Large-Scale Sugarcane Ethanol Production and Its Implications to Ethiopia

A System Dynamics Approach

By

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Abstract

Ethiopia imports oil products for its fuel requirements, and the demand for fuel is rapidly increasing. Research indicates that imported fuel accounts for the lion's share of the total import expenditure and absorbs much of the total export earnings, closer to 75%. Oil consumption from the transport sector is growing especially fast, accounts for nearly 49.5 % of the imported oil every year. Coupled with the fact that Ethiopia is a land locked country with no oil reserves, the issue has become a bottle neck for the overall development in the country. On top of its effect on the country's trade balance, significant increase in the GHG emission released from fossil fuel combustion in the transport sector is also another area of concern. In order to reduce oil import dependency and support the green economy effort in the country, ethanol production and official blending have been started since 2007. Although a lot of sugar factories are being built, the production and consumption of ethanol have shown a steady progress against the country's goals to make a shift to renewable energy sources and the need to build a greener economy. Hence, bio-fuel accounts for a small share in the transport sector. This is of concern because the resources used to produce sugar in the existing sugar factories are simply wasted when it is possible to further process and produce ethanol without requiring additional land use and other input changes. Various theories across agriculture, economics, energy, and environment sectors were combined and applied to build a bio-fuel energy simulation model for representing ethanol production on a country level. The model is calibrated to the case of Ethiopia and its sugar factories in order to test a large scale sugarcane ethanol production from molasses, a by-product from sugar factories that used to be thrown and dumped to rivers. Simulation results suggest that the current inputs in the sugar industry, land, water and capital, theoretically have the potential to significantly increase the level of ethanol production and reduce the level of oil products imported every year. Scenario tests indicate that outlining the appropriate blending strategy is vital for the sustainable and consistent implementation of ethanol substitution in the transport sector, and that performance could be further improved when ethanol production cost is subsidized for an amount of 3500 ETB per TOE ethanol.

Key words: Oil products import, Trade balance, GHG emission, Ethanol, Blending, Sugar factory, Model simulation, Ethiopia, Molasses, By-product, Subsidy.

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Acronyms

CRGE- Climate Resilient Green Economy

ETB- Ethiopian Birr (Currency)

EEA- Ethiopian Economics Association

EIA- U.S. Energy Information Administration

ERA- Ethiopian Road Authority

IEA- International Energy Agency

FAO- Food and Agricultural Organization of the United Nation

FAOSTAT- Food and Agricultural Organization of the United Nation Statistical Division

GDP- Gross Domestic Product

GHG- Greenhouse Gas

GTP- Growth and Transformation Plan

Lge- Liter of gas equivalent

MOFED- Ministry of Finance Economics and Development

MOWIE- Ministry of Water Irrigation and Energy

MW- Mega Watt

NBE- National Bank of Ethiopia

NOC- National Oil Ethiopia

OPEC- Organization of the Petroleum Exporting Countries

SD- System Dynamics

TOE- Ton of Oil Equivalent

WB- World Bank

Chapter 1: Introduction

Geopolitical tensions, energy price increases, uncertainties about remaining resources of fossil fuels and the environmental impacts of using such fuels, even if they exist, have provided a driving force for a strong interest in bio-fuels in many parts of the world (FAO, 2007). As a result, countries are strengthening their effort to look for alternative energy sources to mitigate the aforementioned problems. Bio-fuels are among the options considered as renewable and relatively cleaner substitutes for conventional energy sources. An increasing number of countries initiated bio-fuel production to meet domestic market and international demand; global production of these bio-fuels has been growing rapidly over the past years, reaching the level of 105 billion liters a year in 2010, 3% of transport fuel demand, (IEA-ETSAP and IRENA, 2013). The US and Brazil are the largest producers of ethanol, generating over 70% of the world's total production, whereas the EU (European union) produces almost 95% of the world's biodiesel (Slater, 2007 sighted by Ferede, T. et al., 2015). Nevertheless, bio-fuels' share of the energy mix is expected to grow over time as policy makers worldwide encourages greater bio-fuel production with tax exemptions, as well as blending and consumptions mandates & subsidies (Portner, B et al., 2014). For instance, the European Union has mandated that bio-fuel accounts for 10% of the energy used in transportation by 2020 while India's plan was to meet 20% by 2017 and Brazil was planning to expand its bio-fuel exports (Mersha, G., 2016).

Ethiopia has set a vision for greening its economy, Climate-Resilient Green Economy (CRGE) strategy, is based on its national Growth and Transformation Plan (GTP), which seeks to enable the country to reach middle - income status by 2025. Launched in 2011, the CRGE aims to support the improvement of agriculture, sustainable management of natural resources and poverty reduction (CRGE, 2011). The strategy is expected to play a major role in Ethiopia's near-term growth, transforming the country into a "green economy front runner" while fostering development and sustainability. One of the four major pillars the CRGE strategies rests on is strengthening the efforts toward reducing GHG emissions from transport fuel, as well as producing biodiesel and ethanol. The planned implementation of 5% biodiesel and 15% ethanol blends by 2030 (GTP I, 2010; Portner, B et al., 2014). Following the plan, Bio-ethanol production was started in 1999 with one sugar factory, Finchaa Sugar Factory. The factory had a production capacity of 1820 ton of ethanol from molasses and only one oil company, Nile Petroleum, took the initiative to blend and distribute (E5) to consumers during that period, but the blending and distribution of ethanol practically started in 2005.

Later in 2011, Metehara Sugar Factory was introduced to the production of ethanol with two additional oil companies as distributors, Oil Libya and NOC, and in the same year, the blending was adjusted to E10 (Sugar Corporation).

Energy is a backbone for the development of a nation. Ethiopia is producing various kinds of energy to fulfill its energy demand. Hydro power is a major source in addition to efforts on solar, wind and geothermal energy productions. However, there is a huge energy demand and supply gap which is currently covered by importing fossil fuel. Ethiopia is currently using 75% of foreign currency earnings from export sector to buy and import oil; the majority of the fossil fuel is used by the transport sector and this is a huge burden for the economy of the country. Bio-fuel production, which can be a substitute for fossil fuel that Ethiopia is currently importing, is given a little emphasis. Research shows that it is possible to totally substitute fossil fuel with bio-fuel or percentage mix can be used in the transport sector for road vehicles. There is a little effort in the country to produce bio-fuel energy. This little effort should be organized and converted to a large scale bio-fuel production level in order to minimize the huge energy gap in the country.

