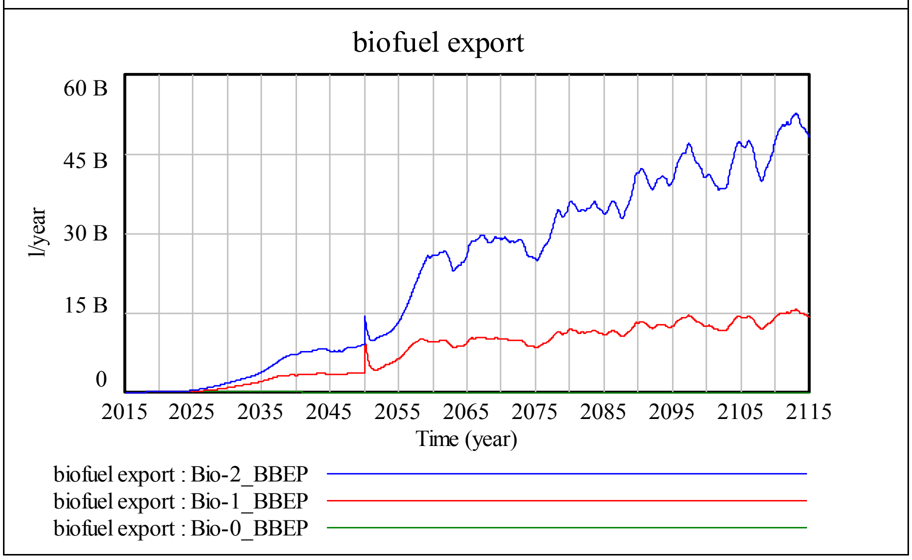
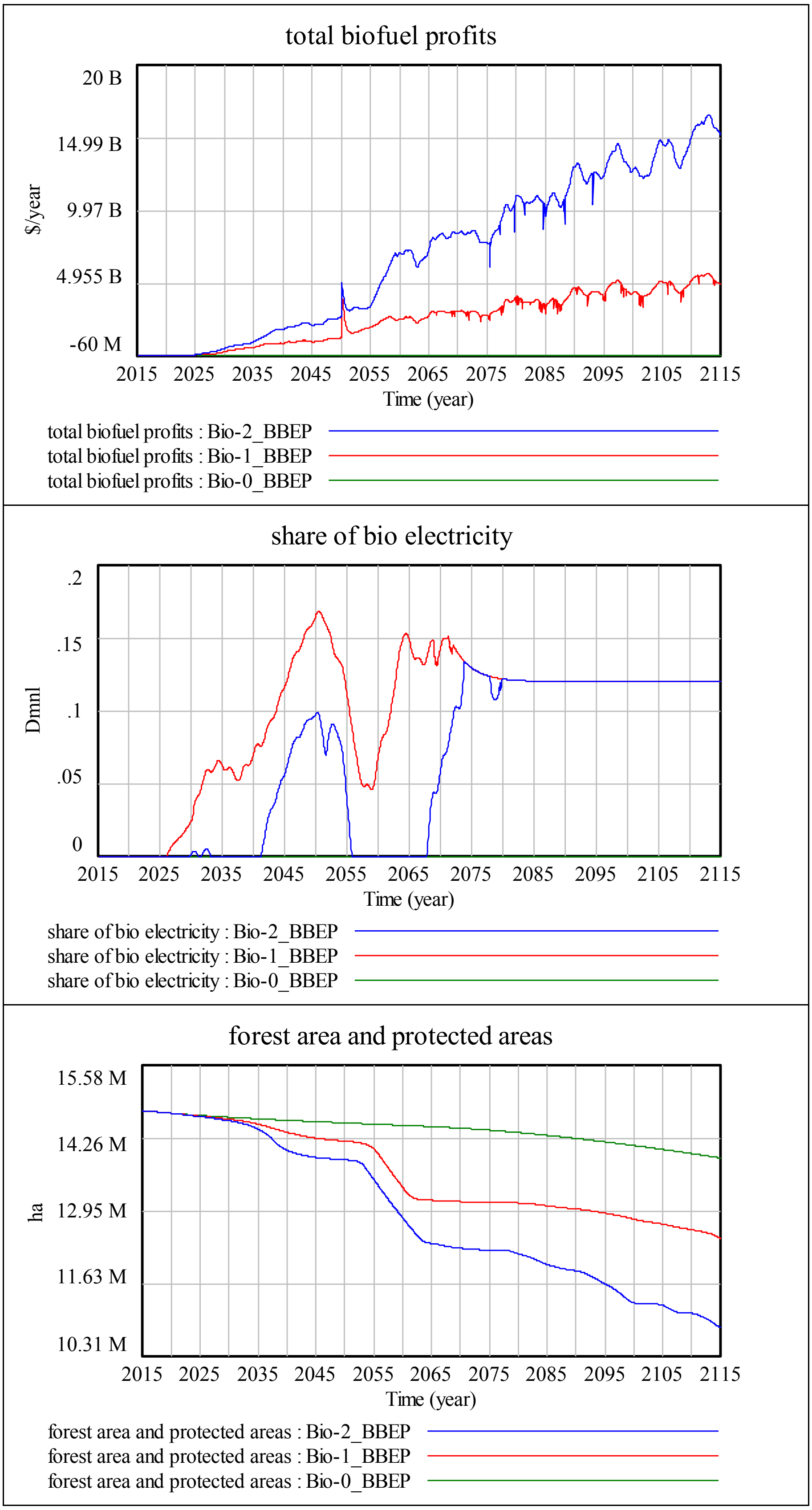


