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

Devin Diran

Delft University of Technology

Address: Michiel de Ruyterweg 484, Delft, The Netherlands

Telephone: (+)31 628983035

e-mail: d.d.d.diran@student.tudelft.nl

June 07, 2016

Abstract

In this study an economic, environmental and economic assessment is conducted on a potential large scale biofuel industry in Suriname, South America, by applying System Dynamics. Suriname faces important energy related questions for the future, this with the eye on the 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. Developing a biofuel industry in Suriname will pay off in the future under the condition that a) sufficient government incentives are implemented as a catalyst in the development of a biofuel industry and market b) the policy not only addresses export, but also establishes a local demand to cope with the uncertainty of the international biofuel market and also to establish local CO_2 reduction and energy security and c) sufficient environmental and forest preservation law is implemented with a strict control mechanism. When taking these measures in developing Surinamese biofuel policy, the negative consequences regarding 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.

Keywords: Bio-fuels, Suriname, Sustainable Energy, System Dynamics, Policy Analysis

1. Introduction

Suriname, a Caribbean country on the South American continent, faces important energy related questions for its future. Suriname is considered the 17^{th} richest country in the world in terms of natural resources by the World Bank, with many of those resources still untouched (International Business Publications, 2012). 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 along with the economy and the population. Suriname realized an economic growth of 4.4% on average for the period 2000-2013, which is among the highest in Latin America (World Bank, 2015). However, the country is in an economic recession since late 2015, among others caused by the low commodity prices (Fitch Ratings, 2016). It proves that diversity is required in Suriname's economy to decrease the volatility to commodity export prices. A more diverse and sustainable economy is also a must with the eye on the responsibility in terms of climate issues, biodiversity- and forest conservation.

Biofuels possess great potential to not only clean up the energy supply, but also boost and diversify 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 et al., 2013). Conditions which are comparable, if not better, than in the areas where bioethanol out of sugarcane is a success in the neighboring Brazil (Coelho et al., 2006). Bioethanol can be blended with conventional 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 fully renewable power generation.

Several 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. An example is the promising plan by Staatsolie N.V. in Suriname, known as the Wageningen Sugarcane to Ethanol and Sugar Project (WSESP), to initiate a biofuel industry in Suriname (ERM, 2012).

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. A big 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, non-sustainability related, is that very strong government involvement and support is needed in terms of policy and various incentives (Franco et al., 2009).

1.1 The aim of this study and the problem definition.

This paper 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 (SD) methodology. According to Sterman (2002) and Pruyt (2013), 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. First of all, this study includes 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. If it was to be studied in the same detail as bioethanol, the model would require a significant expansion of the scope leading to an uncontrollably big system not feasible to study with the available resources. 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. When studying the LUC, food agriculture is taken into account in terms of the competition for land between food agriculture and biofuel agriculture.

Furthermore, 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. Detailed population developments and interactions are left out. The model 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, situates outside the study boundaries. However, the local oil prices and the subsequent influence on the oil demand and the potential biofuel demand are taken into account.

1.3 Outline of the paper

First this paper 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 paper is concluded and a reflection of the model and the study is discussed in chapter 5.

2. Background information

This chapter contains background information on biofuels and Suriname, aiming to provide insights, which should lead to a better understanding of the case. Background information on Suriname and its energy supply is followed by literature on previous System Dynamics studies in the field of biofuels.

2.1 Suriname and its energy supply

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 in 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 for modern power generation. Examples are: uranium, oil, gas, sunlight, hydro-power and biomass (Government of the Republic of Suriname, 2006). The Government of Suriname (2006) even state 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 imports were accounted for by energy in 2009 (IDB, 2013).

In the transport, predominantly gasoline is consumed. This fuel is imported. Staatsolie recently took a new refinery worth nearly US$ 1 billion, into 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 limit climate change. That is where biofuels might come into the picture as a potential candidate to build a clean and green energy supply.

Up till now Suriname has not developed biofuel policy. However, the expertise and support to develop biofuel policy is requested at various organizations (Shah et al., 2012). This indicates that the interest is present for biofuel, but the knowledge and experience are lacking. The vast availability of land and water along with an appropriate climate for agriculture are among positive drivers behind a potentially successful biofuel industry in Suriname (Shah et al., 2012). However, some obstacles, blocking 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 et al., 2012).

To kick-off a biofuel industry in Suriname, Staatsolie had a plan called WSESP (ERM, 2012). WSESP includes a sugarcane plantation, a bioethanol refinery, a sugar factory and a power plant in Wageningen, 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 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, 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 were obtained from studies such as Barisa et al. (2015), studying the future biodiesel policy and consumption patterns in Latvia. Franco et al. (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 measures are required at the production side. Musango et al. (2011) study the sustainability assessment of biofuel technology in the Eastern 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 et al. (2012) and Vimmerstedt et al. (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.

In addition to the economic and supply chain related aspects, certain studies are focusing on the environmental aspects of biofuel systems. Hereby the focus is especially 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 others, human drivers behind 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 markets 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 biofuels 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, food security and 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 blocking 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: biofuel production sector, biofuel demand sector and feedstock supply sector. Depending on the scope and aim of the study common additions are: land use sector, (agricultural) food sector and sectors of various rest products resulting from the agricultural and food production sector.