For a landlocked country like Ethiopia, it wouldn’t be realistic to merely depend on imported oil to satisfy its energy demand. Hydro power is currently considered as the major source of energy for green economy, but this effort has to be strengthened and supported by other renewable energy sources.

We therefore understand that the growth in oil import is a critical problem, and reducing dependence on foreign oil can release important resources to support progress in other development areas and this research aims to address the following questions in the rest of this thesis:

- Is large- scale ethanol production from sugarcane as a by-product of sugar factories, a possibility?
- Can ethanol support the effort in oil products import?
- What proportion of blending is appropriate given the production capacity and the consumption trend in the transport sector?
- Is ethanol blending cost effective compared to international fuel market price?
- How can the country be benefited in reducing the GHG emission resulted from ethanol substitution in the transport sector?

This thesis is organized in six chapters. An overview of the literature covering related areas; various concepts and definition of bio-fuel energy are discussed in the second chapter. In the third chapter, the dynamic problem, hypothesis and a detailed description of the model, sub-divided in major sectors, is presented. The fourth chapter includes the model validation tests and the comparison between the simulation results and historical data. The fifth chapter explains the future policy options and the test of policies under various scenarios. The conclusion, limitations and recommendations of the study are presented in chapter six.

Chapter 2: Review of Related Literatures

Although bio-fuel is a collective term for liquid and gaseous fuels derived from renewable sources, including ethanol, biodiesel, and other renewable liquid fuels (EIA, 2012), this study focuses on ethanol, the most widely available bio-fuel. Various researches show that currently, bio ethanol is produced in a larger quantity worldwide and used as a substitute for both diesel and gasoline consumption, especially in the transport sector. However, the subject also poses an important question on the effect of bio-fuel production on food security, as resources such as land and water are scarce, especially in developing countries. The impact of bio-fuel production on GHG emission reduction is also an area of concern that needs to be addressed.

This chapter discusses the sustainability of producing bio-fuel ethanol in the Ethiopian context; it reviews various literatures on the appropriate feedstock selection based on the resources required to produce bio-fuel without affecting the food security of the country.

2.1. Definition

Bio-fuels are liquid and gaseous fuels that are produced from biomass feedstock. They can complement and/or replace fossil fuels and reduce carbon emissions in the transport sector with/without modest changes to vehicle technology (i.e. engines) and to the existing infrastructure for fuel distribution (IEA-ETSAP and IRENA, 2013). Based on the biomass feedstock, bio-fuels are classified in to three different generations (Biofuel.ORG.UK; IEA-ETSAP and IRENA, 2013).

- First generation bio-fuels: food crops are used as a feedstock in this category. The bio-fuel is ultimately derived from the starch, sugar, animal fats, and vegetable oils that these crops provide. Corn, wheat and sugar cane are the most commonly used in this generation.
- Second generation bio-fuels: the feedstock used in this generation are generally food crops but the only time the food crops can act as second generation bio-fuels is if they have already fulfill their food purposes. For instance, waste vegetable oil is a second generation bio-fuel because it has already been used and is no longer fit for human consumption.
- Third generation bio-fuel: bio-fuel of this generation is derived from algae and it is a very recent phenomenon. Previously, algae was under the category of second generation bio-fuels, however, when it is identified that algae are capable of much higher yields with lower resources inputs than other feedstock, they moved to their own category.

According to (IEA-ETSAP and IRENA, 2013), first generation bio-fuels are referred as conventional bio-fuels and they are based on commercial feedstock and processes currently in use in many countries including the most common bio-ethanol, bio-diesel and bio-gas. Whereas, second and third generation bio-fuels are referred as advanced bio-fuels and are limited with respect to application, on a research phase.

2.2. Performance and sustainability

2.2.1. Food Vs Bio-fuel Debate

The production and utilization of bio-fuels has been implicated to compete with food production. A study by (GAIA Association, 2014) confirms that this is not the case and in fact bio-ethanol assists food production. Major feedstock of bio-ethanol is molasses which is a by-product of sugar production. Molasses would be a source of pollution for the environment if not used for ethanol production. Hence ethanol production from molasses has three fold advantages.

(Mersha, G., 2016) under a study that investigates the economy wide impact of bio-fuel investment in Ethiopia, indicates that bio-fuel development is a positive motivator to enhance economic growth, food security, improve welfare and reduce poverty. The research also claims that the benefits of bio-fuel investment would further be improved if it results in technology spill over to other agricultural crops. In addition, a report (IEA-ETSAP and IRENA, 2013) indicates that apart from sugar cane ethanol, the large-scale production of liquid bio-fuels based on today's technology and feedstock would compete with food production for arable land and water. However, the report admits that bio-fuel has a capacity to substantially reduce greenhouse gas (GHG) emissions in the transport sector (70%-90% compared to gasoline). It also suggests that by using shared international standards and implementing further research and development strategy, it is possible to produce bio-fuels in a sustainable manner by minimizing the possible environmental and social impacts due to land use change and competition for food.

(Birur, D., 2016) assessed the sustainability of bio-fuels production in china and the analysis indicates that it is possible to sustainably meet the stated bio-fuel demand of the country without substantial impact on food supply and water needs.

(Rosa, 2005) also claims that countries with large territories and small oil resources can profit from the use of ethanol to satisfy part of their fuel requirements, and added that ethanol is more efficient than gasoline as an automotive fuel.

2.2.2. Feedstock Selection

Review of (IEA, 2008) on bio-fuel industry and research development activities leveled sugar cane ethanol as an exception; it is already being successfully produced in several African and South American countries. The report, however, indicates that some bio-fuels have received considerable criticism recently as a result of rising food prices, relatively low greenhouse gas abatement (or even net increases for some bio-fuels based on full life cycle assessments), impacts on land use change.

The following table indicates the performance of some feed stocks in the process of bio-fuel production.