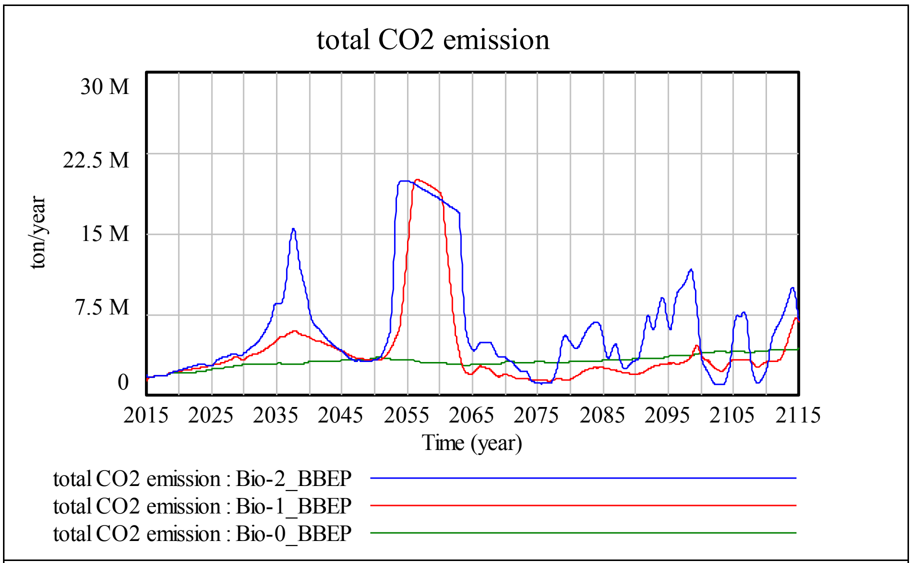
Table 10: the graphs for the KPI's when implementing BBEP under all three scenarios individually







total biofuel profits
20 B
14.99 B
9.97 B
4.955 B
-60 M
$/year
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
total biofuel profits : Bio-2_BBEP
total biofuel profits : Bio-1_BBEP
total biofuel profits : Bio-0_BBEP
share of bio electricity
.2
.15
.1
.05
0
Dmnl
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
share of bio electricity : Bio-2_BBEP
share of bio electricity : Bio-1_BBEP
share of bio electricity : Bio-0_BBEP
forest area and protected areas
15.58 M
14.26 M
12.95 M
11.63 M
10.31 M
ha
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
forest area and protected areas : Bio-2_BBEP
forest area and protected areas : Bio-1_BBEP
forest area and protected areas : Bio-0_BBEP


total CO2 emission
30 M
22.5 M
15 M
7.5 M
0
ton/year
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
total CO2 emission : Bio-2_BBEP
total CO2 emission : Bio-1_BBEP
total CO2 emission : Bio-0_BBEP