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

3. The BioSU simulation model

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

3.1 Methodology

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) supports this description of biofuel systems. To study and understand these type of systems, a comprehensive methodology, fitting the purpose is System Dynamics (SD) (Sterman, 2000). According to Pruyt (2013) SD starts from the assumption that system behavior is primarily caused by the structure of the system. Hereby system structure consists, 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, 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**: identify the issues and document them in a problem statement.
2. **Model conceptualization**: develop causal theories on the issues to be addressed.
3. **Model formulation:** develop a dynamic simulation SD model, starting from the causal theories. In this study the model is built on the Vensim software platform, provided by Ventana Systems.
4. **Model testing**: conduct various tests to gain confidence in the usefulness of the model.
5. **Model use**: apply the model to develop, test and analyze policies and strategies, possibly under various scenarios.

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 its supply chain in Suriname, together with the associated LUC, the nation's energy supply and the environmental impact. With the BioSU model, exploring future developments in terms of mainly behavior, is far more important than generating very accurate quantitative forecasts, as far as that is possible. 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 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 is made of the extent to which factors will be incorporated in the model. The first category consists of the *thoroughly modeled internal variables*. These are considered to be the core of the biofuel system and the backbone of the model. 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 biofuel and feedstock, b) biofuel and feedstock prices, 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.

The second category is the *superficially modelled internal factors.* These are also considered an integral part of the biofuel system, but are scaled lower on importance relative to the thoroughly modelled factors. Hence they are modelled to a lesser extent of detail to prevent the model becoming too large. These factors are in the field of: 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 difficult and highly uncertain.

The third category are the *external factors.* These cannot be influenced by the parties 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 performance of biofuel policy. These variables are in the field of: a) foreign biofuel policy and the international biofuel and biomass demand, b) population growth, c) amount of cars and the average fuel consumption and d) the success of biofuel alternatives. These factors cannot be neglected when studying biofuel systems. However, their inclusion as endogenous variables make the model to large and uncontrollable for the modeler, which may lead to decreasing credibility and usefulness of the model 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 although these factors are not modeled explicitly, effort has been made to at least include their effects in factors which are modeled explicitly.

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 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 SD methodology. Due to its sheer size and detail, the causal diagram is not discussed in this paper, but only in appendix A. As an alternative, 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. 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 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 is classified in four sectors or sub systems:

- *The biofuel industry sub model*: 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, where a biofuel industry can have an enormous impact, with 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.

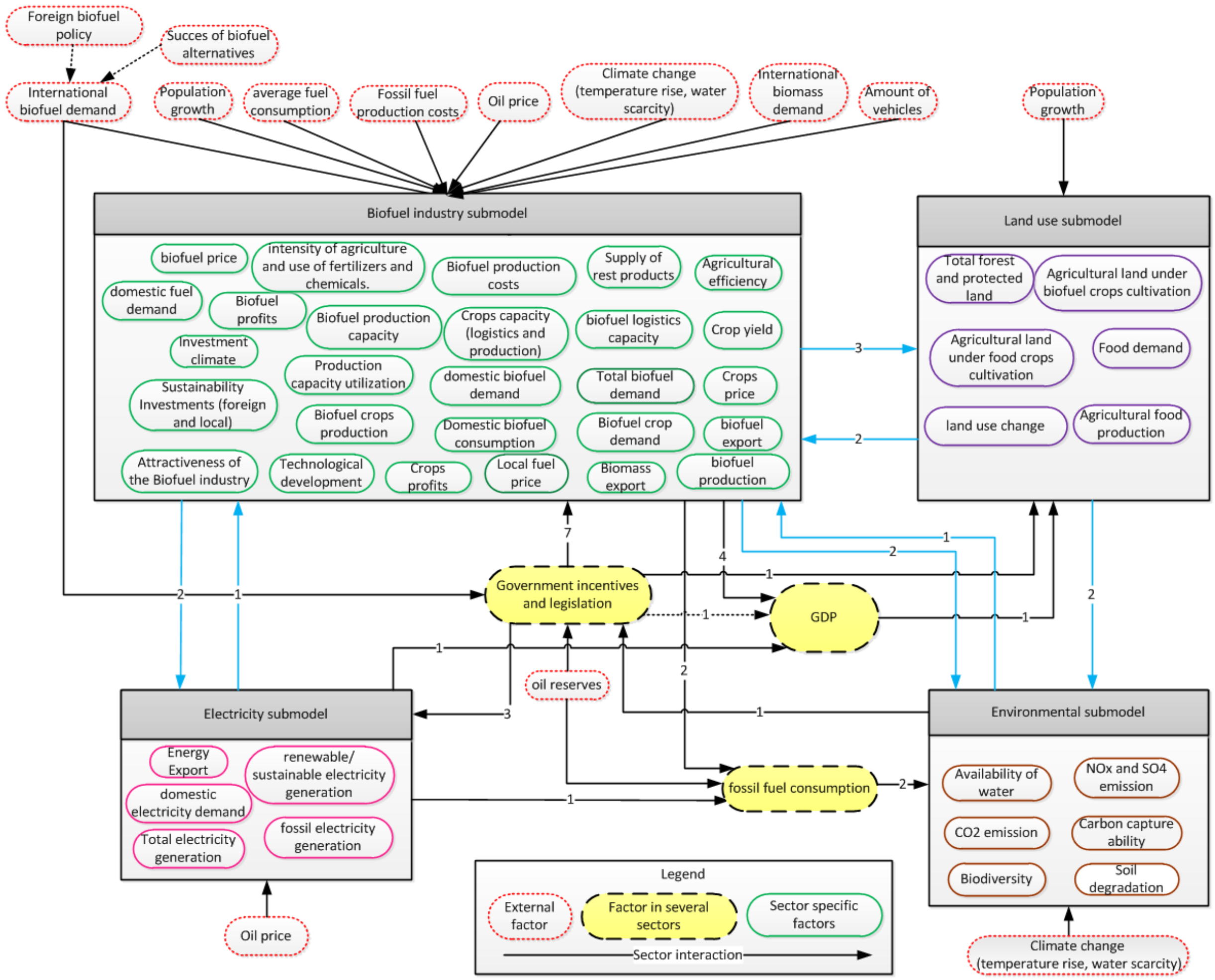

Figure 1: The sector diagram

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 marked with a number, this number indicates the 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 SD research are elaborated in Appendix A2.2. 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 such as: *(+) 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 model thus includes the evolution of biofuel attractiveness in Suriname, through influences of *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. Sub chapter 3.3 addresses the BioSU simulation model.