Performance		bio-ethanol		bio-diesel
feedstock	cereals, maize	sugar beats	sugar cane	vegetable oils
Fossil fuel energy input (%)	60-80	na	10-12	30-40
production cost ($/lge)	0.6-0.8	0.6	0.3-0.5	0.7-1.0
co2 reduction %	15-25	50-60	90	40-60
land use (lge/ha)	1500-3000	2000-4000	3000-6000	700-1300 (3000-palm)
Crop water requirement(m3/kg)	0.84	0.2	0.12	2.02rapeseeds 3.20-soybean

Table 1: Feedstock performances

Source: IEA, 2007; H. Yang et al., 2009

Ethanol from sugar cane feedstock uses fossil fuel input 10%-12% of final energy and results in up to 90% of CO_2 reduction compared to gasoline. Production of ethanol from sugar cane is energy-efficient since the crop produces high yields per hectare and the sugar is relatively easy to extract. If bagasse is used to provide the heat and power for the process, and ethanol and biodiesel are used for crop production and transport, the fossil energy input needed for each ethanol energy unit can be very low compared to 60%-80% for ethanol from grain. As a result, ethanol CO_2 emission can be as low as 0.2-0.3 kg CO_2 eq per liter of ethanol compared with 2.8 kg CO_2 per liter of conventional gasoline, which is 90% reduction (IEA, 2007).

Water foot print is the volume of water consumption per unit of feedstock crop. Water required for producing a kg of sugar cane is estimated around 0.12 m^3 (H.Yang et al., 2009). Based on the study, sugar cane consumes less water than the rest of the feed stocks.

2.2.3. Emission from agricultural production

Refers to the GHG emission resulted from agricultural operations, cane harvesting and transportation, and fuel oil consumption for the production of chemicals and the energy embodied in equipment, buildings and their maintenance (Alckmin, G & Goldemberg, J., 2004).

Based on the report (IEA, 2007), using a liter of sugar cane ethanol enables 90% co_2 reduction that could have been emitted in a liter of gasoline; using one liter of gasoline results in2.8 kg of CO_2. The rest 10% emission is caused due to the use of fossil fuel during the harvesting, production and distribution period and this of course could be avoided by using ethanol in this process too. In the process of growing sugar cane feedstock and harvesting, the release of GHG emission during cane field burning and the release of N_2O from the soil due to fertilizer decomposition are considered as the major sources of GHG emission (Alckmin, G & Goldemberg, J., 2004). Logically, there is no additional emission from agricultural production caused by ethanol production in this context of Ethiopia; as ethanol is a byproduct of sugar production process and there is no special addition of cane plantation for this purpose. As long as the sugar factories produce sugar, sugar cane plantation is inevitable whether ethanol is produced or not. But, this study tries to look at the case 'what if ethanol is produced as a main product in a separate process?', somehow a conservative approach. And hence, although there are various sources of GHG emission in the process of sugar and ethanol production some of them can be ignored as their level of emission is very low and two emission sources can be considered as major (Alckmin, G & Goldemberg, J., 2004).

The sugar cane plant that is used as a feedstock should be burned and cropped before it is delivered to the processing plant. The reason for this is that the stalks are separated from the leaves, which are burned and whose ashes are left in the field as fertilizer, and from the roots that remain in the ground to sprout for the next crop. Researches from Brazil show that 77% of the mass of the raw can represents burned and cropped cane that is ready for further processing (Rosa, 2005). On the other hand, Ethiopian based research shows that the clean stalks of a sugar cane plant represents around 50% of the total weight (Birru, 2016). Methane and N_2O emission from this process of burning sugar cane trash is equivalent to 9 kg CO_2 eq per TC (tone of cane). Whereas, N_2O soil emission refers to the use of nitrogen fertilizers starting from cane planting and for the whole cane cycle. Most of the fertilizers used are of the NH_4 type and the resulting emissions are 1.76 kg N_2O/ha/year; since N_2O has a global warming effect of 296 larger than CO_2, these results in 521 kg CO_2 eq/ha/year or 6.3 kg CO_2 eq/TC (Alckmin, G & Goldemberg, J., 2004). In addition, methane emissions from bagasse burning in boilers could be ignored because significant unburned organic compound emissions, including methane, in bagasse fired boilers take place only during operational transients or uncontrolled disturbances in the combustion process. Because of almost continuous operation during the crop season, which is the ethanol production period, such transients and disturbances are relatively small in the ethanol distilleries and sugar mills, and this substantially reduces methane emissions.

In addition, the expansion and new sugar factory projects in Ethiopia have plans to integrate sugar and electricity production (Dechassa, B., 2009). According to the study, 40.7, 41.82, 9.00, and 86.61 MW power from Wonji-shoa, Metahara, Finchaa and Tendaho sugar factories respectively, will be cogenerated to fulfill the captive requirement for sugar and ethanol processing and the excess be available to be sold to the national grid.

Chapter 3: Research Problem and Hypothesis

The objective of this research is to develop and test a system dynamics model for analysis of economic and environmental impacts of the production of bio-fuel and of the process of substituting (blending) it with fossil fuel in the transport sector. We do so with the aim of identifying possible interventions to reduce fossil fuel import and consumption, with a particular focus on transport sector. Providing a complete picture of the process that starts with feedstock production, actual ethanol processing and extends to fuel substitution phase requires detailed descriptions from several perspectives.

In the following section of this chapter, we begin this process by discussing the causes of the problem and identifying the systems structure underlying the problem behavior based on information from various sources. On the later section of this chapter, the structural components of the model (SD) are presented with their details in the form of a description of each sector.

3.1 The Problem of Oil Import over the Years

Ethiopia imports oil products for its fuel requirements, and the demand for fuel is rapidly increasing, which is associated with its growing economy and expanding infrastructures. Imported fuel accounts for the lion's share of the total import expenditure and absorbs much of the total export earnings. According to a report produced by the secretariat of the round table on sustainable bio-fuels (EPFL energy center, 2012), fuel import accounts for over 90% of Ethiopian foreign earnings and suggests that looking for alternative fuel is important to cover domestic fuel needs as well as a potential export opportunity. In addition, ministry of water irrigation and energy (MoWIE, 2014) in its annual report indicated that the entire fuel import requirements is worth over 80% of the foreign currency earning annually, and that the demand for fuel is increasing rapidly due to the growing economy and expanding infrastructure. The ministry finally suggested that it is very critical to look for alternative energy sources. The growth in oil import is thus a critical problem for the country's overall development, and reducing dependence on foreign oil can release important resources to support progress in other areas. In addition, the GHG emission resulted from transport sector; the major consumer of the imported fuel has been increasing significantly against the country's goal in reducing the emission level to today's (2010) 150m ton by 2030, a total of 250m ton reduction from the projected 400m ton.