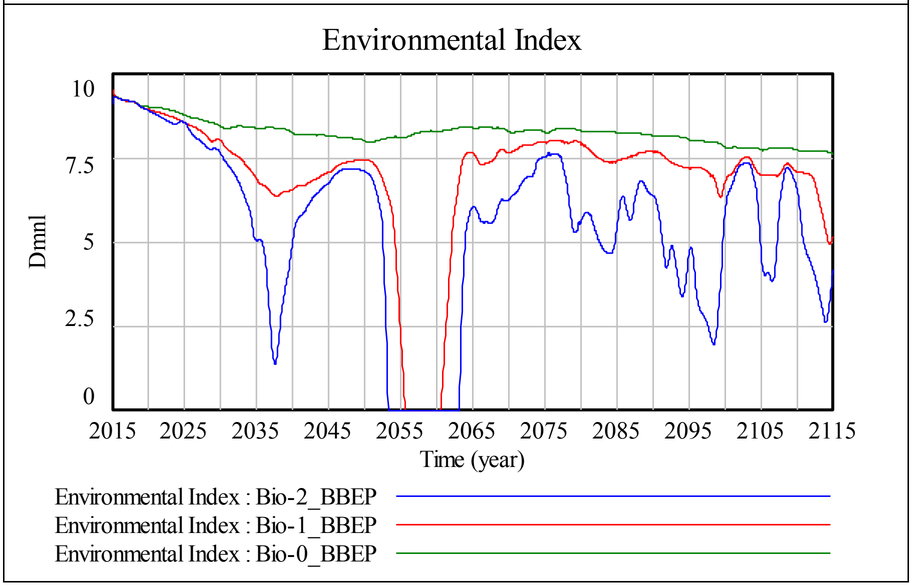
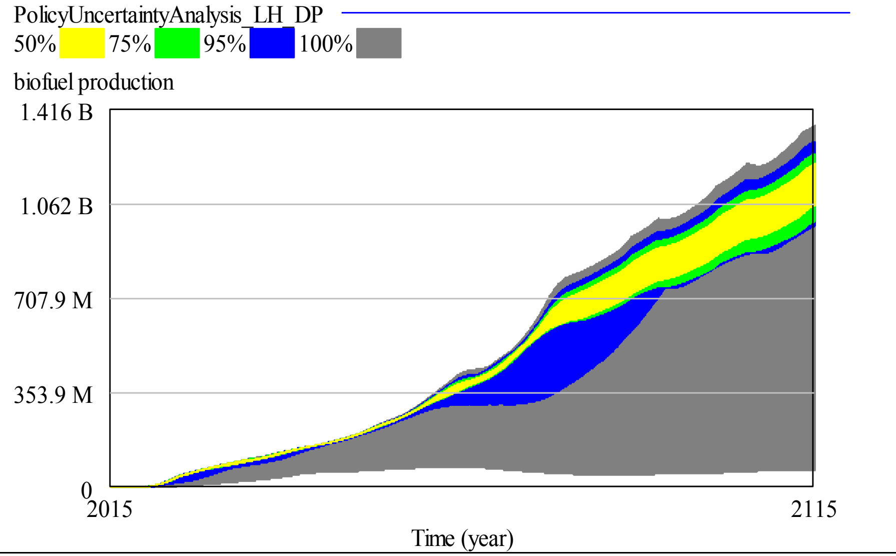
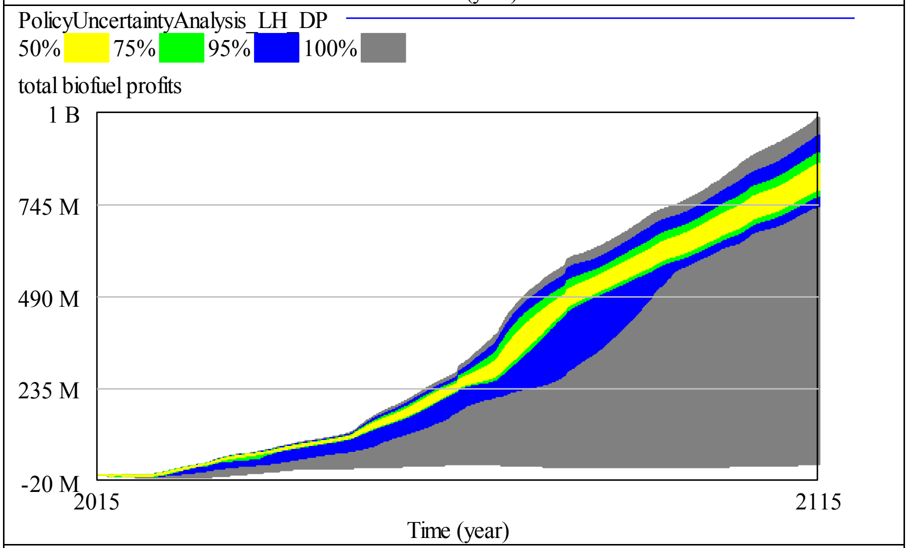
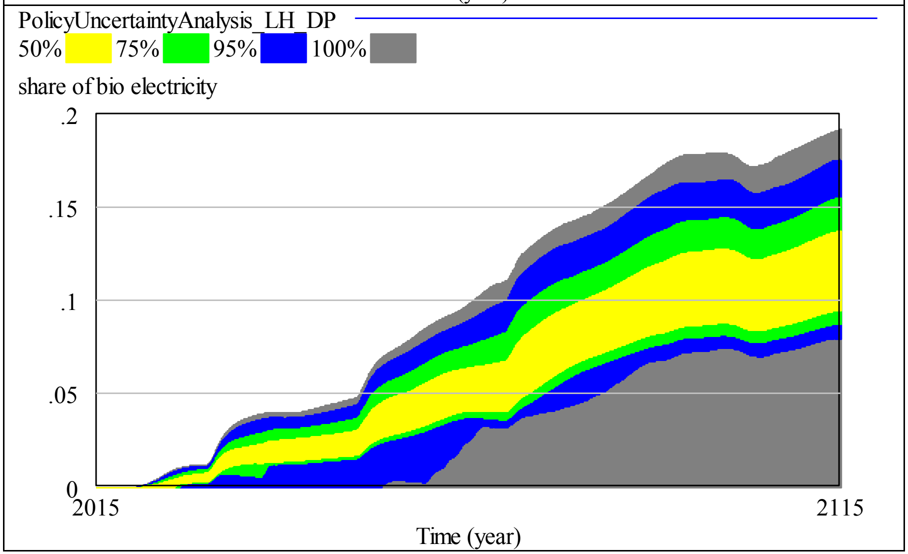

Environmental Index
10
7.5
5
2.5
0
Dmnl
2015 2025 2035 2045 2055 2065 2075 2085 2095 2105 2115
Time (year)
Environmental Index : Bio-2_BBEP
Environmental Index : Bio-1_BBEP
Environmental Index : Bio-0_BBEP

