Supporting Document to paper:

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

Appendix A. Model diagrams

A.1 The bulls-eye diagram

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

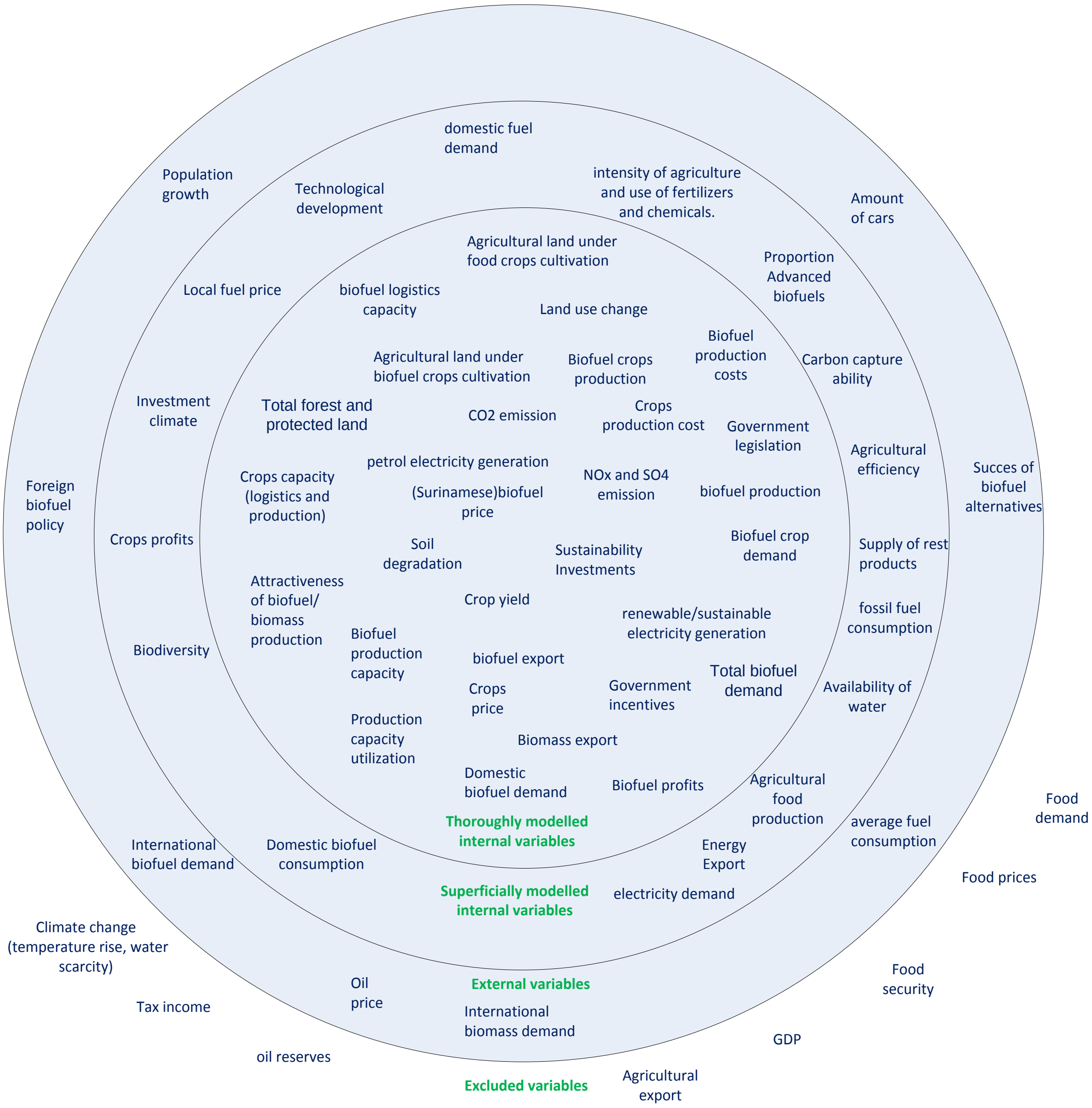


Figure 1: The bulls-eye diagram

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

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

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

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

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

A.2 The Causal Diagram

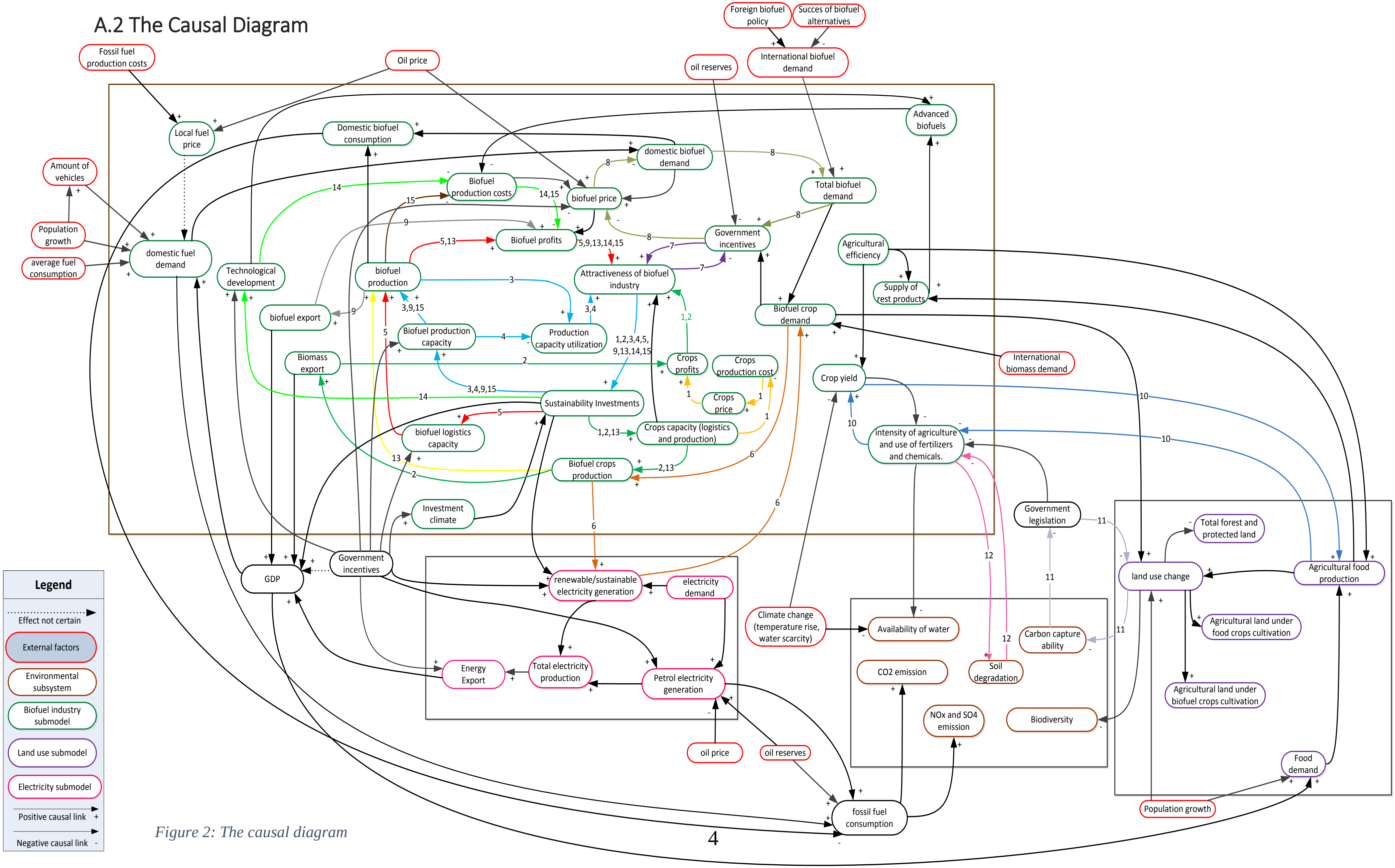


Figure 2: The causal diagram

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

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

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

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

A.2.1 external factors

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

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

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

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

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

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

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

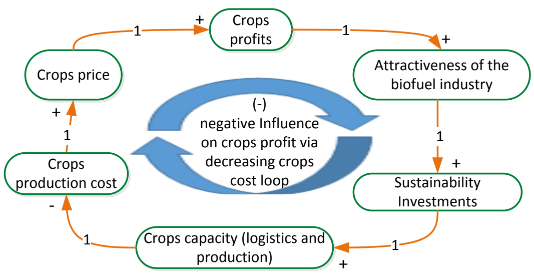
With increasing economic activity and a growing population in Suriname, the expectation is that the ***amount of vehicles*** will also increase. This has a direct influence on the domestic fuel demand. How strong this increase is, is partially dependent on the technological development in terms of the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

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

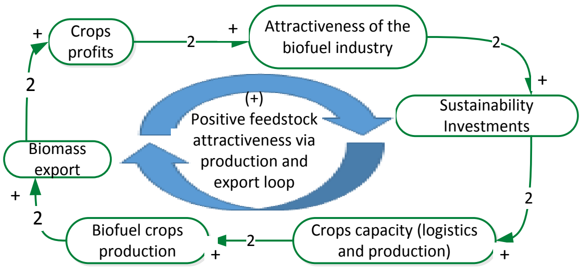
The ***population growth*** is also considered as an important external factor with a direct impact on various sub-models. First of all, as mentioned in the paragraphs above, the increase in food demand, the amount of vehicles and subsequently the local fuel demand is strongly correlated with the population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

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

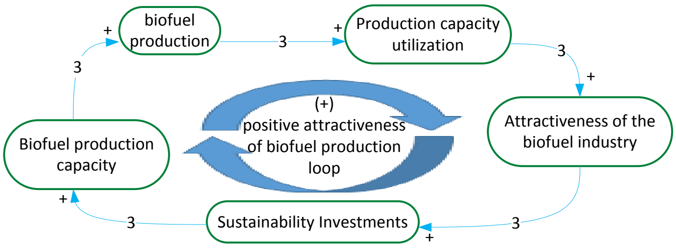
A.2.2 Feedback loops



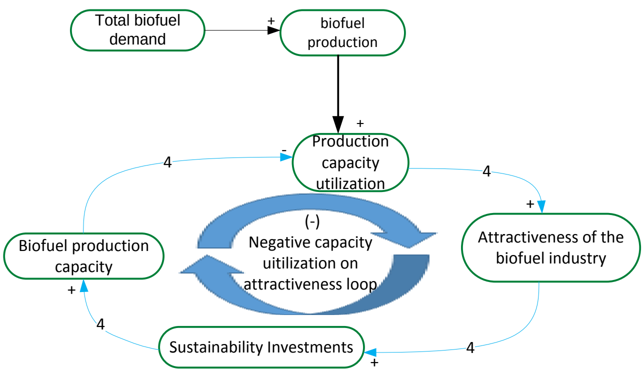
Negative influence on crops profit via decreasing crops cost loop: The first feedback loop discussed is situated in the biofuel industry sub model. This feedback loop implies the fact that increasing crops profits, leads to a larger attractiveness of the industry. Subsequently investments in the industry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