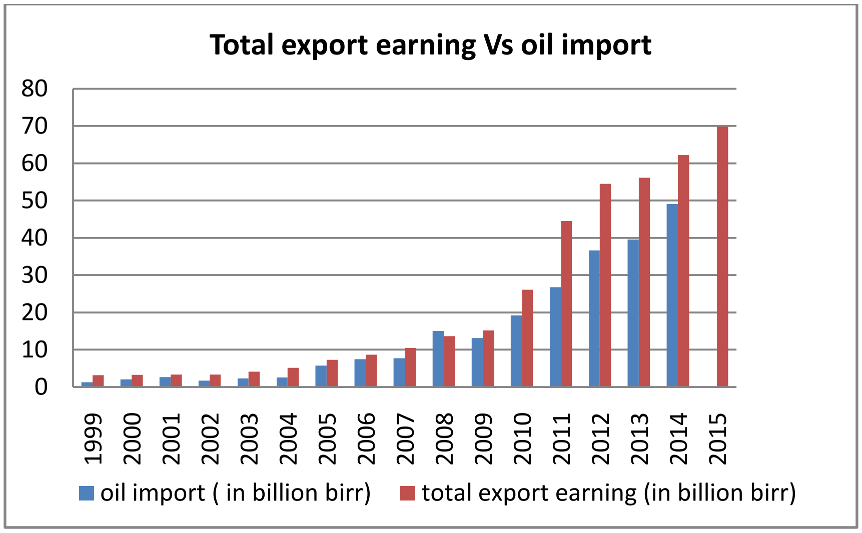


Figure 1: Ethiopian oil products import compared to total export earnings

Source: IEA World energy balance; NBE

Figure 1, illustrates how the value of the country's oil imports has increased substantially overtime. More specifically, the value of oil imports relative to export earnings has increased from 41 % in 1999 to 78 % in 2014. In 2008 the country's oil bill exceeded for the first time the total export earnings (WB, 2010; NBE, 2010 sighted by Mersha, G., 2016). The high cost of oil imports has aggravated the country's balance of payments problem, and has serious implications on the macroeconomic stability of the country.

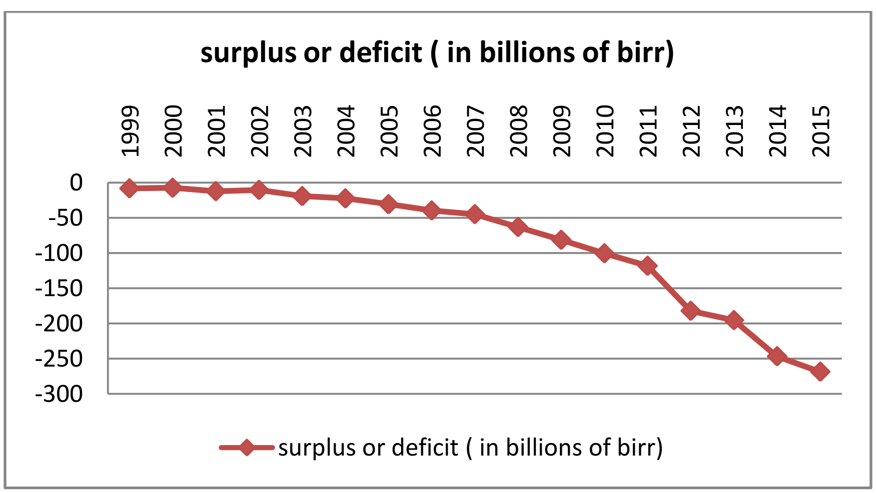


Figure 2: Value of surplus or deficit

Source: NBE Annual report 2015/2016

The increasing oil import demand is the result of the growth in economic activities: GDP has been growing double digit rate (on average 11% in real GDP) witnessed by the country for over the last 12 years (MoFED, 2010; NBE, 2010).

Oil consumption from the transport sector is growing especially fast. The sector accounts for an average of 49.5 % of the imported oil consumption per year. Road transport handles more than 95% of both passengers and freights mobility in the country (Tefera, T., 2012).

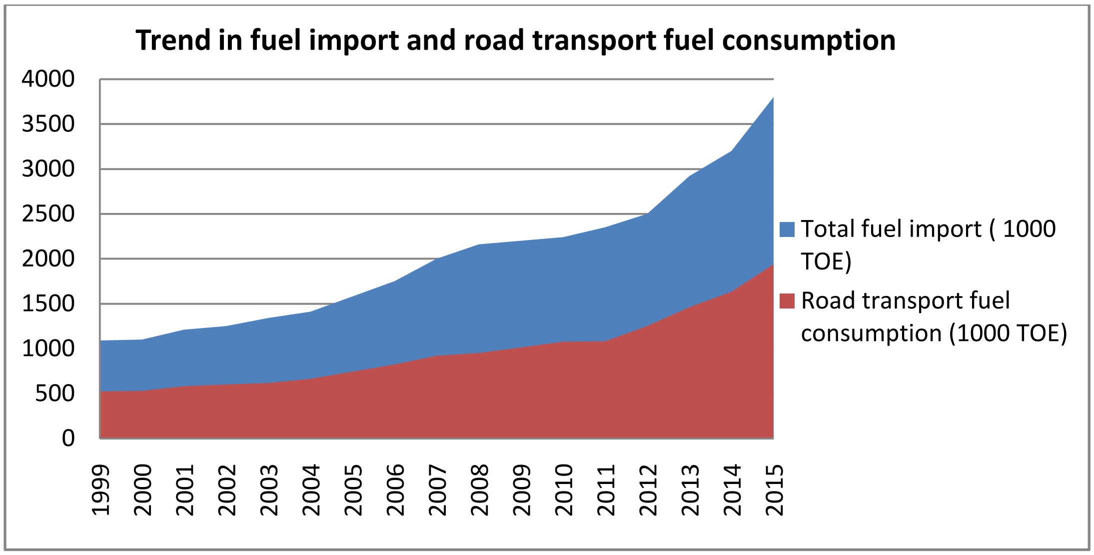


Figure 3: Trend in fuel import and road transport fuel consumption

Source: IEA World energy balance; NBE

Due to the fact that Ethiopian economy is growing, the amount of fossil fuel consumption in various sectors has also been increasing over the last twelve years. As a result, the GHG emission level from fossil fuel combustion has shown a tremendous increase. Fossil fuel combustion in the transport sector is the major source of GHG emission, accounting for nearly 48% of the total GHG emission released from fossil fuel combustion; which is not in line with the country's objective of limiting net GHG emissions in 2030 to below today's 150 MT of CO_2e which is around 250 MT CO_2e reductions from estimated (CRGES). Ethiopia's contribution to GHG emission is very low on a global scale. However, the projected environmental impact of conventional economic development in Ethiopia risks following the pattern observed around the globe. If current practices prevail, GHG emissions in Ethiopia will more than double from 150 MT CO_2e to 400MT CO_2e in 2030. On a per capita basis, emission are set to increase by more than 50% to 3 ton CO_2e, and will thus exceed the global target to keep per capita emissions between 1 to 2 ton in order to limit the negative effects on climate change (CRGES).