Table 11: Policy Scenario Analysis graphs of the KPI's for DP







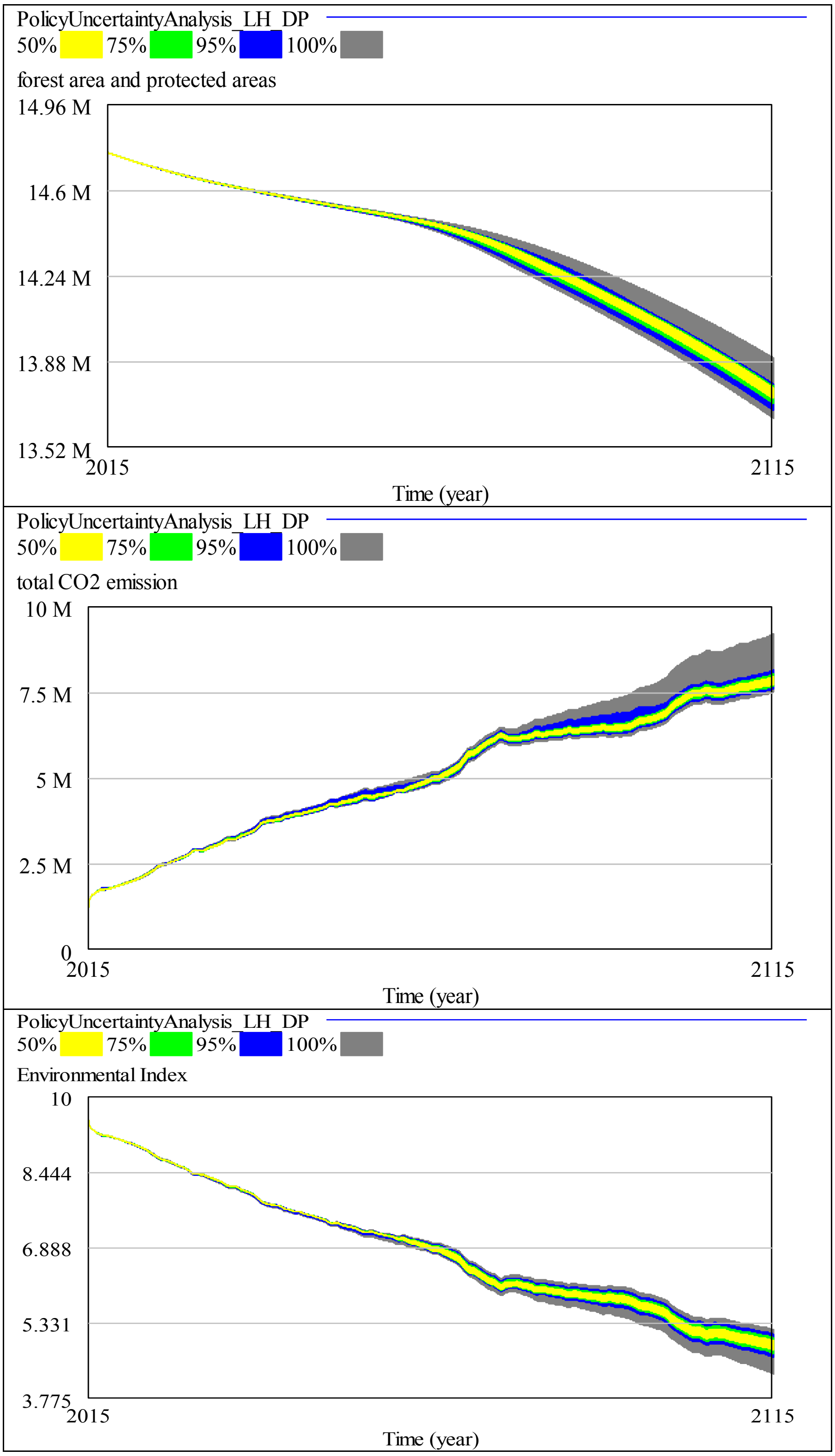
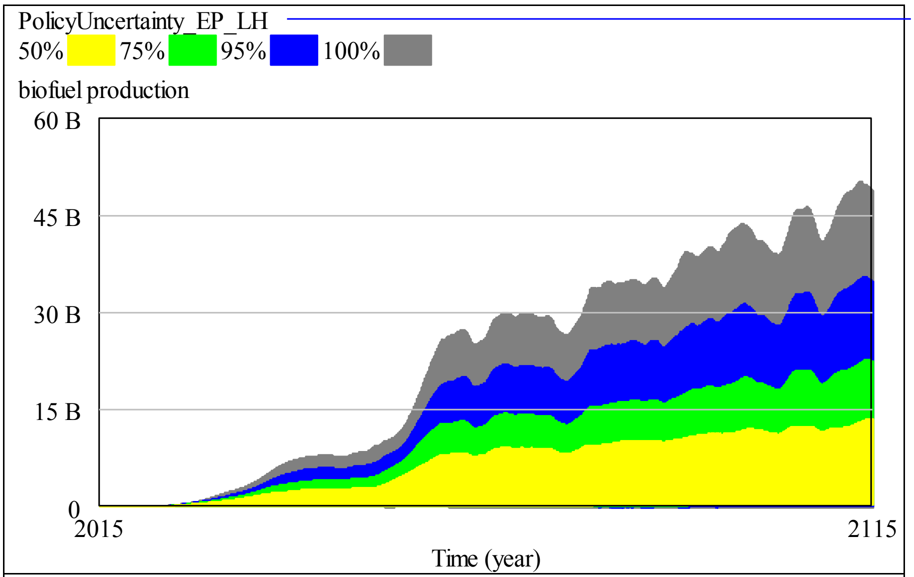
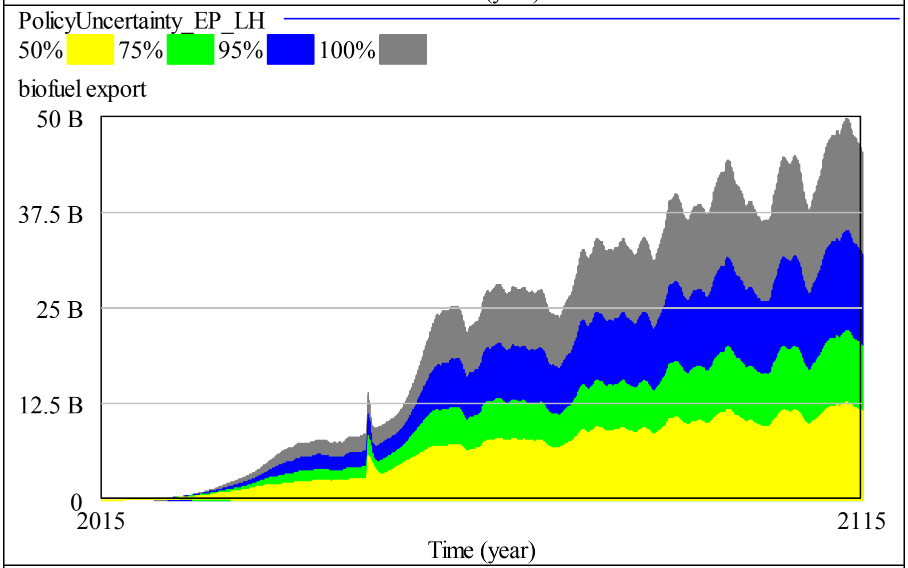
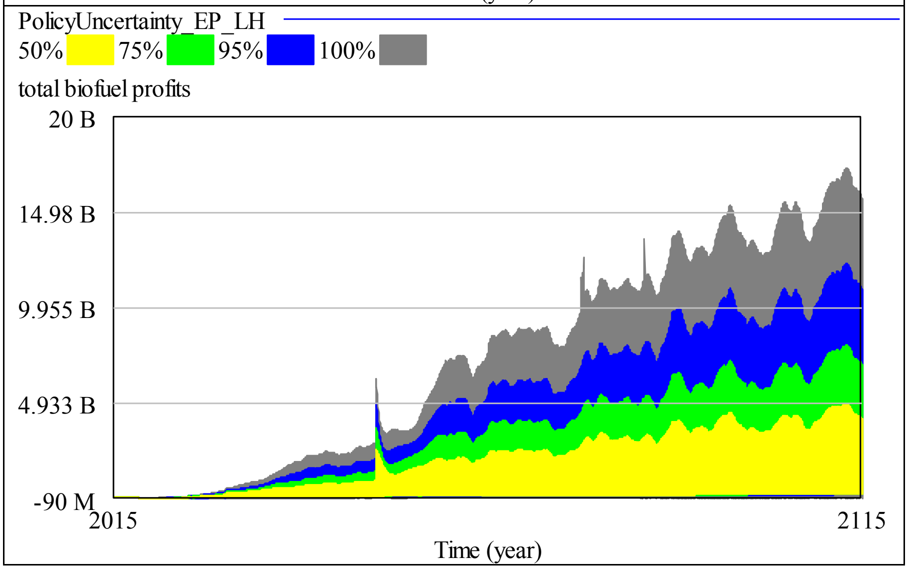
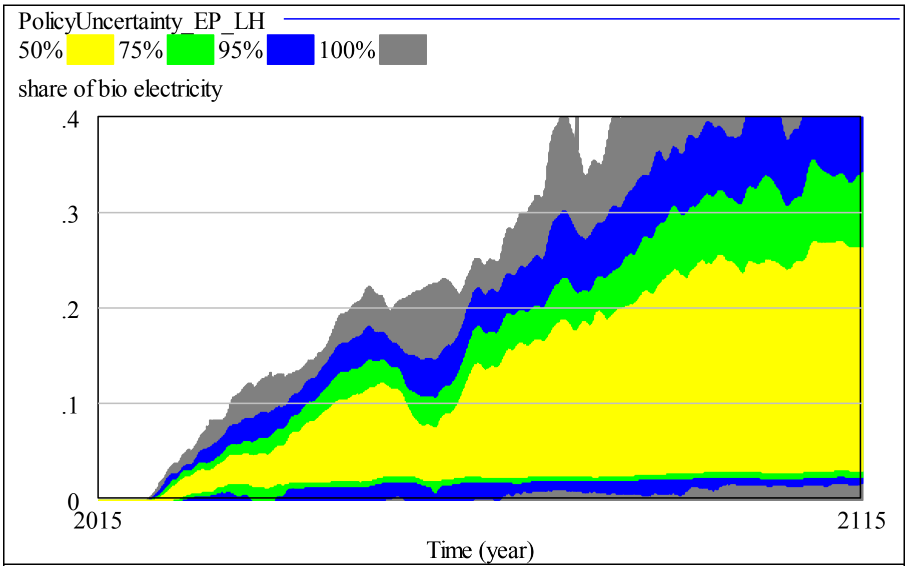