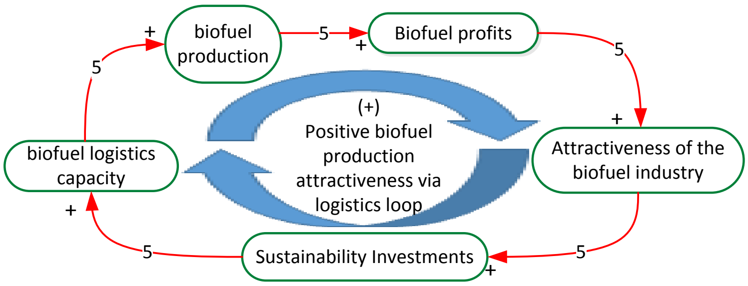
Positive feedstock attractiveness via production and export loop: This loop is also located in the biofuel industry sub model and represents the reinforcing effect of crops production and export on the attractiveness of the industry. The more sugarcane is produces as bioethanol feedstock, the more of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



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

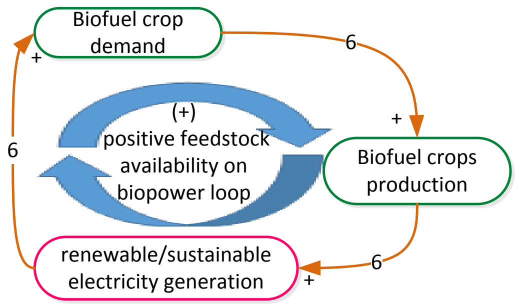


This loop thus functions as a mechanism which tries to restore the balance between the biofuel production and the production capacity via the capacity utilization.

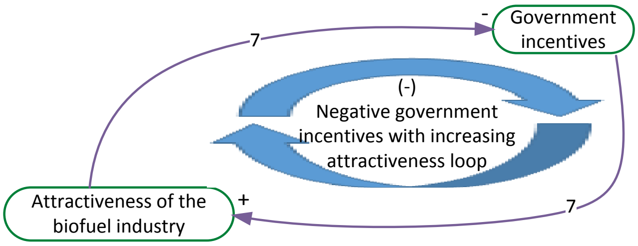


Positive biofuel production attractiveness via logistics loop: this loop and its effect are very similar to the *Positive attractiveness of biofuel production loop*. However, this loop focusses on the biofuel logistics capacity rather than the production capacity. In time an increased logistics capacity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

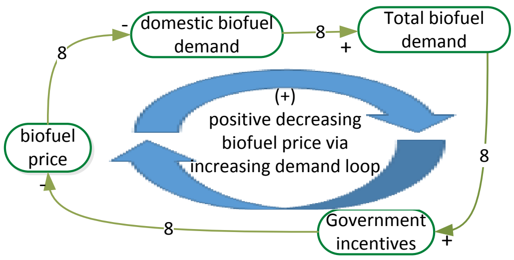
In the biofuel industry, logistics capacity is not less important relative to the production capacity, because distribution is a prominent part of the biofuel supply chain (Vimmerstedt, Bush, & Peterson, 2012). The term logistics capacity covers the whole range of biofuel transportation, storage and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



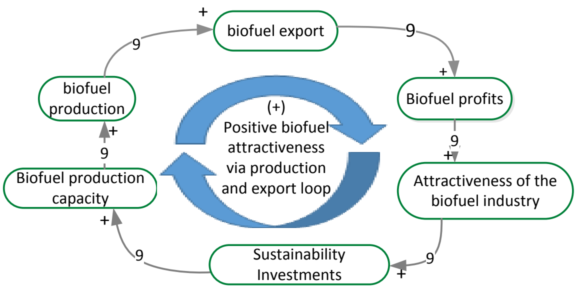
Positive feedstock availability on bio-power loop: this loop is the first inter-sub model loop which will be discussed, meaning that the loop involves factors from more than one sub model. The two sub model which are relevant in this loop is the *biofuel industry sub model* and the *electricity sub model*.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



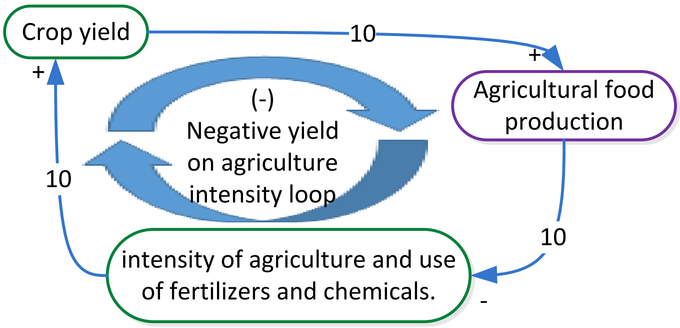
Negative government incentives with increasing attractiveness loop: this loop is located in the biofuel industry sub model. Government incentives in the biofuel industry in the form of tax exemptions, subsidies or other means lead to an increased attractiveness of the biofuel industry. The effect of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



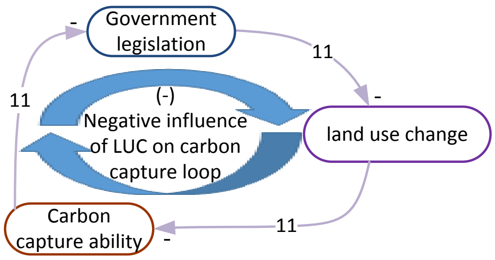
Positive decreasing biofuel price via increasing demand loop: Located in the biofuel industry sub model, this loop emphasizes the influence of the increasing demand for biofuel on the biofuel price. As the demand for biofuel increases, the market will indicate that the supply has to increase to fulfill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



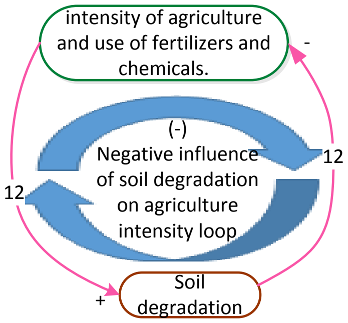
Positive biofuel attractiveness via production and export loop: this loop is located in the biofuel industry sub model and shows large resemblance with the *Positive feedstock attractiveness via production and export loop.* However, this loop focusses on the biofuel production and its influence on the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



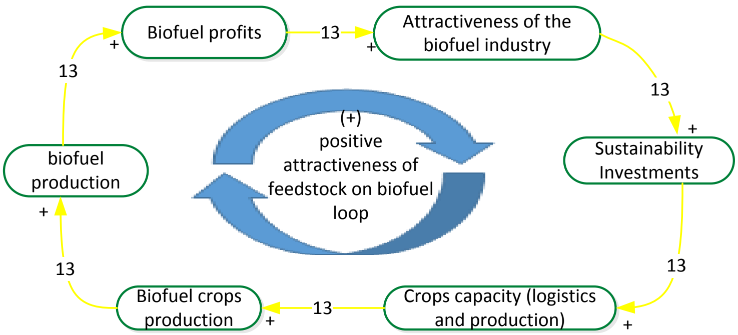
Negative yield on agriculture intensity loop: this loop is the second inter-sub model loop including both the *biofuel industry sub model* and the *land use sub model* wherein the agricultural food production is situated as a factor. In order for higher agricultural productions, the intensity of agriculture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



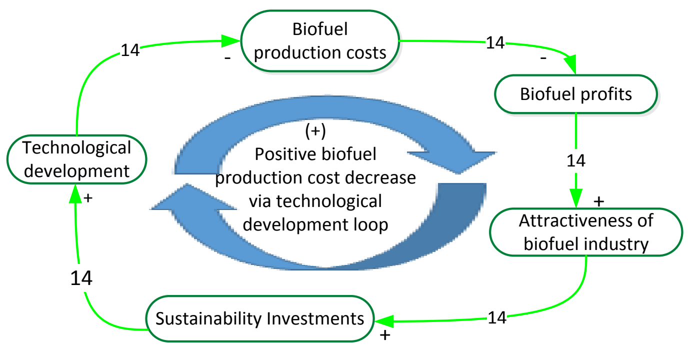
Negative influence of LUC on carbon capture loop: this loop is also inter-sub model including both the *land use sub model* and the *environmental sub model*. Government legislation, e.g. in the form of deforestation restricting law, can be a very important and effective measure to prevent major negative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



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

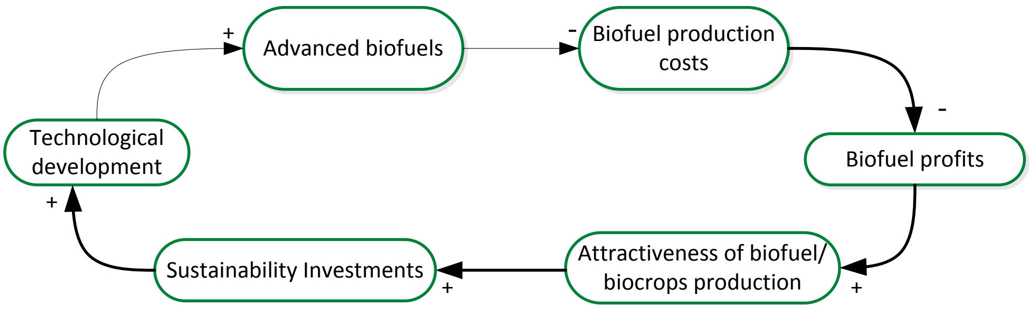


Positive attractiveness of feedstock in biofuel loop: this feedback loop simply implies the looped reinforcing influence of increasing investments in crops capacity on the biofuel production and profits. As investments are conducted in the crops capacity, more crops can be produced and subsequently more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



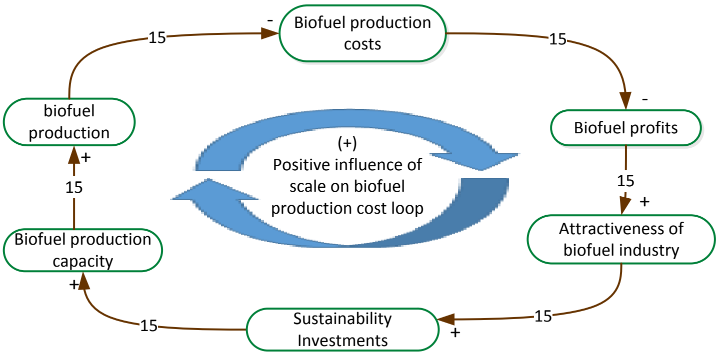
Positive biofuel production cost decrease via technological development loop: technological development plays an important role in the biofuel supply chain, especially in terms of cost reduction via higher efficiencies regarding higher yields and lower energy consumption.