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. Of this sub model the following essentials will be discussed: biofuel demand, biofuel production, feedstock production, investments, production costs and the feedstock and biofuel production and logistics capacity.

In the relevant literature, biofuel demand is mostly modeled as a function of the fossil fuel demand, considering biofuel blending in fossil fuels is a very common implementation of biofuels in existing energy mixes (Turckin & Macharis, 2010). In BioSU this is also the case, 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 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, $Dsur$, and international biofuel demand, $Dint$, are 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
X_1 = success of biofuel alternatives
X_2 = international biofuel policy

For the biofuel production, the structure in BioSU is displayed in figure 2.

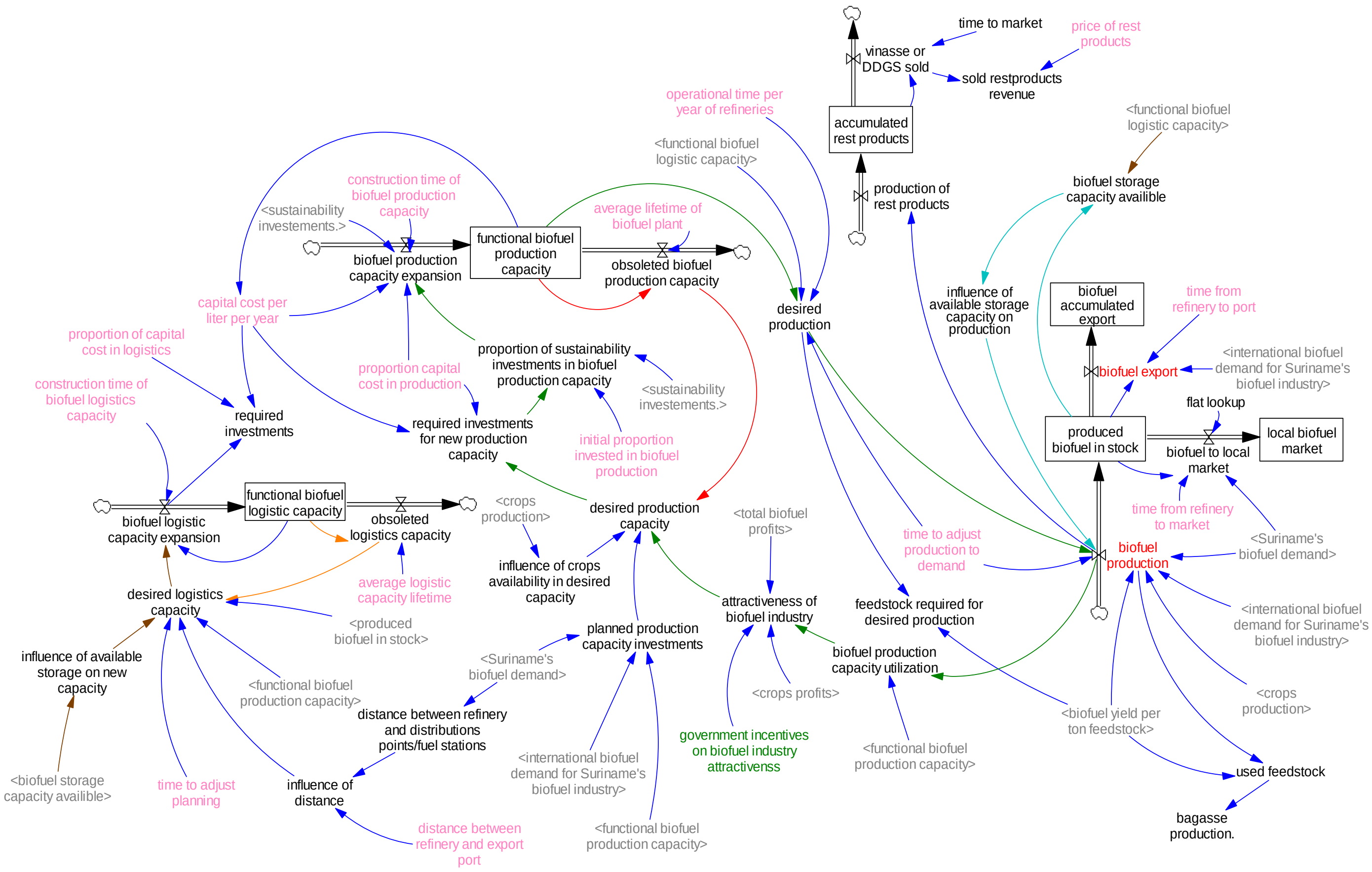

Figure 2: The structure of the biofuel production as part of the bio industry sub model

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. Figure 3 represents the structure concerning the sugarcane production as feedstock section. This structure and the associated equations are comparable to those of the biofuel production. 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 of all, the total costs associated to the biofuel supply chain, 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, represents 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