PolicyUncertaintyAnalysis_LH_DP
50% 75% 95% 100%
forest area and protected areas
14.96 M
14.6 M
14.24 M
13.88 M
13.52 M
2015
2115
Time (year)
PolicyUncertaintyAnalysis_LH_DP
50% 75% 95% 100%
total CO2 emission
10 M
7.5 M
5 M
2.5 M
0
2015
2115
Time (year)
PolicyUncertaintyAnalysis_LH_DP
50% 75% 95% 100%
Environmental Index
10
8.444
6.888
5.331
3.775
2015
2115
Time (year)

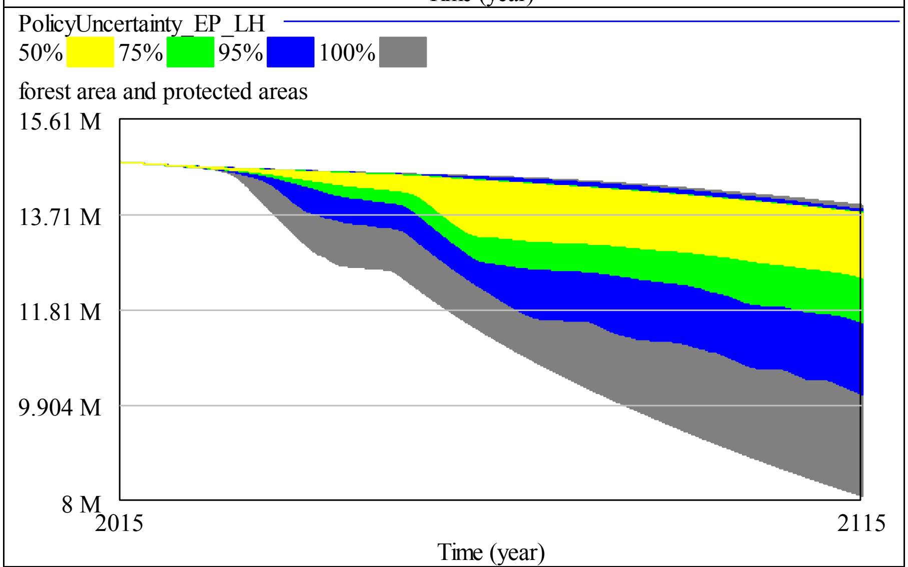
Table 12: Policy Scenario Analysis graphs of the KPI's for EP