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



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

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



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

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

A.4 The sector diagram

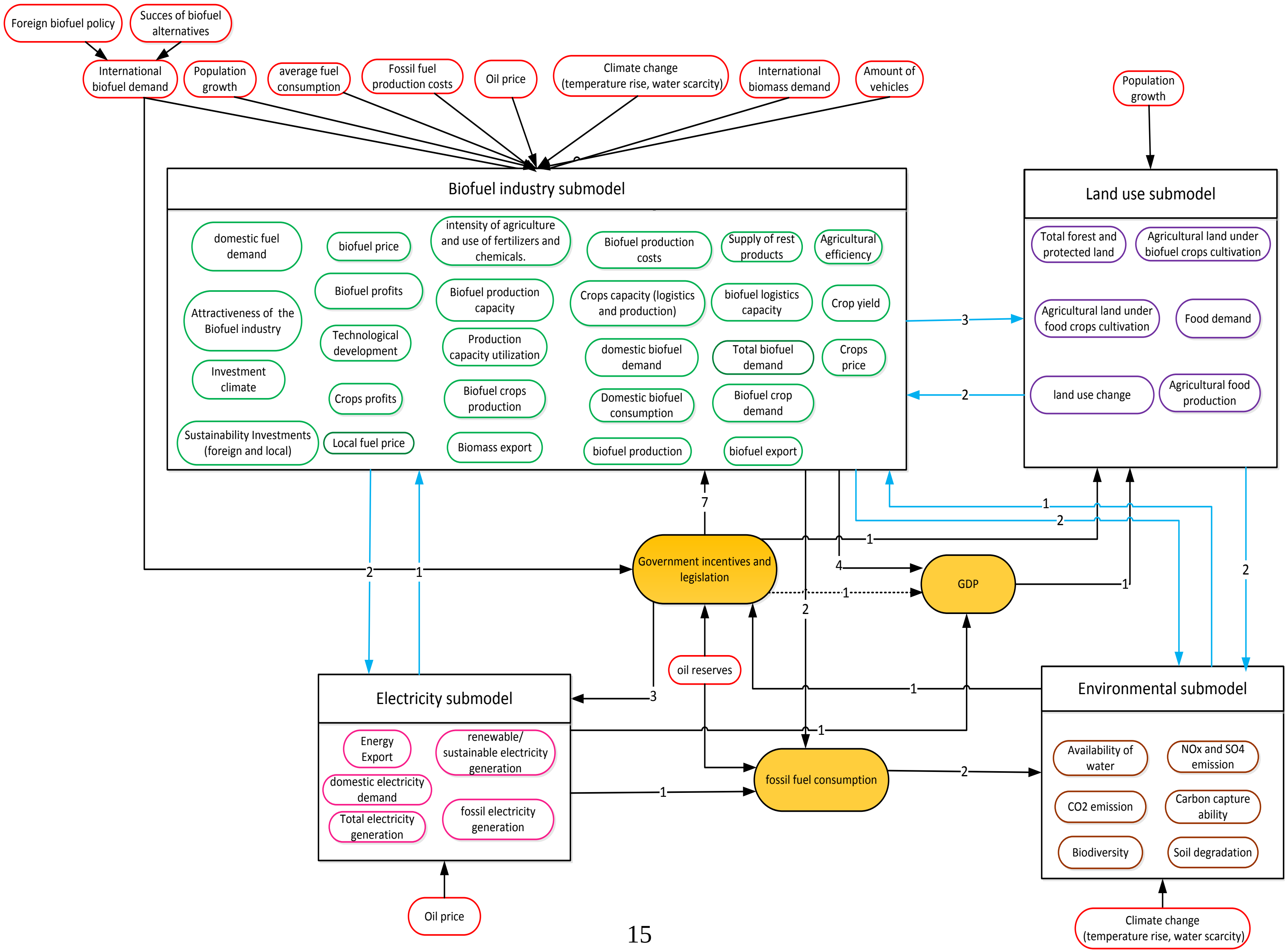


Figure 3: The sector diagram enlarged

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix B. BioSU structure

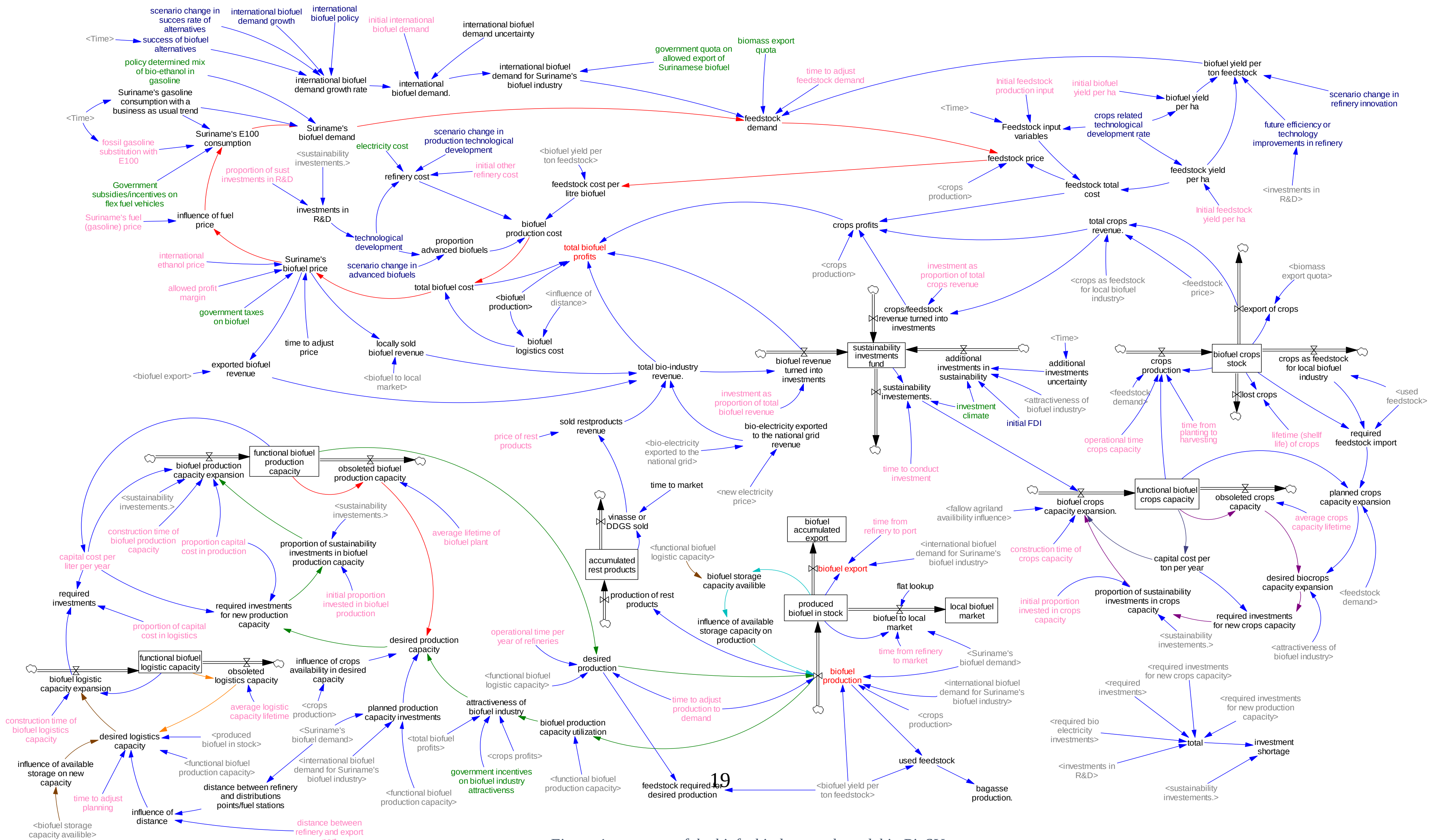


Figure 4: structure of the biofuel industry sub model in BioSU

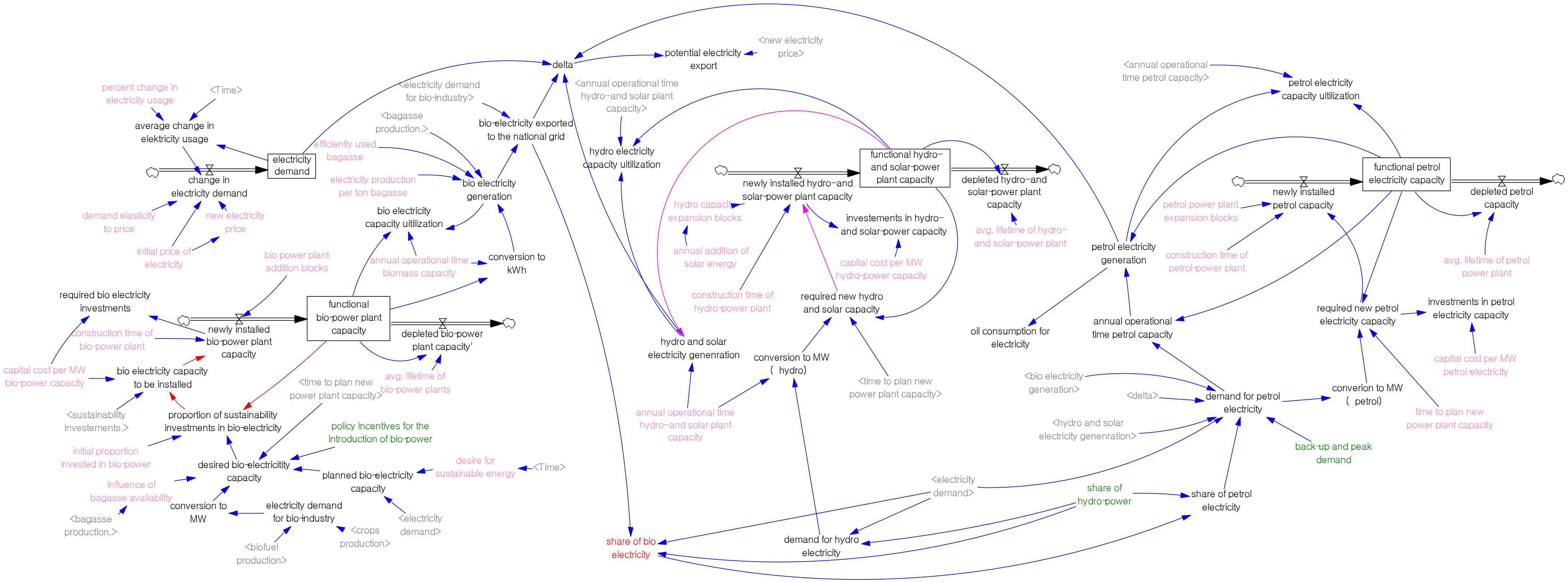