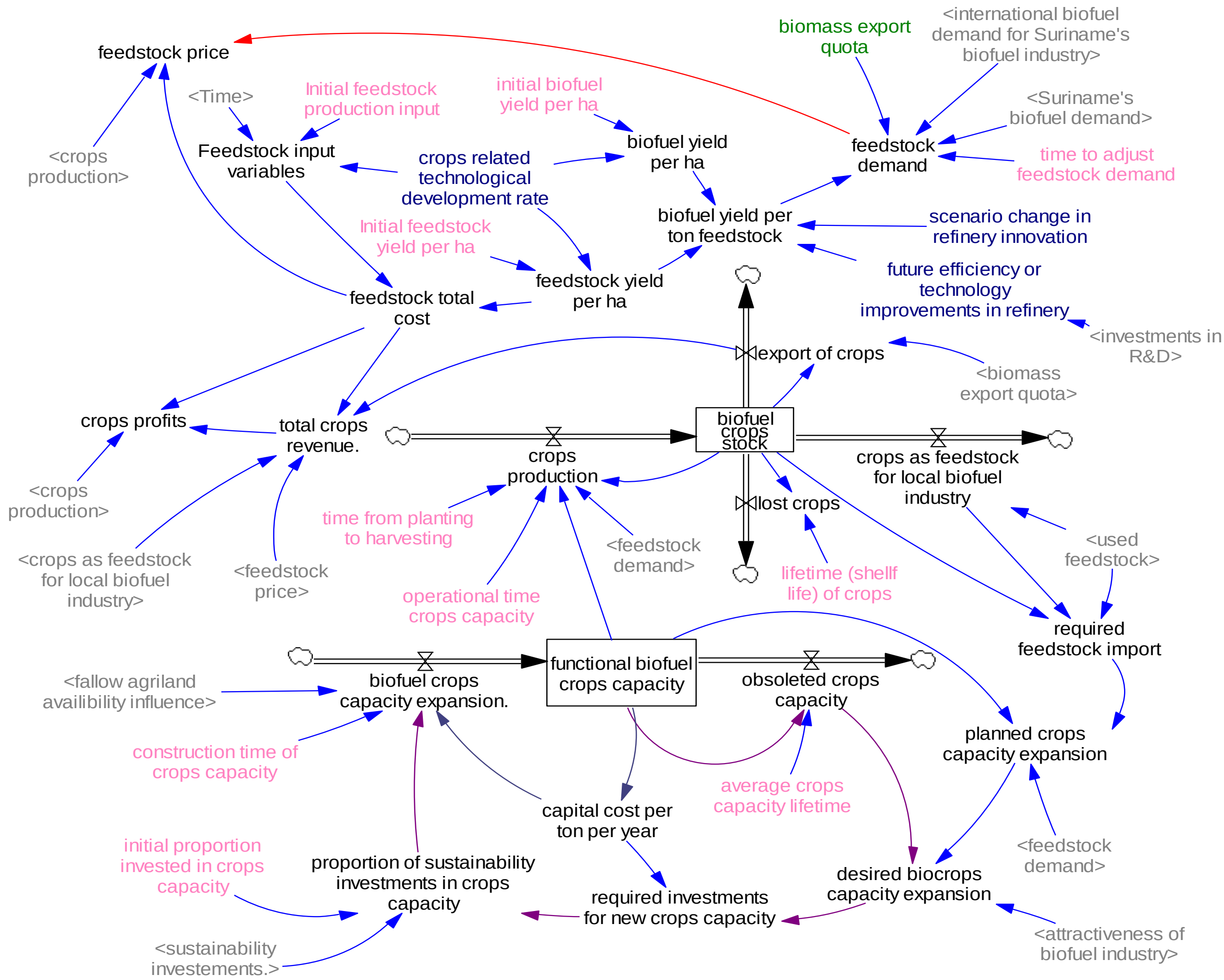

Figure 3: the sugarcane as feedstock production section as part of the biofuel industry sub model

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.