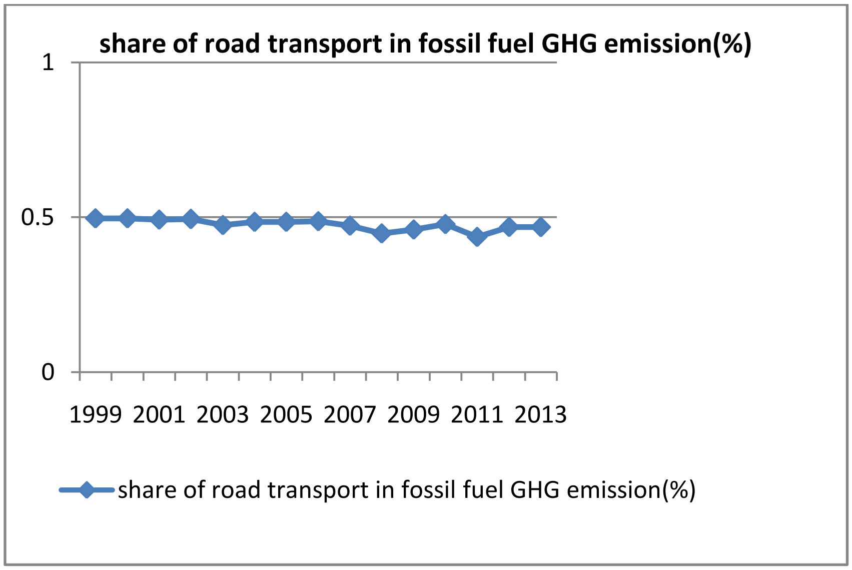


Figure 4: Share of road transport from total GHG emission from fossil fuel combustion

Source: Author calculation from The World Bank.

In order to reduce fossil fuel dependency and mitigate GHG emission, bio-ethanol production was started in 1999 with one sugar factory, 'Finchaa' Sugar Factory. The factory had a production capacity of 1820 ton of ethanol from molasses and only one oil company, Nile Petroleum, took the initiative to blend and distribute (E5) to consumers during that period, but the blending and distribution of ethanol was practically started in 2005. Later in 2011, Metehara Sugar Factory was introduced to the production of ethanol with two additional oil companies as distributors, Oil Libya and NOC, and in the same year, the blending was arbitrarily adjusted to E10 (Sugar Corporation) thinking that the production could increase. But since there was not a strict blending policy and due to limited production and supply of ethanol, share of ethanol in the transport sector remains insignificant. In fact, the government issued a directive in the year 2000 in order to implement the plan. However, the directive couldn't be implemented yet because of the reluctance of both the oil companies and concerned government organs (EEA, 2007).

This research aims at assessing to what extent and under what conditions bio-ethanol can be produced and used as a substitute for fossil fuel in the transport sector. More specifically, I perform a broad cost-benefit analysis, including the following factors:

- Resources needed to produce bio-ethanol
- Cost of production compared with fossil fuel market price
- The economic benefits arising from bio-ethanol production and its effect on the country's trade deficit.
- The effect of ethanol production on GHG emission

A system dynamics (SD) model is developed as a tool to understand the dynamics of fuel production, supply and demand, and their effect on the economic activities, their environmental impacts, and existing natural resource constraints (primarily, land and water).

3.2 Hypothesis

3.2.1. Stock and flow structure

3.2.1.1. Transport sector oil consumption

The overall growth in the transport infrastructure and the increase in the number of vehicles in the country trigger fuel consumption in the transport sector. The number of vehicles in the country was initially (1999) at around 80,000. Vehicles include motorcycles, tricycles and four wheels. The number has been growing on an average rate of 10% per year (Amibe, D.A, 2012; Tefera, T., 2012) and reached 519,816 in 2014 (MEF, 2015).

The number of vehicles is affected by the inflow of growth rate that shows the growth in the number of vehicles every year. The rate is put as 'net' because it considers the number of vehicles that are retired (obsolete) every year; most of the information on vehicles growth rate in the country is put in terms of a net value, therefore, for the purpose of this analysis, net indicates the difference between imported vehicles plus domestically produced and the reduction of those that are obsolete every year. The growth rate is expected to slow down in relation with the increase in taxes, currency devaluations and carrying capacity of the roads available in the country.