Figure 5: structure of the electricity sub model in BioSU

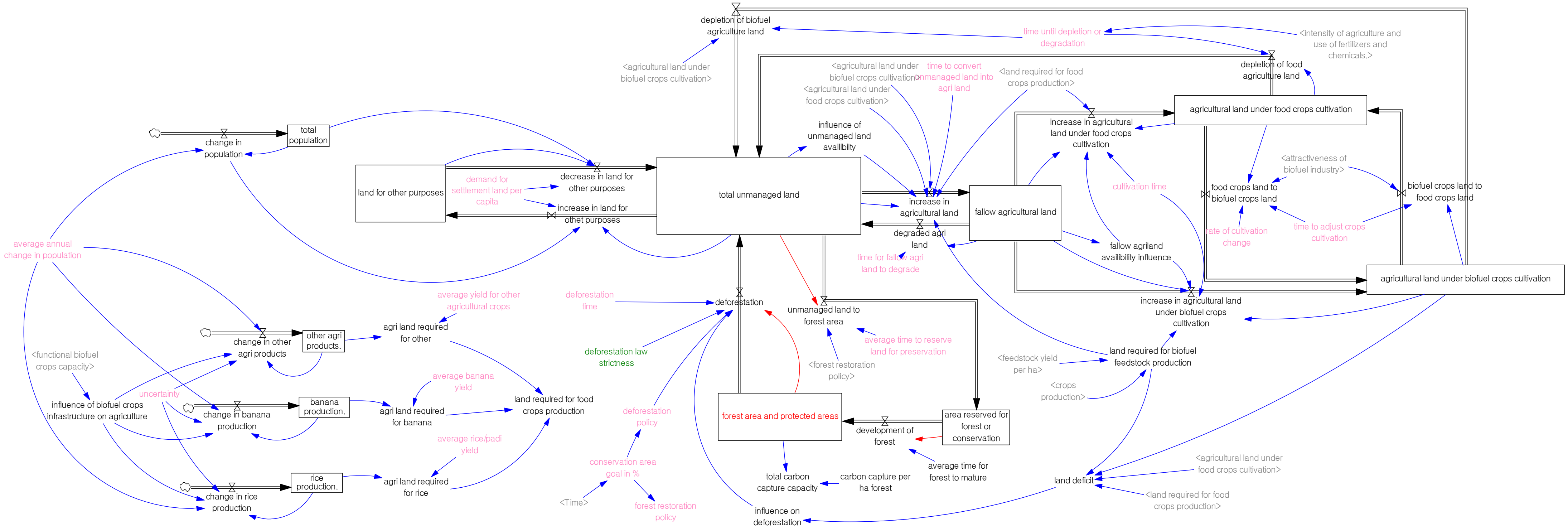


Figure 6: structure of the land use sub model in BioSU

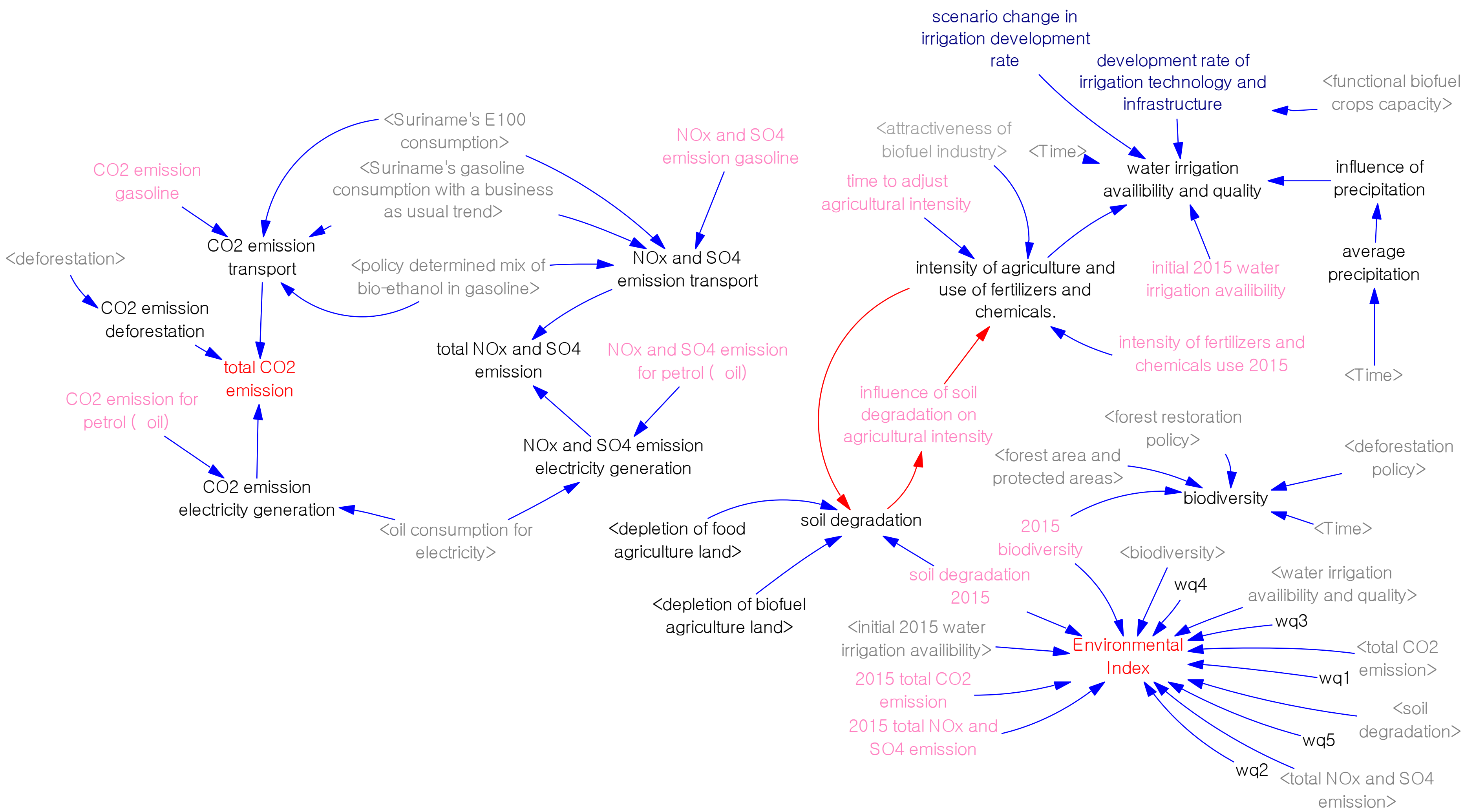
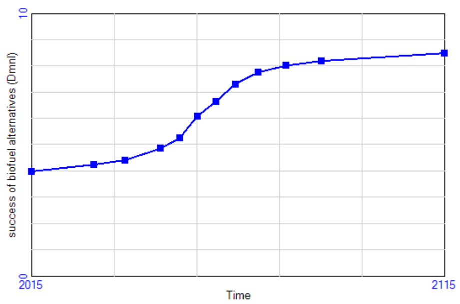
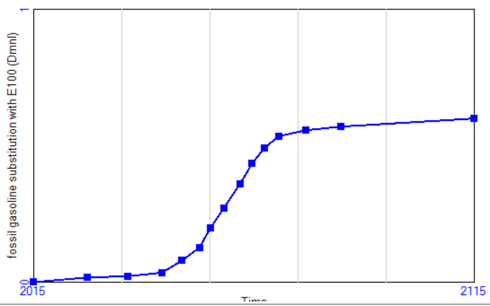
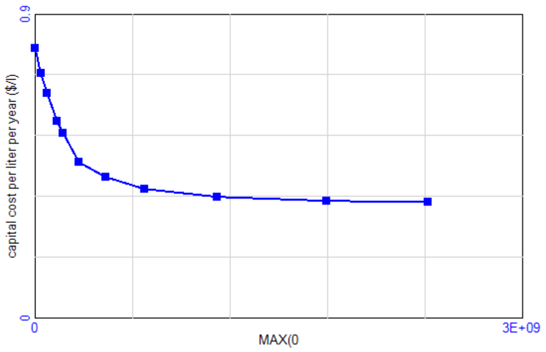
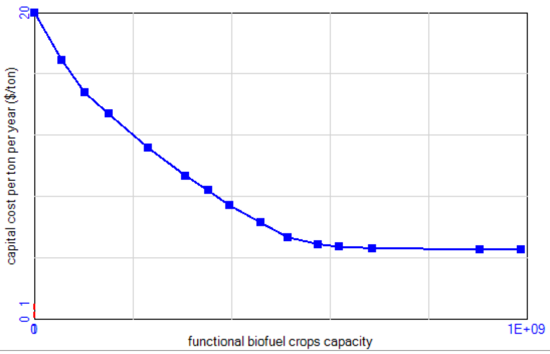


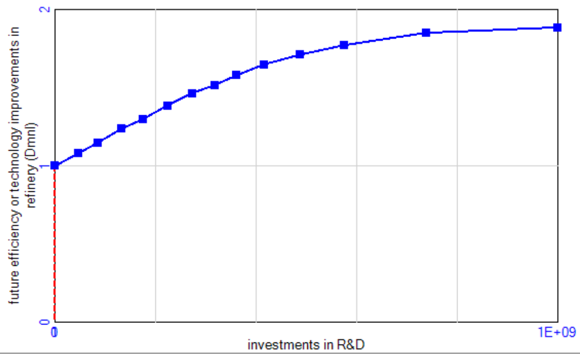
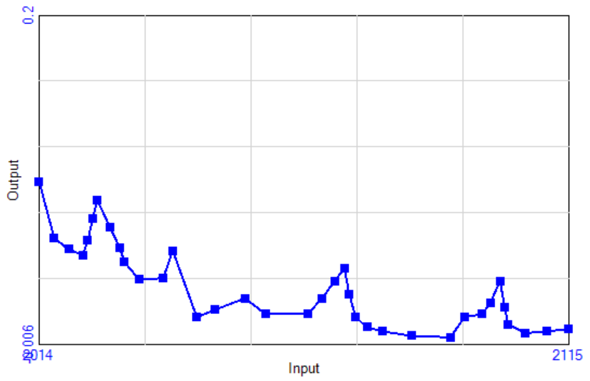
Figure 71: structure of the environmental sub model in BioSU

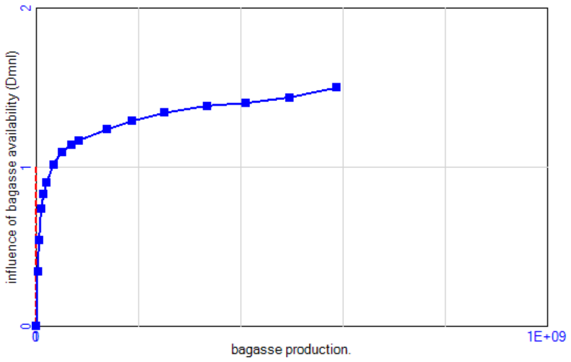
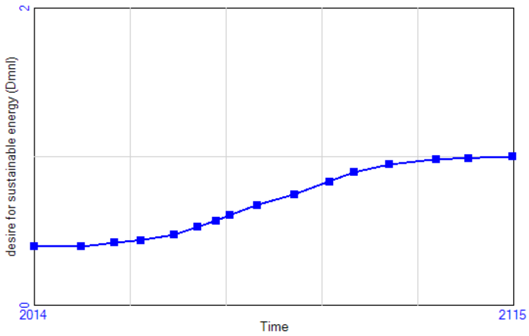
Appendix C. Parameter and factor values and assumptions