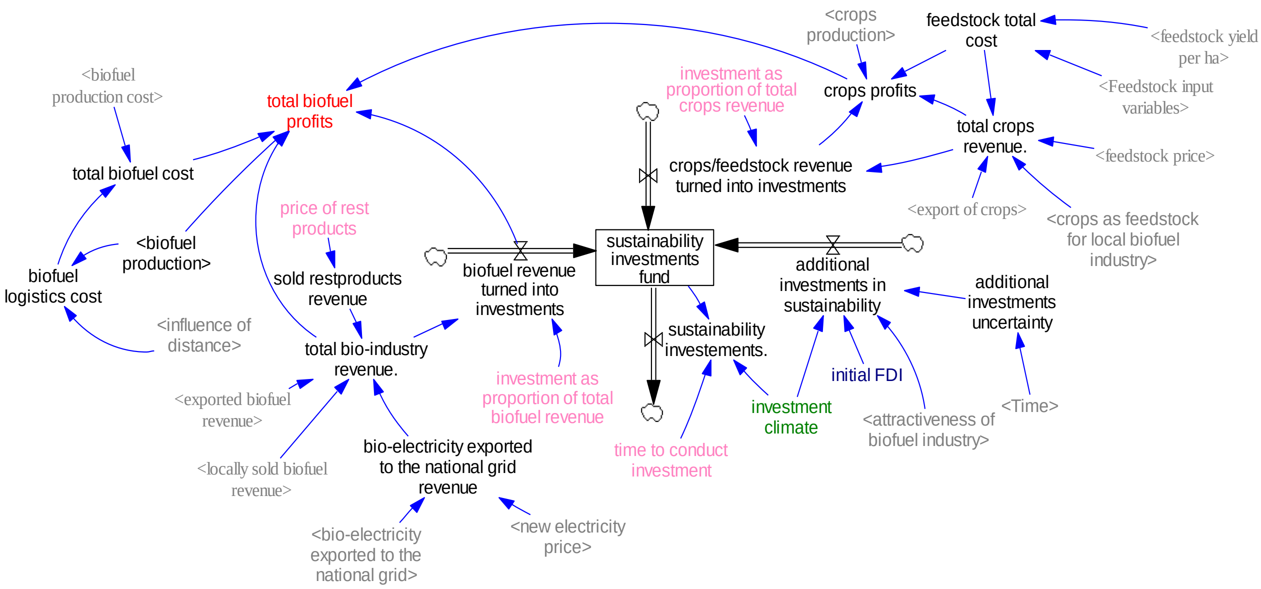

Figure 4: The structure of the investments and revenue mechanism

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, 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.

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 et al., 2005).

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 percentage demand change, complemented with a demand elasticity to price factor and an uncertainty factor included in the percentage change, leads to the change in electricity demand:

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

$D_{\Delta e}$= change in electricity demand
D_e= electricity demand
$c_{\Delta e}$= % change in electricity demand, varying over 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, this 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 et al., (2011).

The land use model is in essence a closed loop of stocks, representing the various land use allocations and flows, representing the LUC. 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 aforementioned 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 EI is based on environmental indicators used by the UNSD (United Nations Statistics Division) (n.d.) and the OECD (2013), adjusted with own insights:

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

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.

3.3 The fitness for use of BioSU

In order to test whether the BioSU model is fit for use, various tests were conducted. The tests have the purpose to verify and validate the model in terms of structure, input data, 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 are discussed.

First of all, the model was verified using 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 and hereby improve each iteration.

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. 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 significant 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 on the 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. This long time span exceeds the average lifetime of biofuel plants, but as the study addresses a whole industry consisting of many pants, with new plants being constructed, while old plants are dismantled, the timespan is considered relevant. The long time-span is also in line with the aim to study long term behavior. Additionally, when 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 accurately. Also, a biofuel industry is new for Suriname, so no past real data is available. For the validation the timespan is extended to 2155 to 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. 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 well (transport, power generation and deforestation) to wheel. 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, only the domestic 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 a maximum of 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 consulted literature. 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 choice. 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 is 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 have 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 et al., 2009), (Barisa et al., 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 (Government take)
8. Improve the investment climate

The three policy strategies are:

1. *Domestic Policy (DP)*: This strategy focusses on establishing a biofuel industry to exclusively serve a local biofuel market. More specifically, the policy measures deployed are: a) domestic E25 obligations, b) subsidies on flex-fuel vehicles, refineries and bio-power plants and c) tax exemptions on biofuel.
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. 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 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. 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 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 and preferences.

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 = only 0, 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.

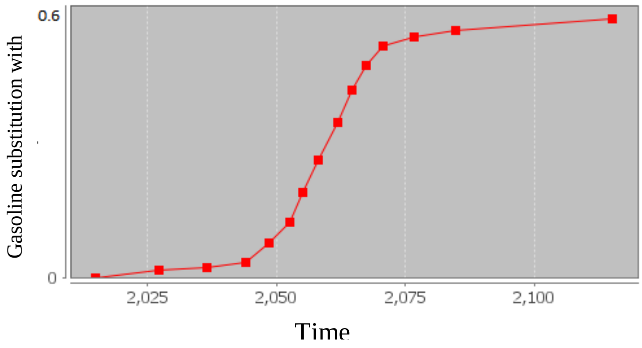

Figure 5: The expected development of the E100 share over time

P3 - Policy determined ethanol-blend in gasoline: This policy lever is the percentage of bioethanol mixed in the traditional fossil gasoline.
P4 - policy based incentive for bio-power: this lever represents the intensity of the government incentives for bio-power and has value between 0 and 1. 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 influencing 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. This 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 but then for biomass.
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 findings, resulting from the simulation runs for the purpose of policy analysis, will be discussed. Hereby the focus is on the KPI's, but also some other interesting performance indicators will be reviewed.

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.

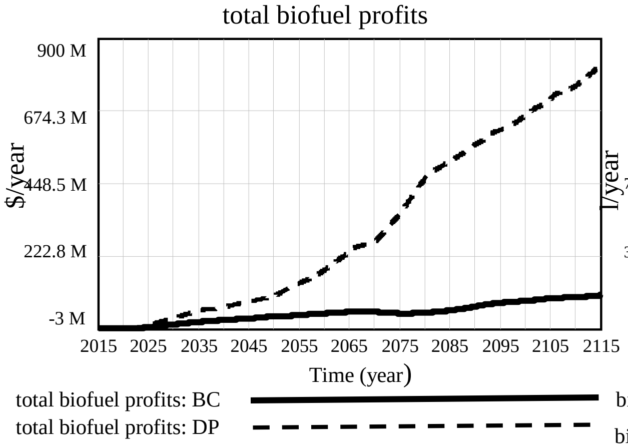

Figure 7: The total biofuel profits for DP and the BC

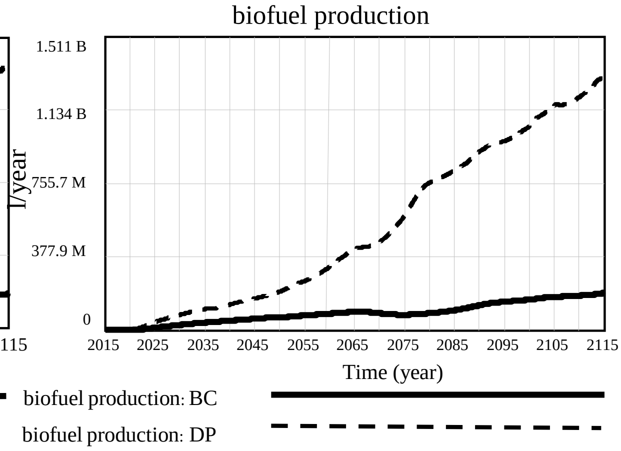

Figure 8: The total biofuel production for DP and the BC

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.