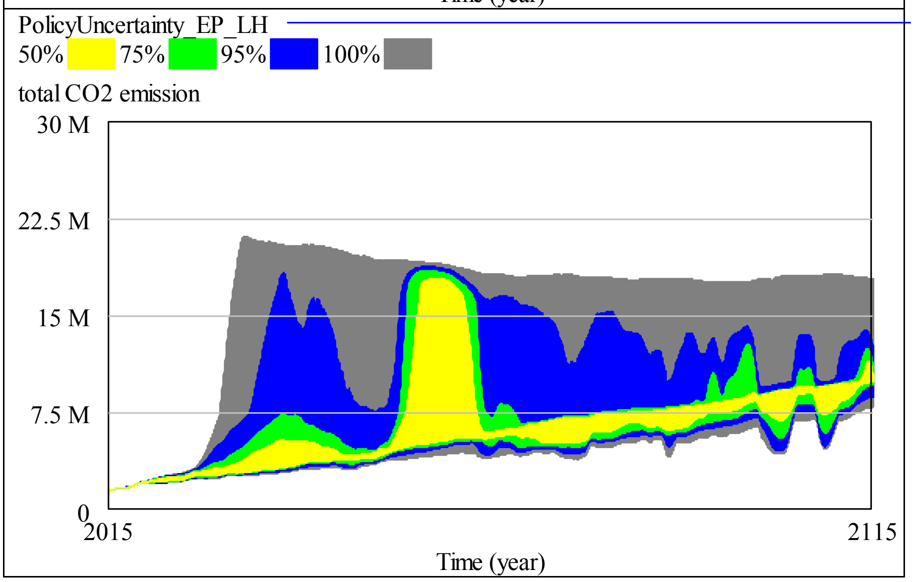







PolicyUncertainty_EP_LH
50% 75% 95% 100%
share of bio electricity
.4
.3
.2
.1
0
2015
2115
Time (year)


PolicyUncertainty_EP_LH
50% 75% 95% 100%
forest area and protected areas
15.61 M
13.71 M
11.81 M
9.904 M
8 M
2015
2115
Time (year)


PolicyUncertainty_EP_LH
50% 75% 95% 100%
total CO2 emission
30 M
22.5 M
15 M
7.5 M
0
2015
2115
Time (year)