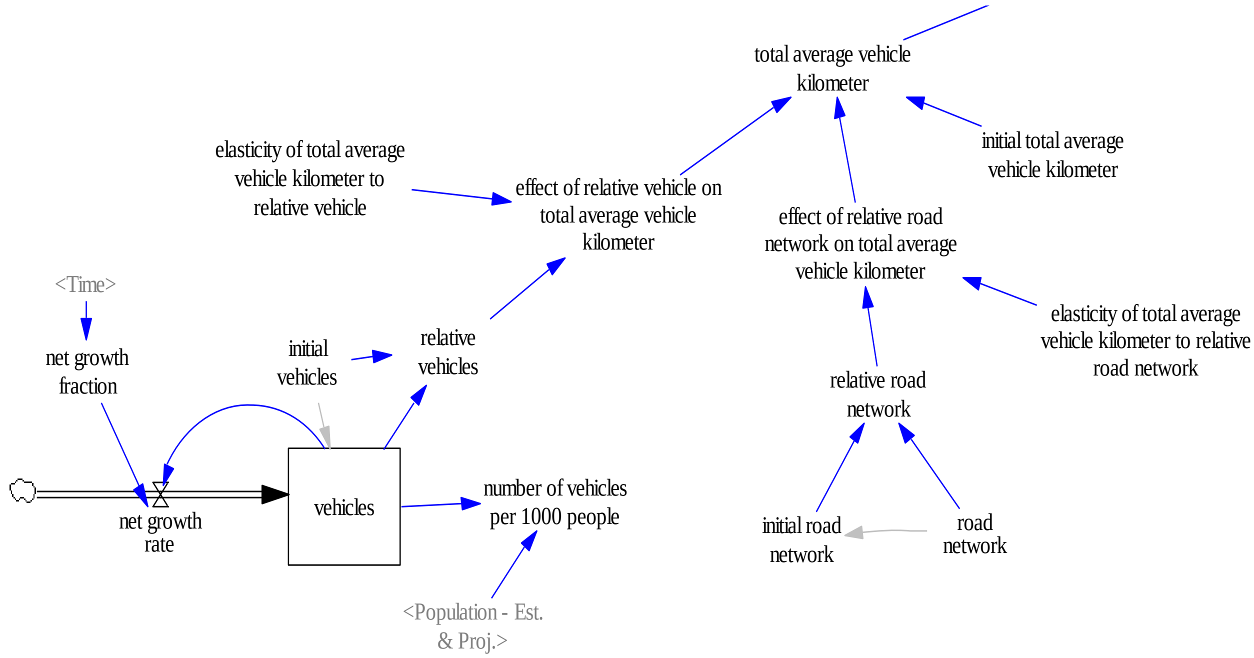


Figure 5: Stock and flow structure of transport sector oil consumption

Total average vehicle kilometer is an indication of the extent of utilization of roads and vehicles and it is also useful in studies of consumption rates of energy (fuel) and others. Average vehicle kilometer indicates the total length of vehicles travel per day multiplied by days in a year. As stated in the annual traffic count report on the federal road network in Ethiopia (ERA, 2011), the total average vehicles kilometer during 2008 and 2009 estimates around 4 billion and 5 billion km respectively. Based on this and through model calibration, we estimate the initial total average vehicles kilometer to be 2.1 billion as there is no data back to date 1999.

Total average vehicle kilometer is affected by the change in the number of vehicles with an elasticity of 0.6, if a 100% increase in the number of vehicles, it will have a 60% increase in the total average vehicle kilometer. Normally, the elasticity would have been 1 or more but, in the Ethiopian context, most of the vehicles are accumulated in major cities of the country and as their number increases, the traffic congestion will also increases and the work load is distributed to the available vehicles due to competition. As a result, the total kilometer that vehicles cover is assumed to increase in a slower pace.

Total average vehicle km is also affected by the road network in the country with an elasticity of 0.6. The assumption is based on the fact that most of the road networks are built towards rural areas and small towns where mobility of the people is minimal and most of the business activities between these small towns and the big cities increases only during public and religious holidays, and during harvesting times of the year. Apart from those days, the available roads give a very minimal service.

Total average vehicles kilometer is also subject to fuel price change. Based on a report (GIZ, 2013) on transport elasticity, the elasticity of vehicle-km with respect to fuel price is estimated around -0.16 in the short run and -0.26 in the long run. This figure is estimated based on information on areas with high vehicle ownership (more than 450 vehicles per 1000 people). Whereas, vehicle ownership in Ethiopia is around 5 vehicles per 1000 people in 2015 (Federal Transport Authority, 2016) and there are no various options to travel e.g. rail ways and electric cars, vehicles km is assumed to be inelastic to fuel price. Therefore, an elasticity of -0.02 is used for this study purpose.

Calculating total average vehicles km and multiplying it with average vehicle fuel consumption per km help us estimate the total fuel consumption by the transport sector. A small share of bio-fuel is considered starting from 2005 as bio-fuel, for the first time, was introduced as a substitute (E10) in this same year.

3.2.1.2. Oil Products Import

Oil products import constitutes the sum of transport sector fuel consumption and other sectors fuel consumption adjusted by the country’s energy efficiency. Even though 100% energy efficiency is almost impossible, energy efficiency of 1 is used for this research purpose as there are no research findings in the area. Whereas, the proportion of other sectors fuel consumption from the total fuel consumption demand is considered as (1- average share of transport sector fuel consumption), in this case it is 49.5%. And the figure is cross checked against the data values found from various sources. A report from the Ethiopian economic association (EEA, 2007) indicates that the major sectors that consume petroleum fuels in large quantities are the transport, household and industry; among the three major sectors, the transport sector has the highest share (51%) of the consumption of fuels in the country. In fact, all other sectors put together consume less fuel than this sector. The following figure shows the values of other sectors yearly fuel consumption from the year 1999 – 2014.

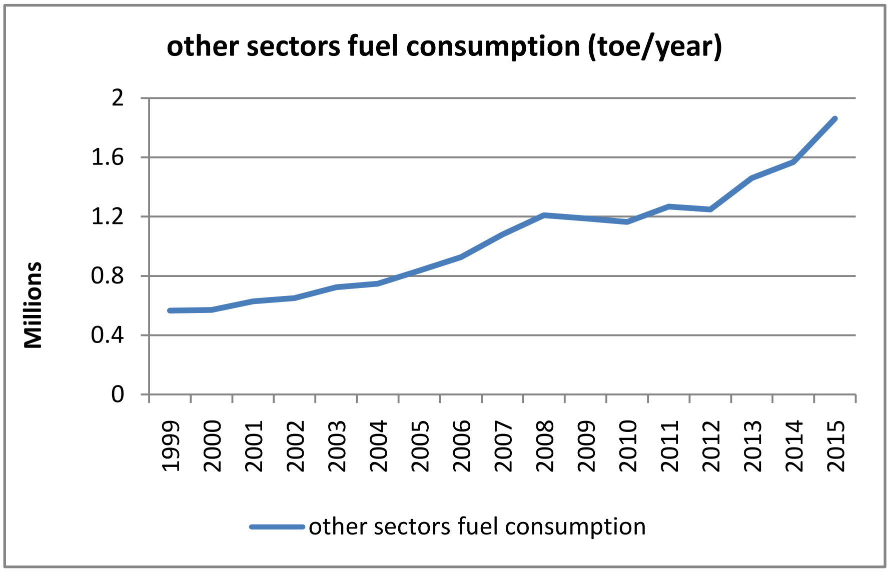


Figure 6: Fuel consumption from sectors other than transport

Source: own calculation from IEA; NBE

3.2.1.3. Trade surplus or deficit

The surplus or deficit could have various components in the real situation, but for this study purpose, surplus or deficit is considered as the difference between the country's total export and total import. Total import is put under two components; non-fuel import and fuel import. Non-fuel import represents the country's import trend other than oil products import and fuel import represents the country's trend on oil products import for various sectors fuel consumption. Splitting total import into two components was essential to identify the specific implication of oil products import on the country's trade surplus or deficit.