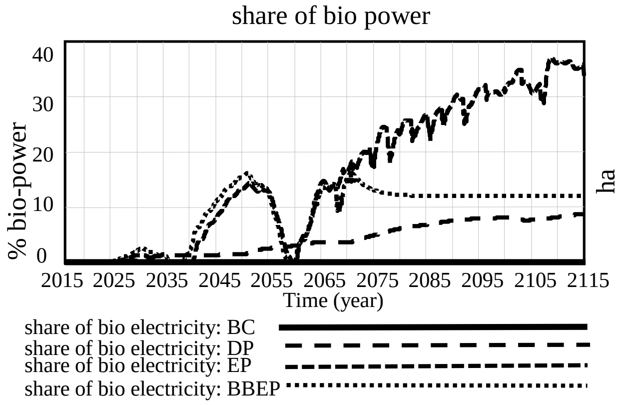

Figure 9: share of bio-power for all three strategies and the BC

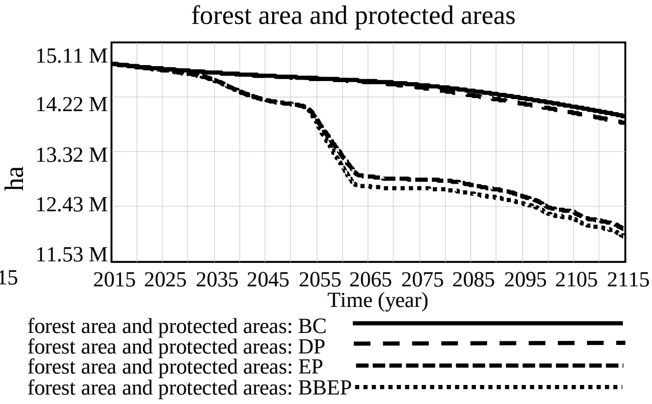

Figure 10: forest and protected areas

The deforestation increases towards 6,000 ha/year in 2060, whereupon it increases further 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.

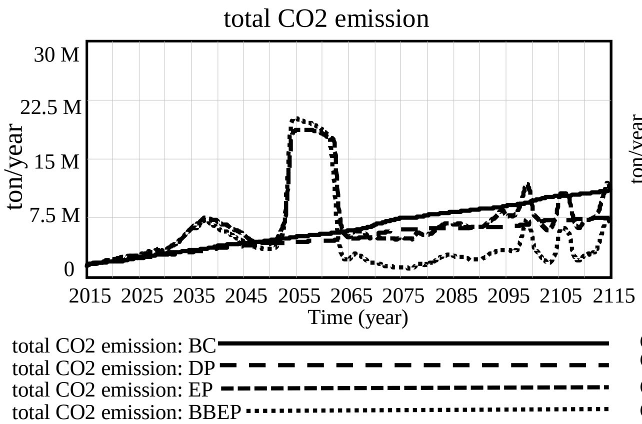

Figure 11: The total CO2 emissions for all three strategies and BC

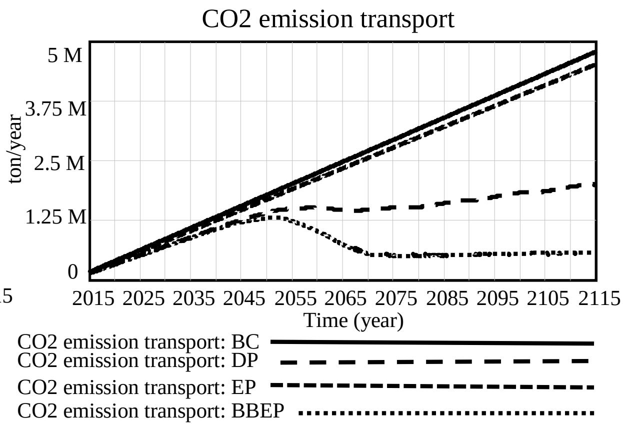

Figure 12: CO2 emission by the transport

In terms of the total CO_2 emissions, the DP strategy is able to limit emission in 2115 to 7.5 million tons/year, as can be seen in figure 11. This despite the strong increase in transport and power generation in a generally 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.

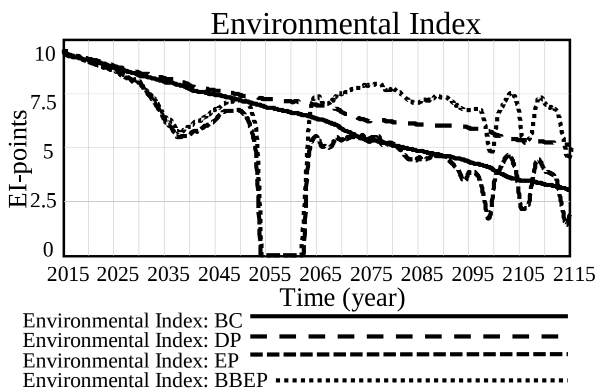

Figure 13: The EI for all three strategies and BC

A worrying observation is that the EI, plotted in figure 13, 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 for DP.