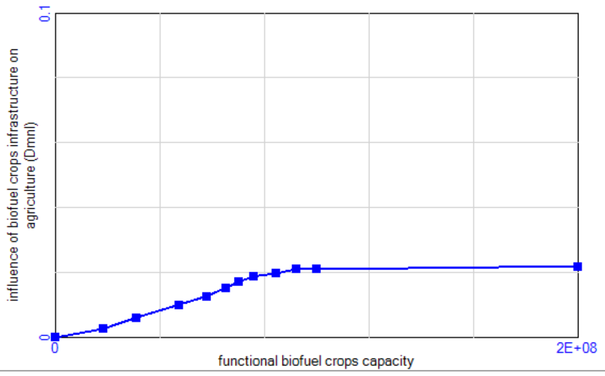
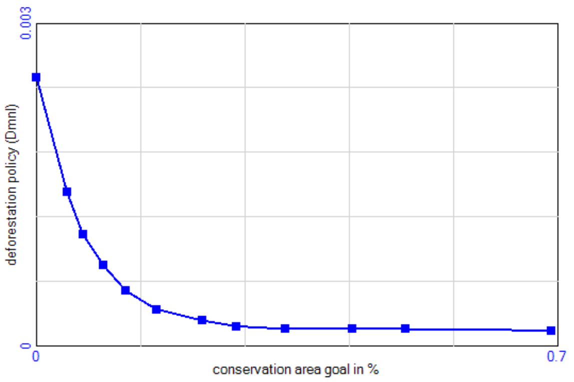
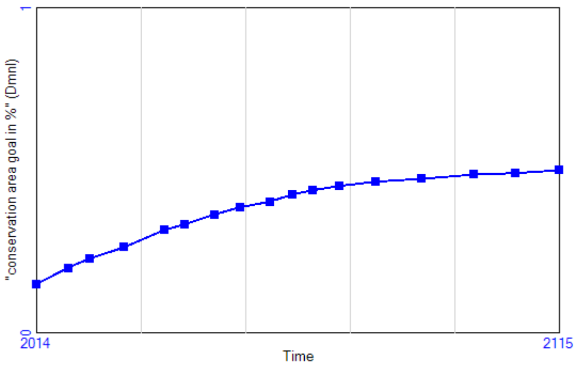
Table 1: Table with parameter and factor values and assumptions

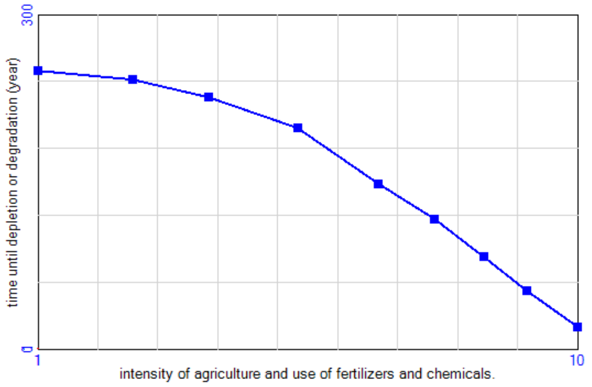
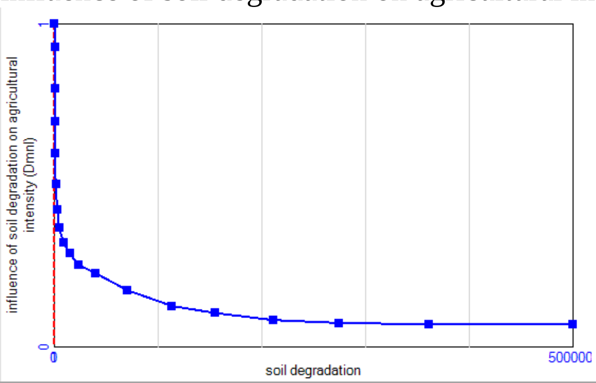
variable	Source
Biofuel industry Sub-model	
International biofuel demand growth rate Bio-2: 7% Bio-1: 2% Bio-0: 0%	(Renewable Fuels Association, 2015) (Navigant Research, 2014) (Faaij, Szwarc, & Walter, 2008)
Success of biofuel alternatives 	Assumption (Faaij, Szwarc, & Walter, 2008) (Navigant research, 2014) (FAO, 2008) Assumption (FAO, 2013) (FAO, 2013) (World Bank, 2015)
Initial international biofuel demand 92,000,000,000 liter/year (2015)	(Renewable Fuels Association, 2015)
International biofuel policy - BC: 0.7	assumption
fossil gasoline substitution with E100 	Assumption based on typical technological developments
Proportion of sustainability investments in R&D - 10%	Assumption
"Suriname's fuel (gasoline) price" - 1.2 $/l	(Ministry of Trade and Industry, 2015)
International ethanol price - 0.49$/l	(Trading Economics, 2015)
Allowed profit margin - 0.1$/l	assumption
Price of rest products (Vinasse and DDGS or Distiller's Dried Grains with Solubles, which can be used as fertilizer or kettle feed) - 200 $/ton	(vin2food, n.d.)
Construction time of biofuel logistics capacity - 2 years	Assumption
Construction time of biofuel production capacity - 4 years	Assumption based on (ERM, 2012)
Proportion of capital cost in logistics - 0.3	Assumption
Distance between refinery and port - 200 km	Average distance to Port Nieuwe Haven in Suriname's Capital Paramaribo, from the various potential biofuel refinery sites

Capital cost per liter per year 	Based on scale of capacity to be installed. (Coelho, Goldemberg, Lucon, & Guardabassi, 2006)
Average logistics capacity lifetime - 20 years	assumption
Proportion of capital cost in production - 0.7	assumption
proposed proportion invested in biofuel production - 0.35	assumption
Proposed proportion invested in crops capacity - 0.25	assumption
operational time per year of refineries - 345 days	assumption
average lifetime of biofuel plant - 30 years	(bp, 2012)
Time from refinery to market - 1 day	Assumption
Time from refinery to port - 3 days	Assumption
investment as proportion of total biofuel revenue - 20%	Assumption
investment as proportion of total crops revenue - 5%	Assumption
Time to conduct investment - 1 year	Assumption
construction time of crops capacity - 2 years	assumption
average crops capacity lifetime - 20 years	assumption
Capital cost per ton per year 	assumption
initial other refinery cost - 0.12 $/l	(Coelho, Goldemberg, Lucon, & Guardabassi, 2006)
Electricity cost 0.05 $/l demand per liter: 0.19 kWh -	(bp, 2012)
Initial feedstock yield per ha - 85 ton/ha	(Velasco, 2013) (UNICA-Brazilian Sugarcane Industry Association, 2015)
initial biofuel yield per ha - 6272.45 l/ha	(ERM, 2012)
Future efficiency or technology improvement in refinery	assumption

	
Crops related technological development rate Bio-2: 0.30 Bio-1: 0.26 Bio-0: 0.1	(The Transnational Institute, n.d.)
Initial feedstock production input - 1010.45 $/ha	(Hess, Wright, & Kenney, 2007)
Time from planting to harvesting - 5 months	(USDA, n.d.)
Lifetime (shelf life) of crops - 1 year	assumption
Government incentives on biofuel industry attractiveness - 0.1	assumption
Time to adjust planning - 6 months	assumption
Time to adjust biofuel production to demand - 3.5 months	assumption
Government taxes on biofuel - 0.5 $/l	assumption
Government subsidies/incentives on flex fuel vehicles - 0	assumption
policy determined mix of bio-ethanol in gasoline - 10%	assumption
Portion of international demand for Suriname's biofuel industry (How much of the international demand will Suriname supply in) - 0%	assumption
international biomass demand - 0 ton/year	assumption
Investment climate - 0.8	assumption
Electricity sub-model	
Percent change in electricity usage 	Assumption based on recent power demand developments in Suriname
Initial price of electricity - 0.22 $/kWh	(Energie Bedrijven Suriname, n.d.)
Demand elasticity to price - 1.3	Assumption
Construction time of bio-power plant - 1 year	Assumption
Capital cost per MW bio-power capacity –3,280,000 $/MW	(International Renewable Energy Agency, 2012)
Proposed proportion invested in bio-power plants - 0.15	Assumption
Influence of bagasse availability	Assumption

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

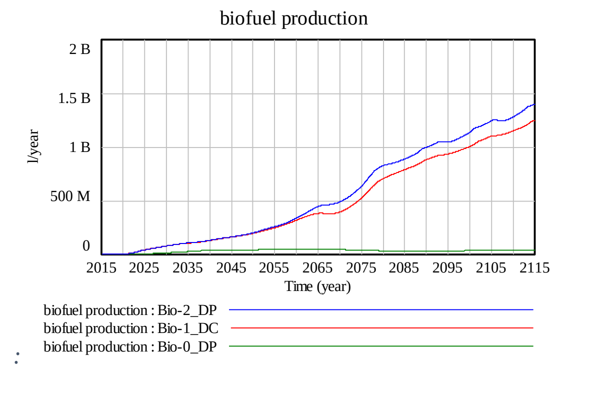
average annual change in population 0.96% - average change determined based on world bank population data up to 2014 and extrapolated to 2015 as base year.	(World Bank, 2014)
Influence of biofuel crops infrastructure on agriculture 	assumption
demand for settlement land per capita (This is land required for various urbanization activities both residential and industrial, but also activities like e.g. mining.) - 1 ha/capita	assumption
average yield for other agricultural crops (Cassava, citrus etc.) - 31 ton/ha	(FAO, 2013) (FAO, 2013)
average banana yield - 39.4 ton/ha	(Fact Fish, 2013)
Average rice yield - 4.5 ton/ha	(World Bank, n.d.)
deforestation time - 3 months	assumption
initial agri land 2015 - 120,000 ha	(Derlagen, Barreiro-Hurlé, & Shik, 2013)
Deforestation policy 	Assumption based on (Plouvier, Gomes, Verweij, & Verlinden, 2012)
Conservation area goal in % 	(Plouvier, Gomes, Verweij, & Verlinden, 2012)
average time to reserve land for preservation - 6 months	assumption
rate of cultivation change - 0.2%	Assumption