Taking initial surplus or deficit as a reference point, the relative values of non-fuel import and fuel-import has an increasing effect and the relative values of total export has a reducing effect from the initial value. Initial surplus or deficit was around 5billion ETB during 1999 (NBE, 2015) and kept on growing very fast since then because of the trade imbalances in the country. Oil import values are calculated using the amount of total oil import quantity that the country imports every year and multiplying it with the average OPEC oil market price and then translated to local currency (ETB) for each year.

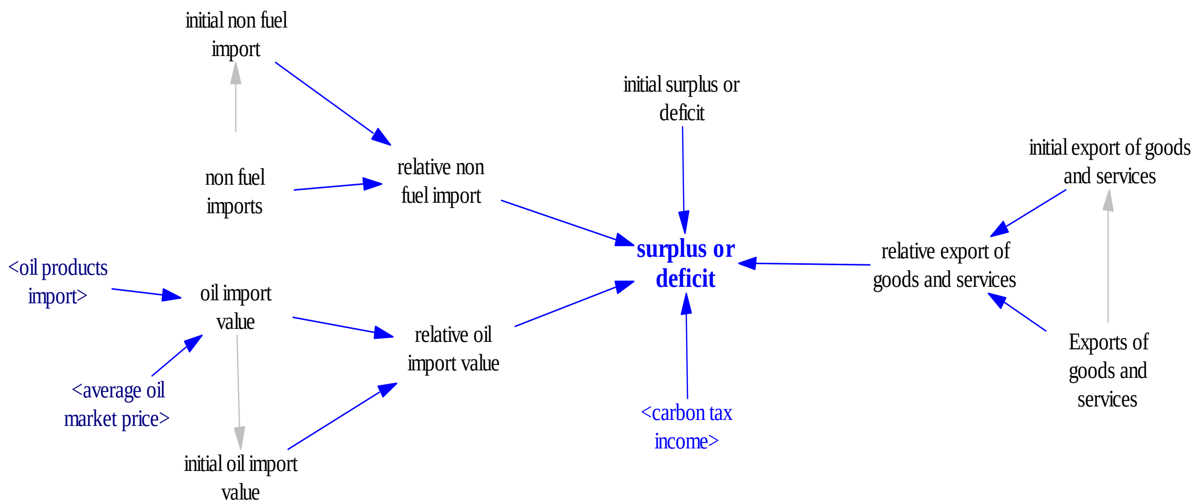


Figure 7: Structure of trade surplus or deficit

The deficit increases as both market price of oil and the quantity of the imported oil rises since both items have an increasing effect on the total import and vise versa. In this structure, trade deficit or surplus also considers the potential revenue that arises from carbon tax by selling GHG emission savings to others as one source of foreign currency earnings. But, since the amount of GHG emission saving during the model simulation period was not significant, the income from Carbon tax has no significant impact on trade surplus or deficit. The following figure shows the average oil market price translated to local currency using the official exchange rate of consecutive years.

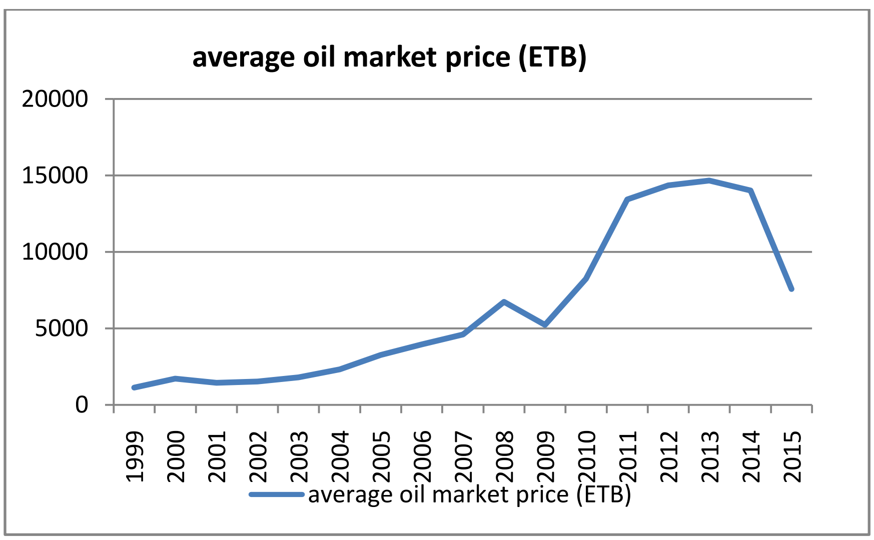


Figure 8: Average oil market price in local currency

Source: author computation from OPEC & NBE

3.2.1.4. Bio-fuel production and consumption

Ethiopian government set a strategy having objectives to 1) substitute fossil fuels by locally produced bio-fuels. 2) Save foreign exchange earnings. 3) Contribute to rural development by creating job in feedstock production, bio-fuel manufacturing, and in transporting and distribution of feedstock and products. 4) Reduce environmental pollution caused by harmful pollutants from vehicles exhausts (GHG emission) (MOWIE, 2012). In line with this strategy, Fincha sugar factory has been in operation since 1998 although it couldn't sell its product in a significant amount because of marketing problems to the local market. The planned initial end use was for vehicles after blending it with gasoline to a level of about 10% (E10 fuel). In fact, the government issued a directive in the year 2000 in order to implement the plan. However, the directive couldn't be implemented yet because of the reluctance of both the oil companies and concerned government organs (EEA, 2007).