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 EP and BBEP. 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.

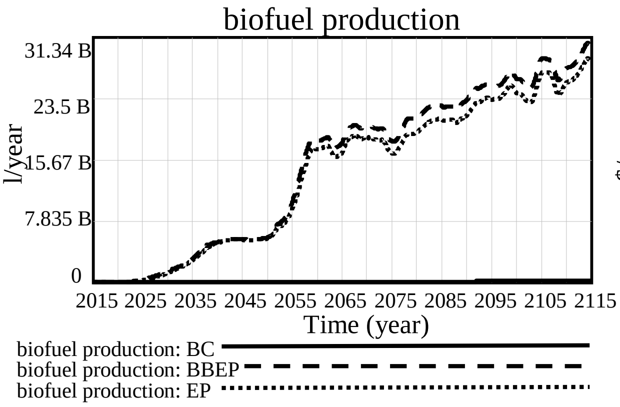

Figure 14: Biofuel production for EP, BBEP and BC

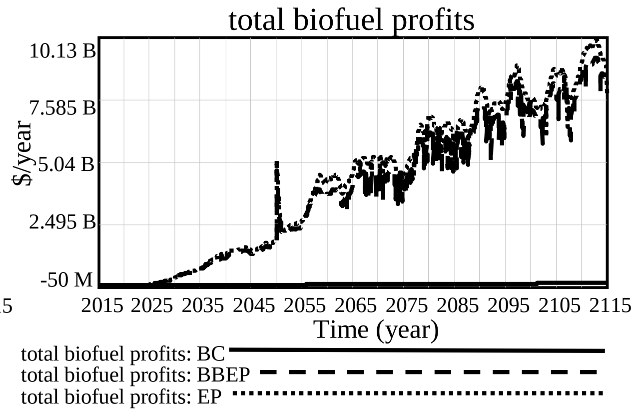

Figure 15: total biofuel profits for EP, BBEP and BC

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.

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 current world's largest bioethanol exporters, exported 3.2 billion liters and 1.5 billion liters respectively in 2014.

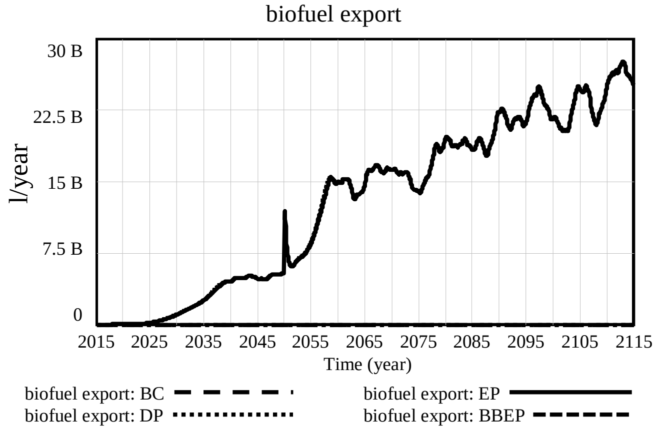

Figure 16: biofuel export for EP, BBEP and BC

With the assumed learning curves, technological developments and their effect on cost reductions, biofuel total costs 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-inclusive for EP, that is including 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% in 2115, as can be seen in figure 9. This limits the share of petrol power to 4% in 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 in revenue.

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 tons/year to 31.33 million tons/year.

From Figure 11 it can be noticed that the total CO_2 emissions show an increasing trend towards 10.9 million tons/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, due 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 as it lacks 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 available. 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 et al., 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, the capacity utilization is mostly high at around 90%.

Next, the biofuel cost reduction observed for EP, also occurs in BBEP. Surinamese biofuel 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 rise, 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 larger scale 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 et al., (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 tons/year. For some periods in which deforestation is stronger than normal, the emissions peak. But in general the emission is around 3 million tons/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 emissions coming from transport tends to balance around 500,000 tons/year. This is considerably lower than in the BC where the transport related emissions can rise up to 5 million tons in 2115.

As a result of the fully renewable power generation from 2070 on, the CO_2 emitted by the power generation is equal to 0 ton/year from 2070 on. 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 negative carbon emissions 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 impacts of the biofuel industry on the environment can be compensated by the positive impacts.

4.2 System context scenarios

This sub chapter discusses the construction of three context scenarios: *Bio-2, Bio-1* and *Bio-0*. These three scenarios are 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 of the driving forces, as can be seen at the ends of the axes.