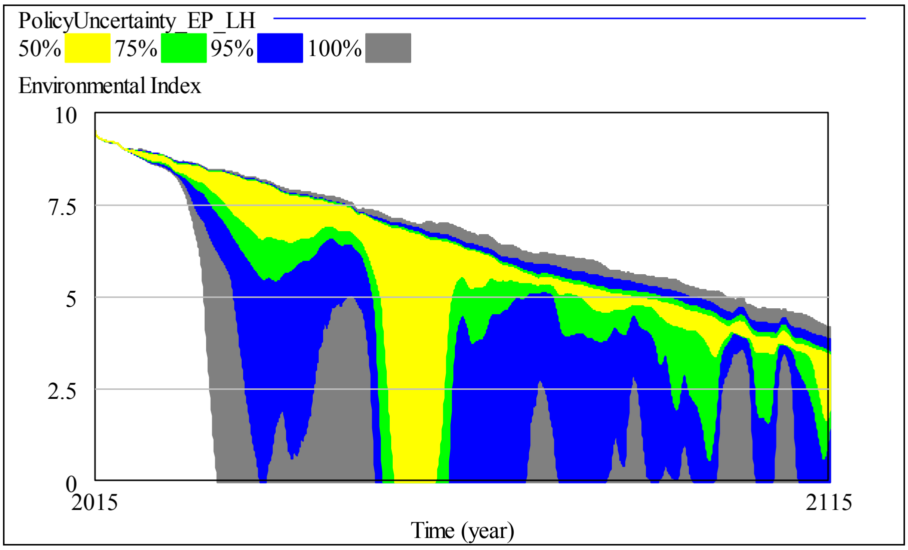
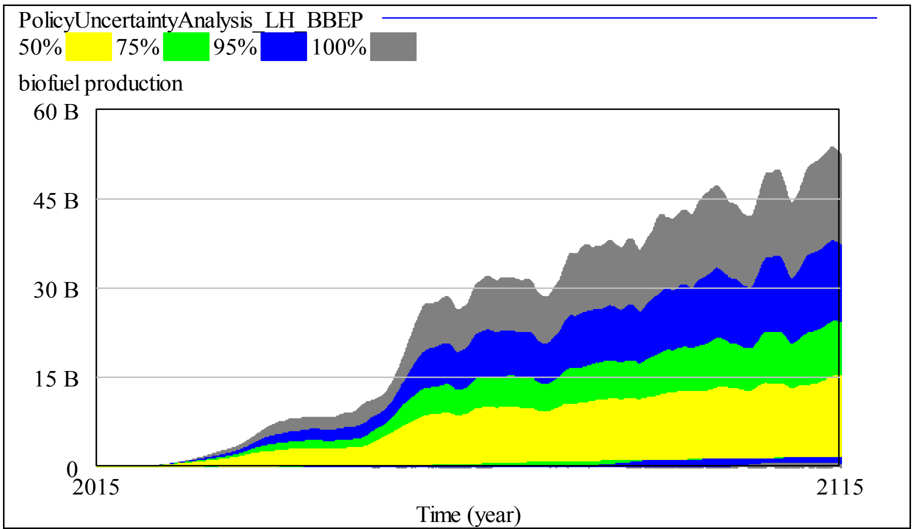
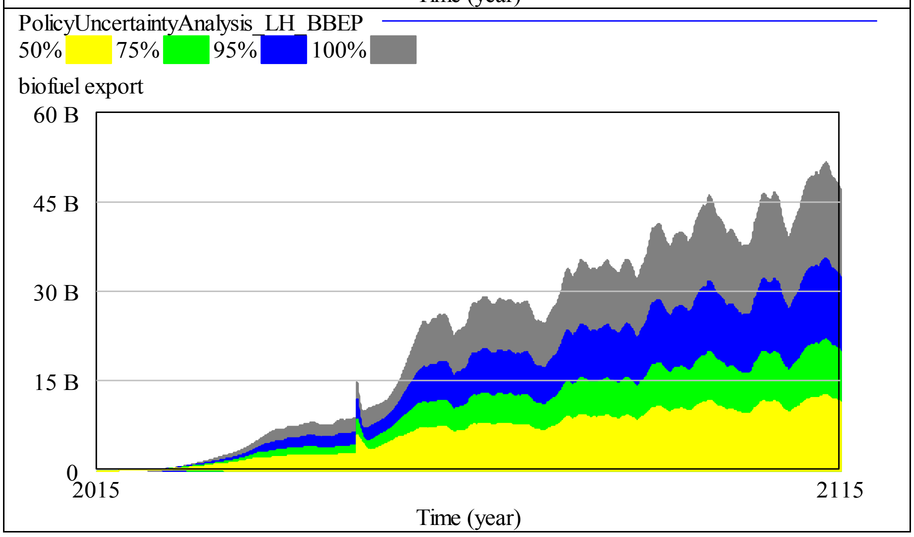
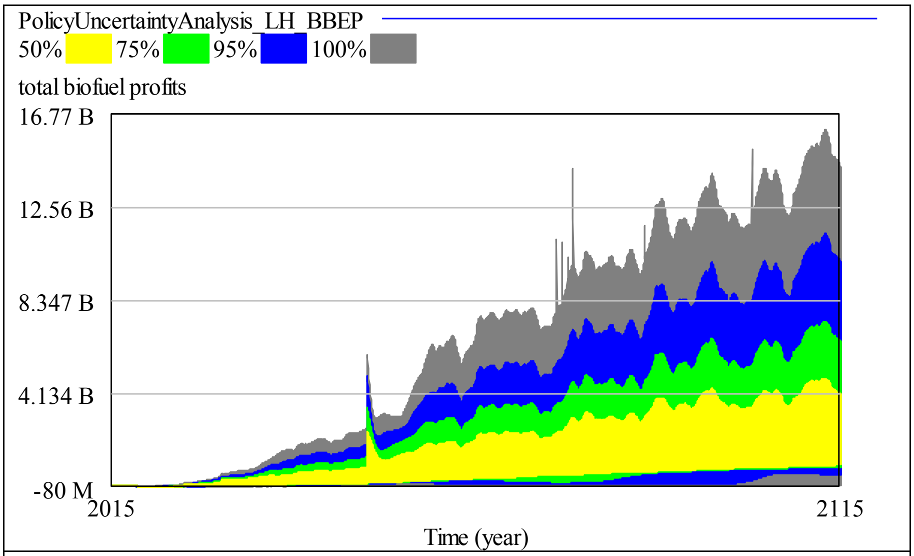
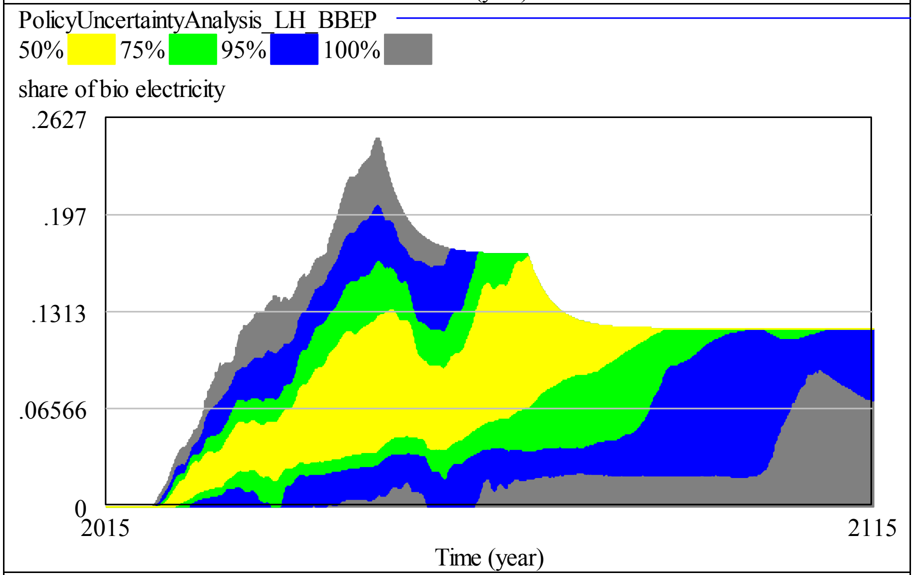