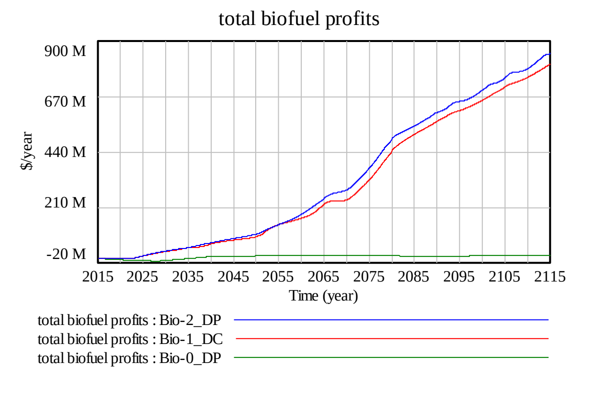
time to adjust crops cultivation - 3 months	assumption
cultivation time - 2.5 months	assumption
time for fallow agri land to degrade - 2 years	Assumption
time to convert unmanaged land into agri land – 3.5 months	Assumption
Time until depletion/degradation 	(UNICA-Brazilian Sugarcane Industry Association, 2015)
deforestation law strictness - 100	Assumption
Environmental sub-model	
CO_2 emission gasoline - 0.00235 ton/l	(U.S. Environmental Protection Agency, n.d.)
"CO2 emission for petrol (oil)" average for diesel and heavy stoke oil used in electricity generators - 0.00286 ton/l heavy fuel oil: 0.0031 ton/l Diesel: 0.0026 ton/l	(Government of Canada, n.d.)
NOx and SO4 emission gasoline - 0.000000921 ton/l	(Government of Canada, n.d.)
"NOx and SO4 emission for petrol (oil)"; 0.00000148 ton/l	(Government of Canada, n.d.)
time to adjust intensity; 5 months	Assumption
initial 2015 water irrigation availability - 55188 m^3/ha/year	Assumption based on the Nickerie area (in which Wageningen from the WSESP project is located) as important agricultural area with the important-for-irrigation Nani Creek (Henstra, 2013).
intensity of fertilizers and chemicals use 2015 - 3	Assumption
influence of soil degradation on agricultural intensity 	Assumption
2015 biodiversity - 35 species/1000ha	(World Bank, 2015)
soil degradation 2015 - 100 ha	Assumption

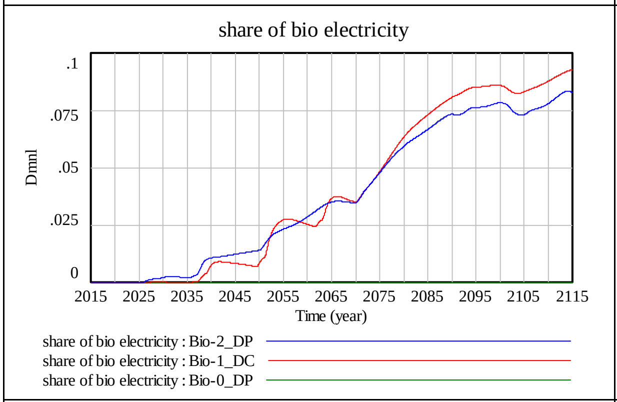
2015 total CO2 emission - 292683 ton/year (average) 183464.5 ton due to gasoline combustion in 2015 292500 ton due to diesel and heavy fuel oil combustion for electricity generation	Based on Surinamese fuel consumption in the considered sectors
2015 total NOx and SO_4 emission - 299.74 ton/year (average) 115.54 ton due to gasoline combustion in 2015 184.20 ton due to diesel and heavy fuel oil combustion for electricity generation	Based on Surinamese fuel consumption in the considered sectors

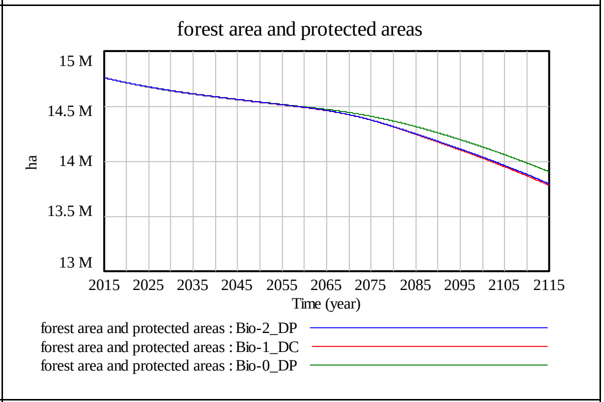
Appendix D. KPI graphs for Policy Scenario Analysis

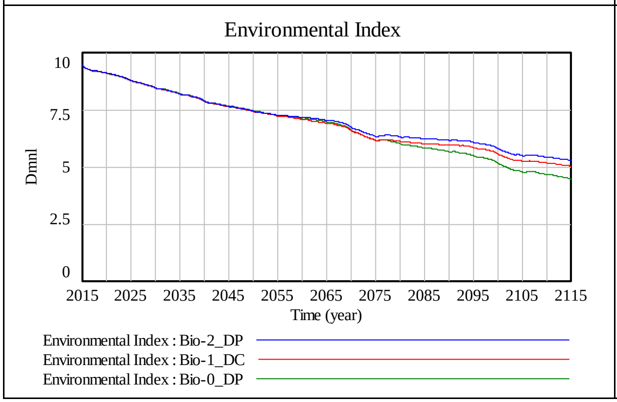
Table 2: the graphs for the KPI's when implementing DP under all three scenarios individually











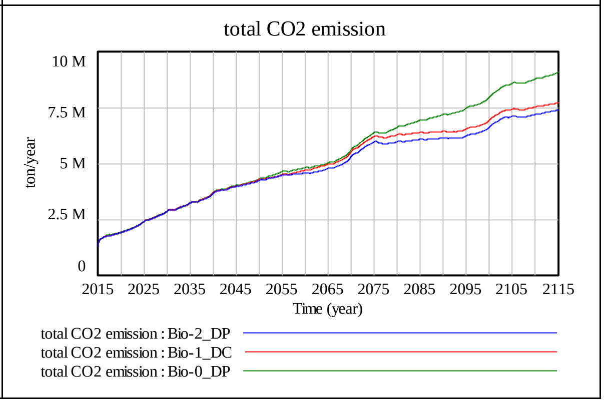
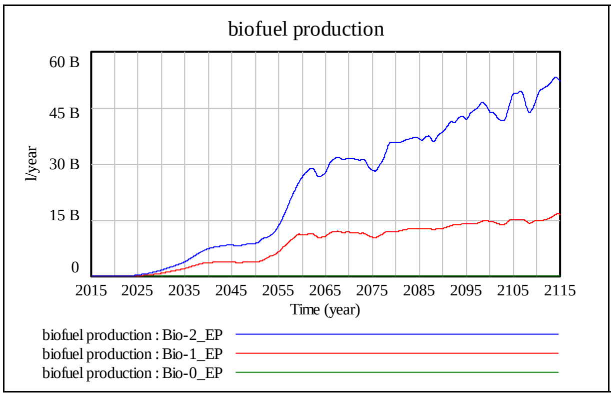
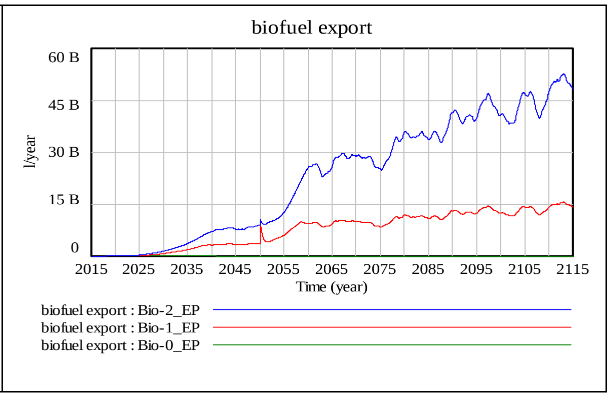


Table 3: the graphs for the KPI's when implementing EP under all three scenarios individually





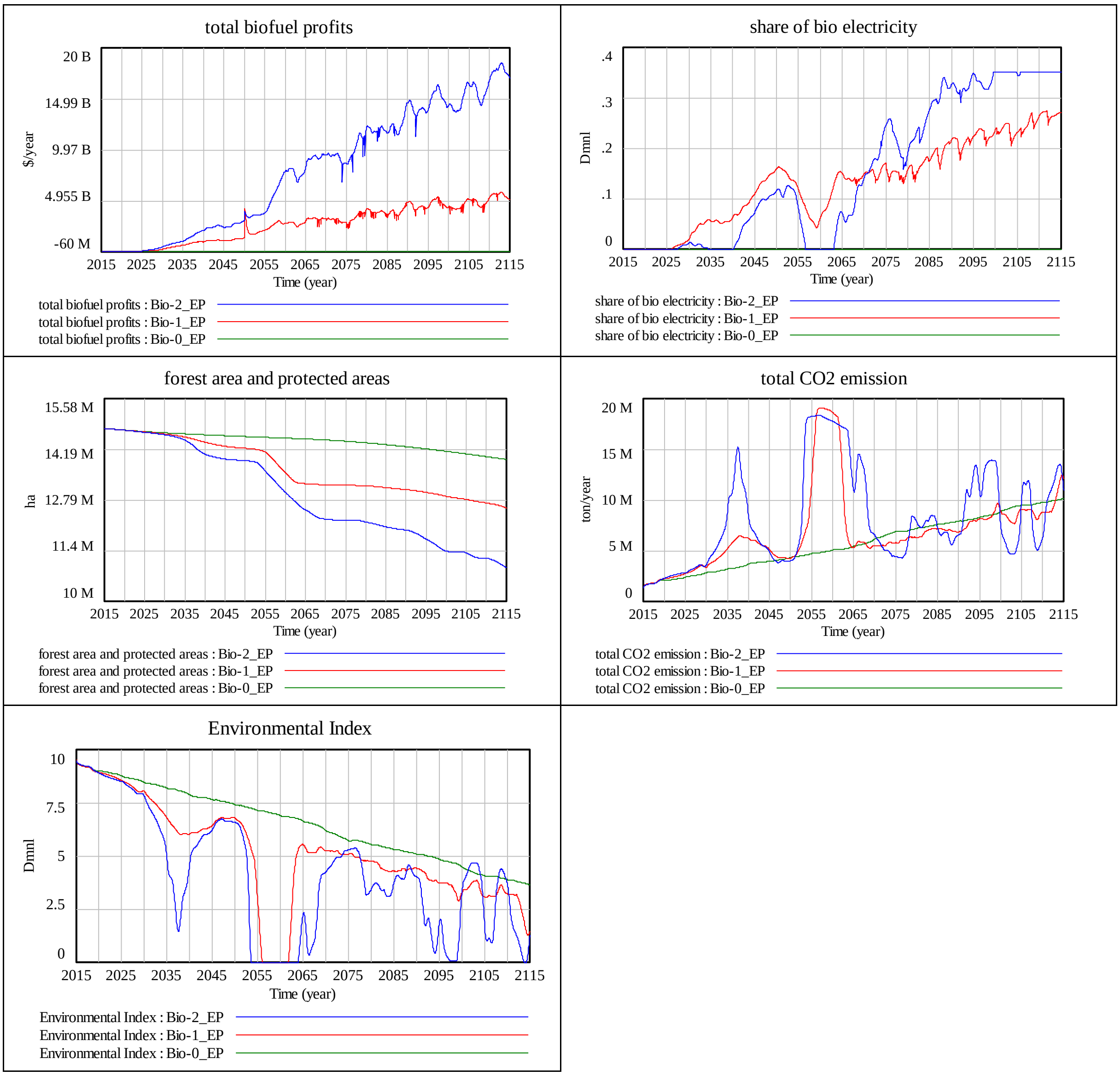
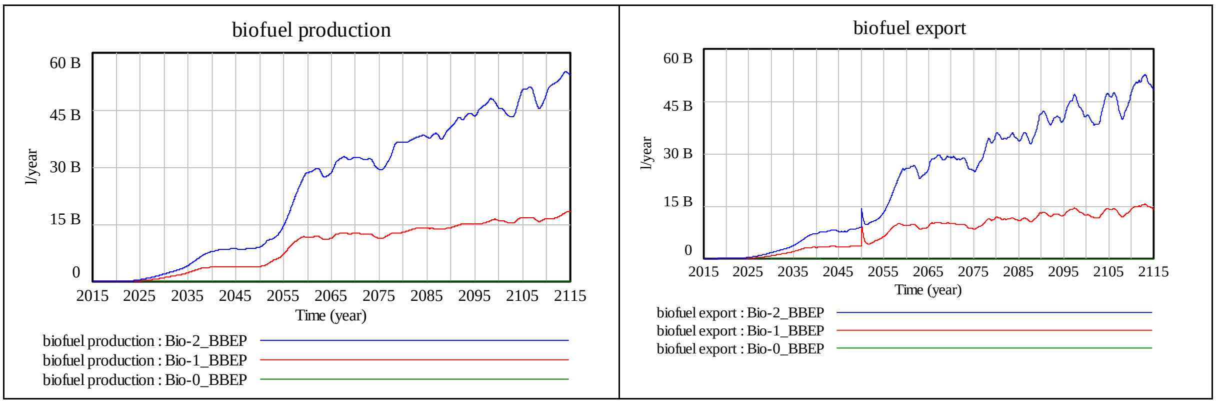