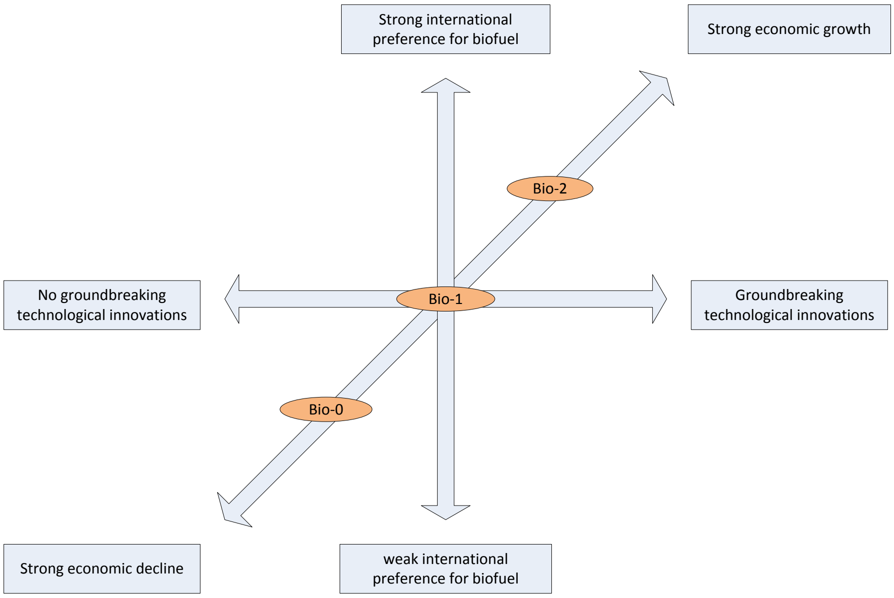

Figure 67: the scenario logic

Economic development, is relevant considering its relationship with (foreign direct) investments in the Surinamese biofuel industry. Hereby in particular the economy in the countries and regions where biofuel plays 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 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 and pull-back of subsidies by the government. These subsidies are, however, crucial for a new biofuel industry to successfully kick-off (Barisa et al., 2015).

Technological development is another interesting driving force behind a successful biofuel industry. Technological development plays an important role in the biofuel supply chain from feedstock cultivation, transportation and (pre-)processing all the way to the biofuel refinery process, storage, transportation and consumption. Cost reductions through higher efficiencies, 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 et al., 2006) and (Janssen et al., 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, requires advanced technology in terms of preparation and combustion to achieve a high efficiency (International Renewable Energy Agency, 2012), this although the feedstock cost are basically the opportunity cost of bagasse (Walter & Ensinas, 2010).

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 largely determines 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 and blending policies in the USA and other 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 for policy analysis. Hereby the study does not focus on the probability of the scenarios to occur, but rather on the plausibility of the scenario. After all, it is not possible to forecast the future, as it will always be incorrect. 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:

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 Surinamese 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 et al., (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 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 4.3 these scenarios are used to assess the robustness of the policy strategies.

4.3 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 4.2. 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 D, the graphs belonging to the scenario uncertainty analysis are attached for a detailed view. In this sub chapter, 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 onwards. 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 tons/year in the Bio-2 and Bio-1 scenario. In the Bio-0 scenario the emission increases to 9 million tons/year, mainly due to the absence of bio-power and the higher petrol power generation. 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 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 focusses 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 liters. The production is almost completely exported. In Bio-0 the production peaks at 45.12 million liters in 2115, while the export is negligible due to the shift to biofuel 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 annually. However, Bio-0, would be fatal for a large scale biofuel industry in Suriname due to constant losses.
For 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, 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 tons/year for Bio-2, Bio-1 and Bio-0 respectively. 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, 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 a 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.

Furthermore, 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 more aggressive deforestation in order to cover the increasing demand and subsequently to further deterioration of the Surinamese forest and environment.

4.4.3 BBEP scenario analysis

The behaviors of the biofuel production, export and the profits for the BBEP strategy are comparable to that of the EP strategy for all three scenarios, with only numerical differences occurring.

The BBEP strategy 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 supply can be completely carbon neutral with only hydro-, solar- and bio-power. The forest coverage in 2115 for BBEP is 69.42% for 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 tons/year. At last, due to the strong emission reductions, BBEP limits the EI decrease, in particular for Bio-1 and Bio-2. For Bio-0, 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 of the biofuel production over time. 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 DP, 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.

5.1Conclusions

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. However, this would have dramatic consequences for the Surinamese forest and environment. 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 preserved environment and biofuel with zero CO_2 emissions from well-to-wheel.

The second sub question is on 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 infrastructure directly impact the demand and the production of biofuel. In the case of Suriname, it is important that government policy includes improving the investment climate to attract much more FDI, as the biofuel industry will require massive investments. Especially in the start-up phase of the industry, 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 a must 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. Nevertheless, sound policy can minimize this impact, 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 is 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. However, indications are that biofuel will play a significant role 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 et al., 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. Policy strategies like BBEP also establish a domestic market, so that the complete industry does not collapse when the international demand decreases. Over time the industry can recover and the policy can be transformed in a more domestic, DP like, approach. Policy which also enable 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 sector with annual emission limited to no more than 500,000 tons/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 enable 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.

To finalize, with an advice on which policy the Surinamese Government needs to implement, it cannot be said that one of either DP, EP or BBEP are the best. It depends on the aspirations of the government and the private sector and what the available resources allow. However, the DP is a good start to set-up a biofuel industry. But when the aspirations rise to also export, it is important to not forget about the local market and solemnly focus on the export like EP does. Hence, for the more advanced stages of the industry, the policy to implement is more in the trend of BBEP with a strong local market to maximize local benefits and the international market to profile yourself as the largest biofuel exporter in the world on the long term.

5.2 Reflection on the study and BioSU

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

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

- 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 world of biofuels.
- 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 incorporate a balanced set of sustainability criteria, although more aspects are of 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, however, these assumptions need to be scientifically sound (Zeigler et al., 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 adjustable to be applied 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

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

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

Fitch Ratings. (2016, February). *Fitch Downgrades Suriname's Ratings to 'B+'; Outlook Revised to Negative*. Opgehaald van https://www.fitchratings.com/site/pressrelease?id=1000098

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 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

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/

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

International Business Publications. (2012). *Mining Laws and Regulation Handbook.* Washington.

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

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

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.

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

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

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.

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

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

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

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