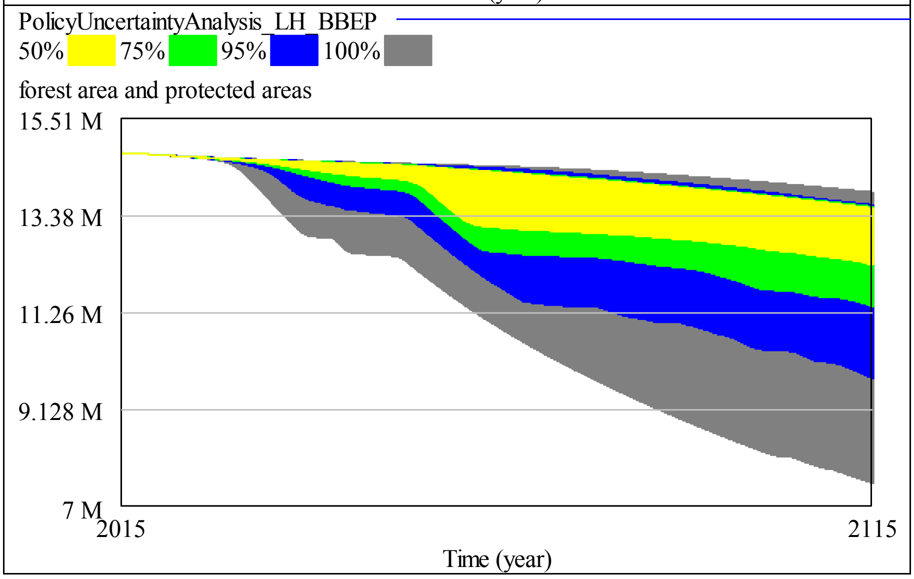
Table 13: Policy Scenario Analysis graphs of the KPI's for BBEP

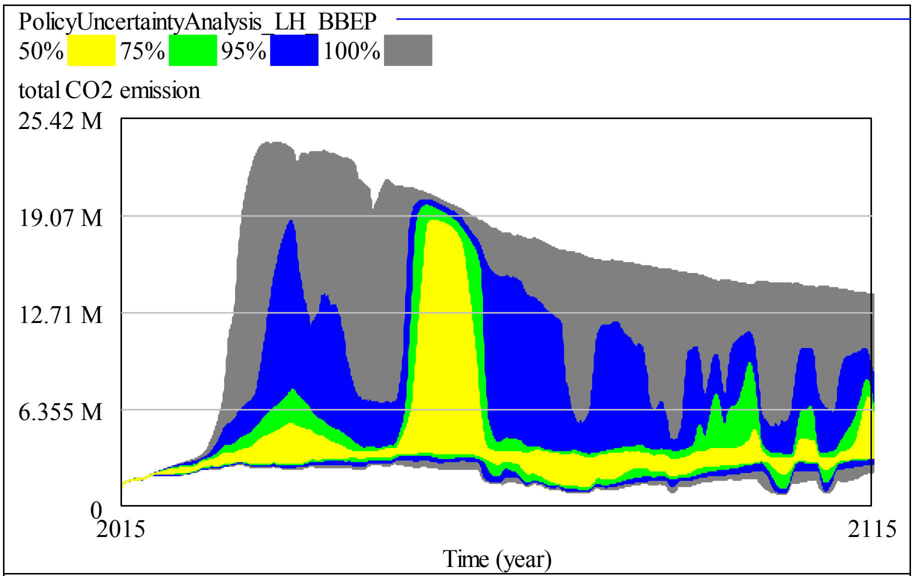


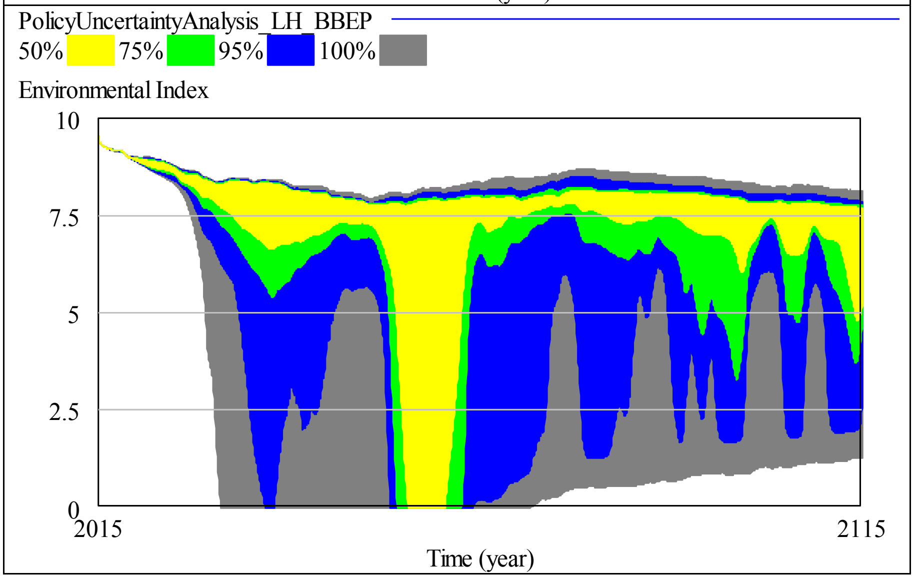



PolicyUncertaintyAnalysis_LH_BBEP
50% 75% 95% 100%
total biofuel profits
16.77 B
12.56 B
8.347 B
4.134 B
-80 M
2015
2115
Time (year)


PolicyUncertaintyAnalysis_LH_BBEP
50% 75% 95% 100%
share of bio electricity
.2627
.197
.1313
.06566
0
2015
2115
Time (year)


PolicyUncertaintyAnalysis_LH_BBEP
50% 75% 95% 100%
forest area and protected areas
15.51 M
13.38 M
11.26 M
9.128 M
7 M
2015
2115
Time (year)


PolicyUncertaintyAnalysis_LH_BBEP
50%
75%
95%
100%
total CO2 emission
25.42 M
19.07 M
12.71 M
6.355 M
0
2015
2115
Time (year)


PolicyUncertaintyAnalysis_LH_BBEP
50%
75%
95%
100%
Environmental Index
10
7.5
5
2.5
0
2015
2115
Time (year)