Table 1: the graphs for the KPI's when implementing BBEP under all three scenarios individually



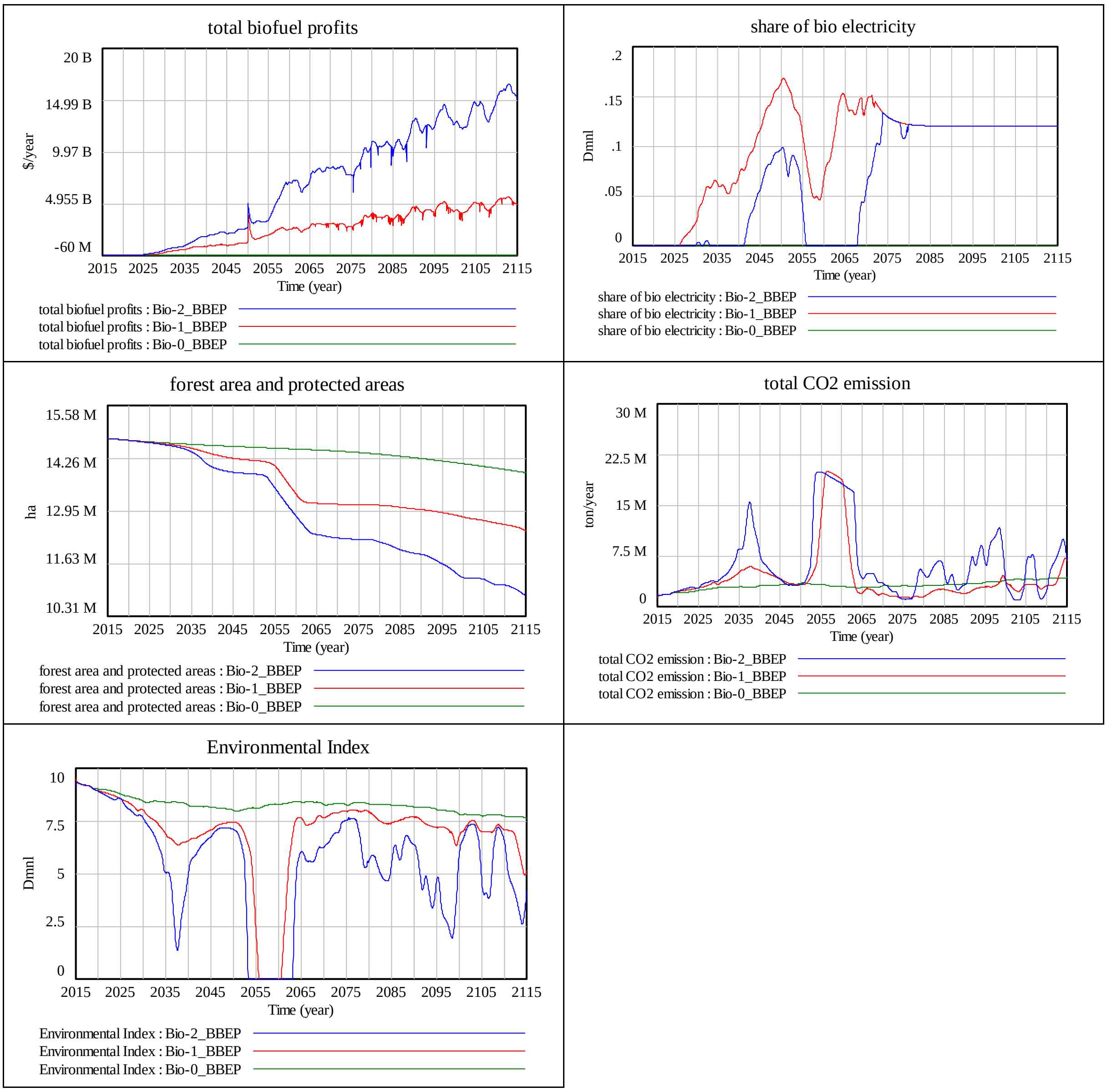
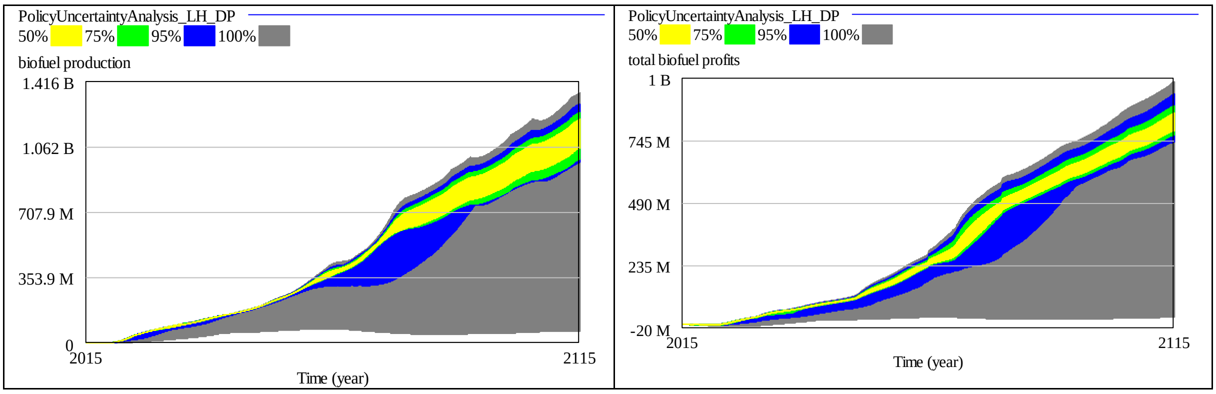


Table 2: Policy Scenario Analysis graphs of the KPI's for DP



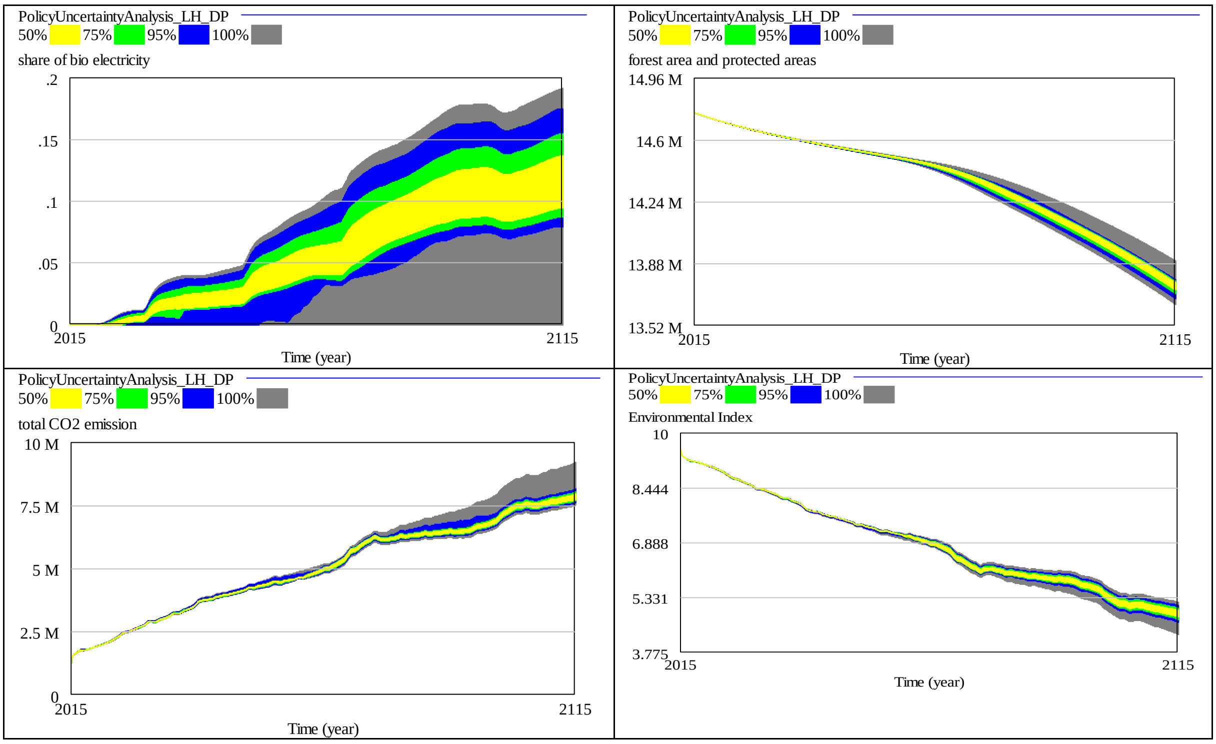
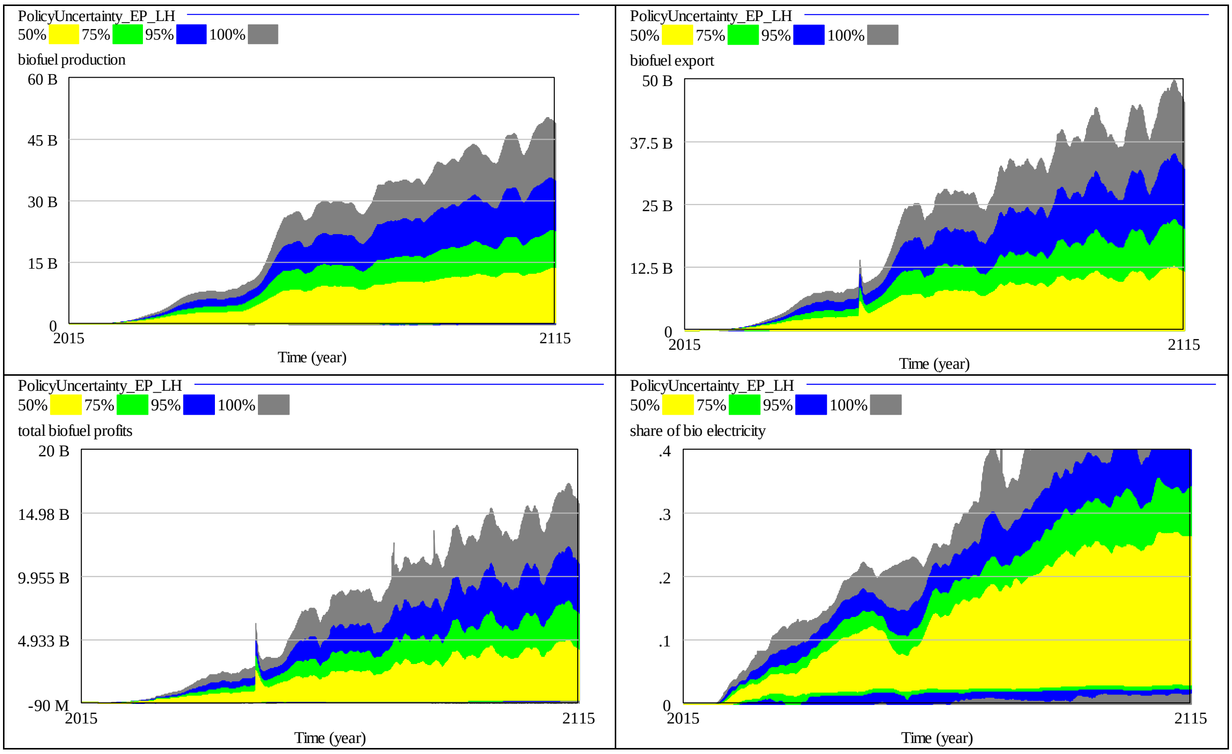


Table 3: Policy Scenario Analysis graphs of the KPI's for EP



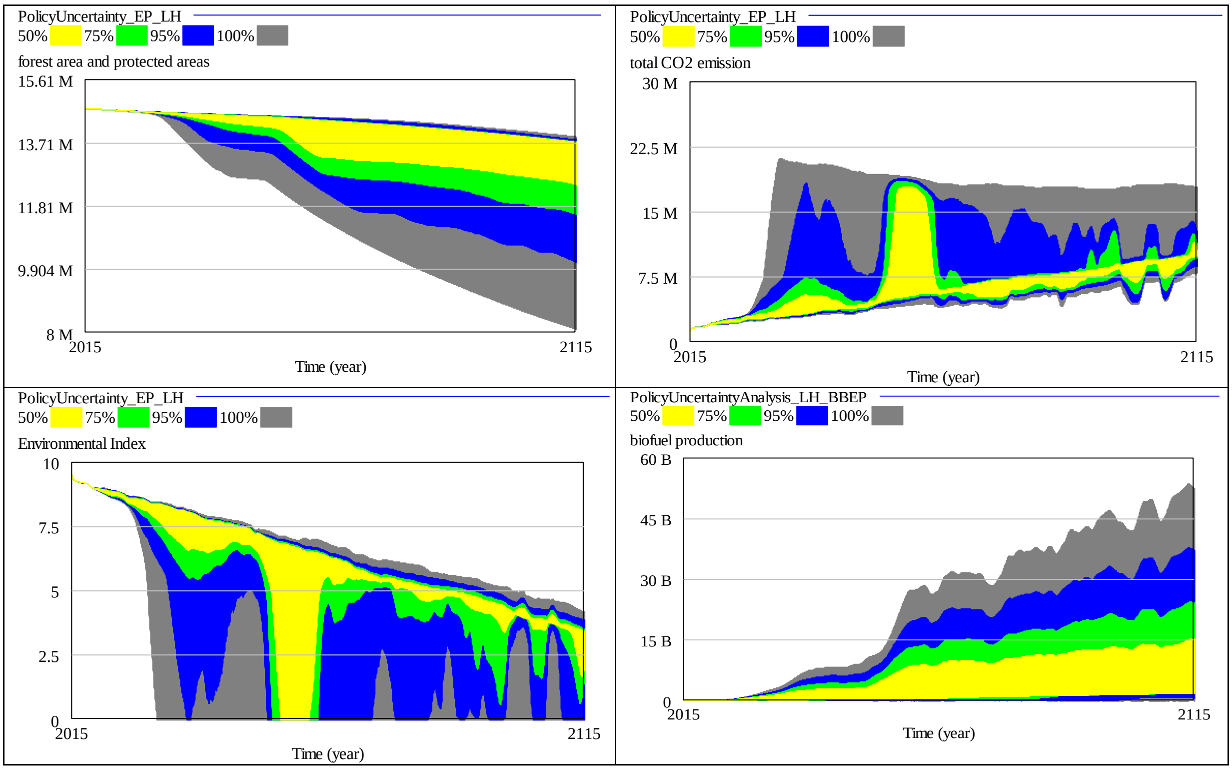
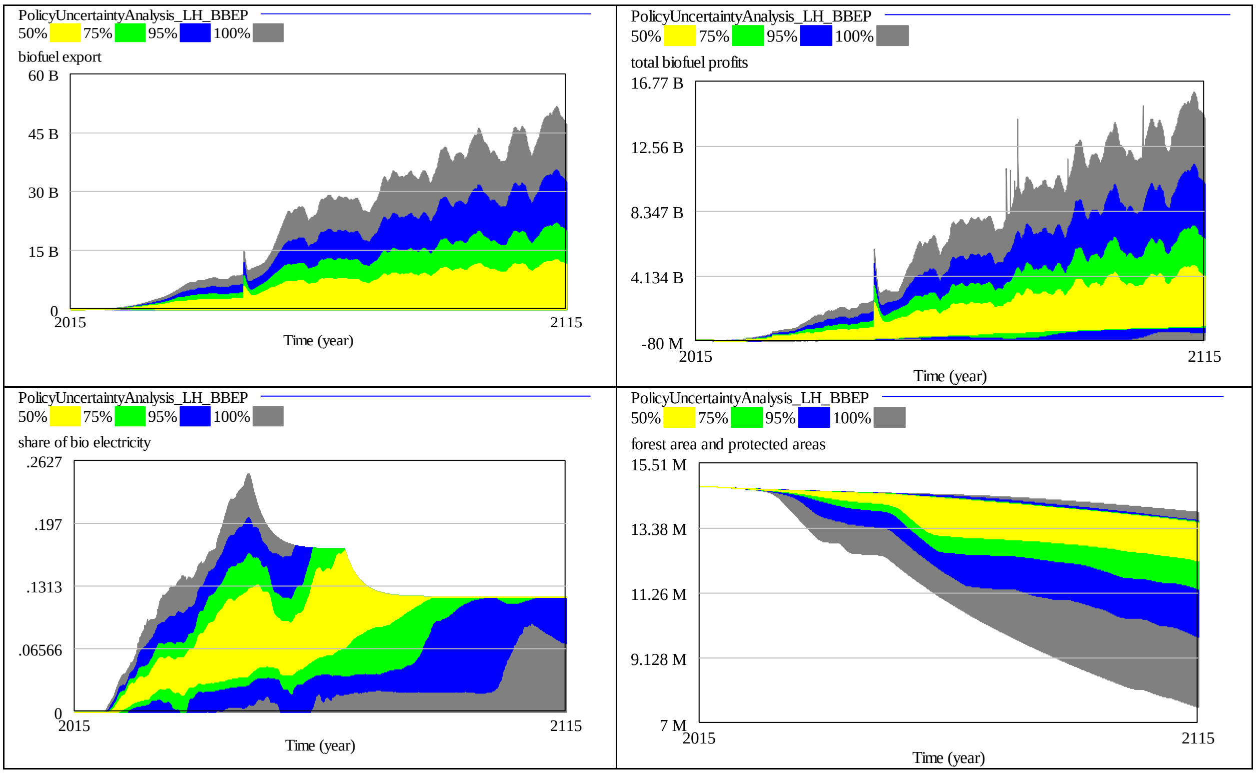
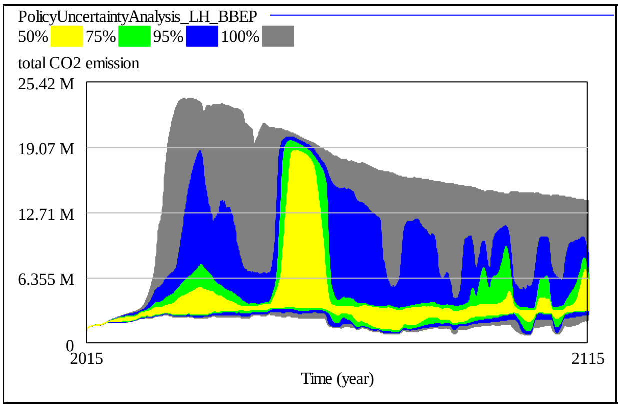
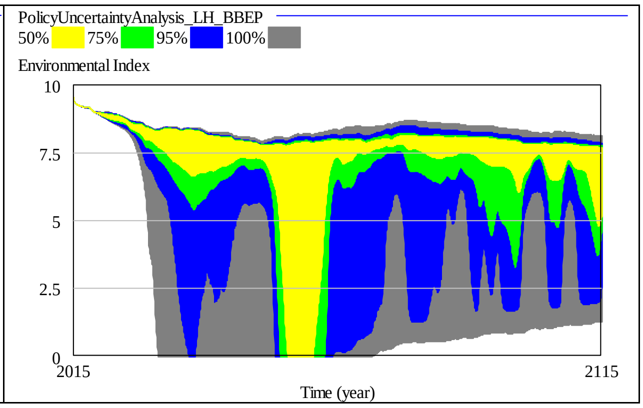


Table 7: Policy Scenario Analysis graphs of the KPI's for BBEP




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


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