Because of the reasons mentioned above, the share of transport fuel consumption from bio-fuel has been very limited. The following figure shows the share of bio-fuel in the total fuel consumption of the transport sector

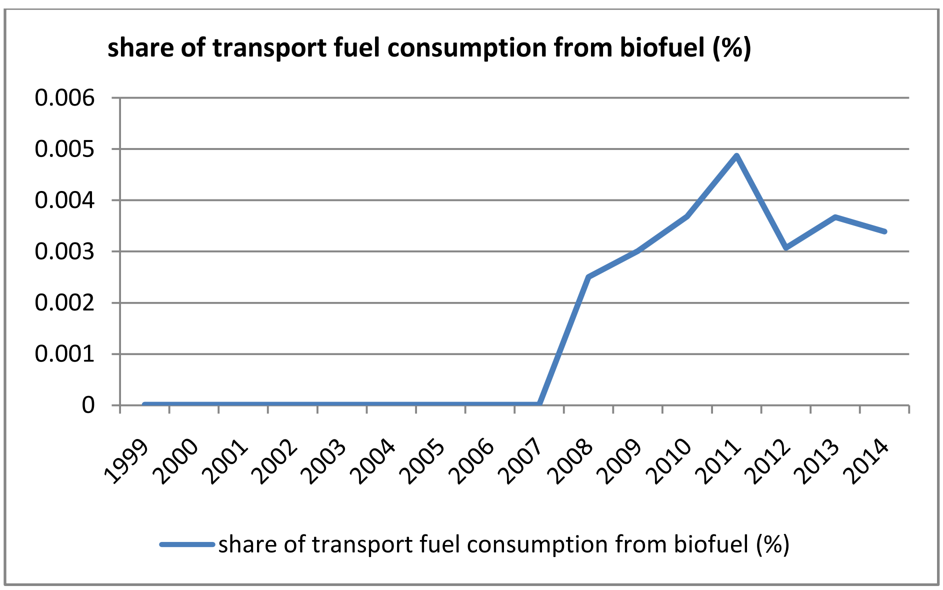


Figure 9: Share of transport sector fuel consumption from bio-fuel

Source: own calculation from IEA

Bio-fuel consumption by transport sector which is considered as a substitute for fossil fuel is derived by multiplying the share of transport fuel consumption from bio-fuel with total transport fuel demand where the share can't exceed the maximum possible blending percentage of bio-fuel with fossil fuel. Researchers suggest that a maximum blending percentage of bio-fuel ethanol with fossil fuel could reach up to 85% - 100%; according to (IEA, 2007), new flexi- fuel vehicles could run up to 85% blends of ethanol- gasoline, where as low ethanol-gasoline blends (5%-10%) can fuel gasoline vehicles with no engine modification. One liter of anhydrous ethanol for a blending up to 25% (E25)

Desired sugar cane land for bio-fuel represents the desired level (ha) of land required to grow sugar cane that is to be used as a feedstock to produce the intended bio-ethanol. The size of the land is calculated as total bio-fuel consumption divided by the country's bio-fuel yield per hectare. However, the land size can't exceed the maximum size of sugar cane irrigation land requirement by sugar factories in the country as bio-fuel production is planned to perform in line with the factories as a by-product.

Desired sugar cane land foe bio-fuel = MAX {total bio-fuel consumption/bio-fuel yield per hectare, total sugar cane land requirement}

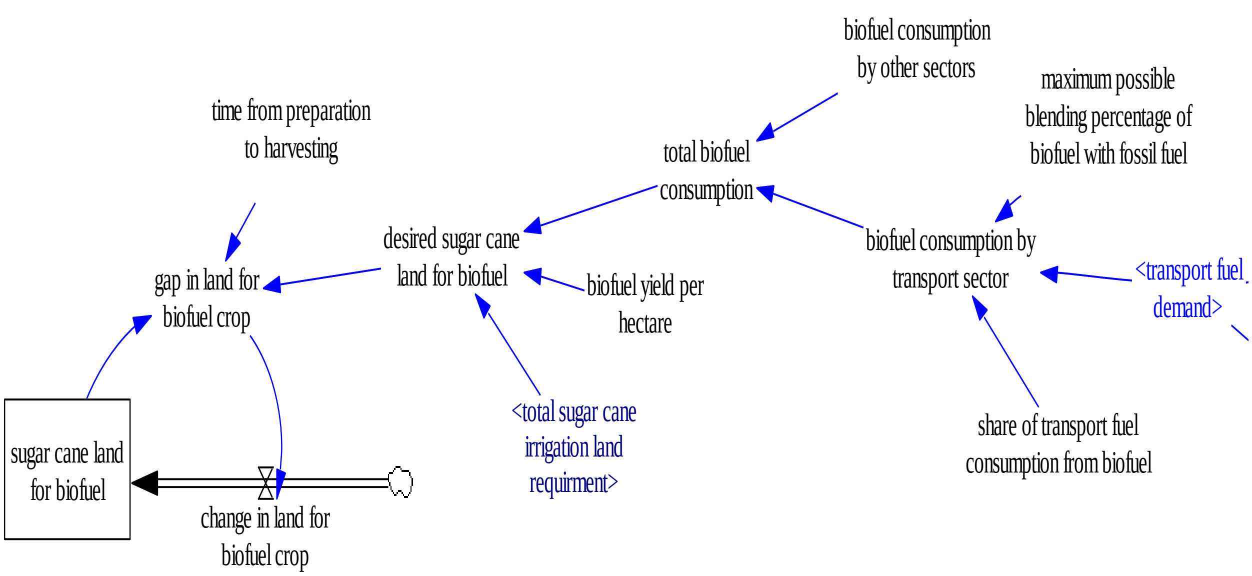


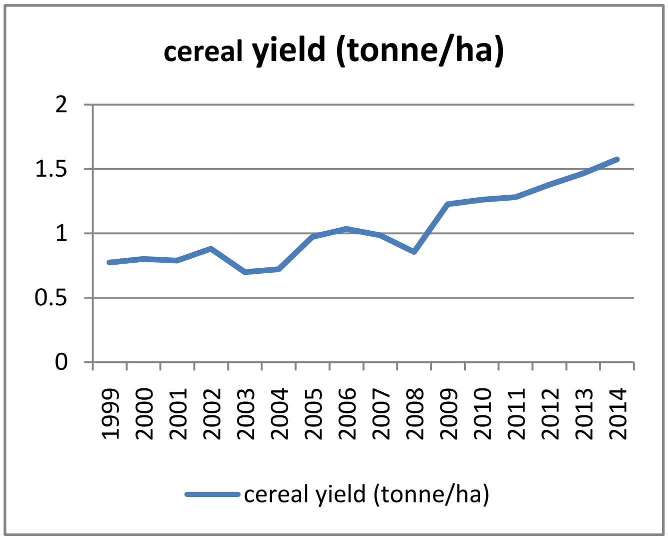
Figure 10: Stock and flow structure of land for feedstock production

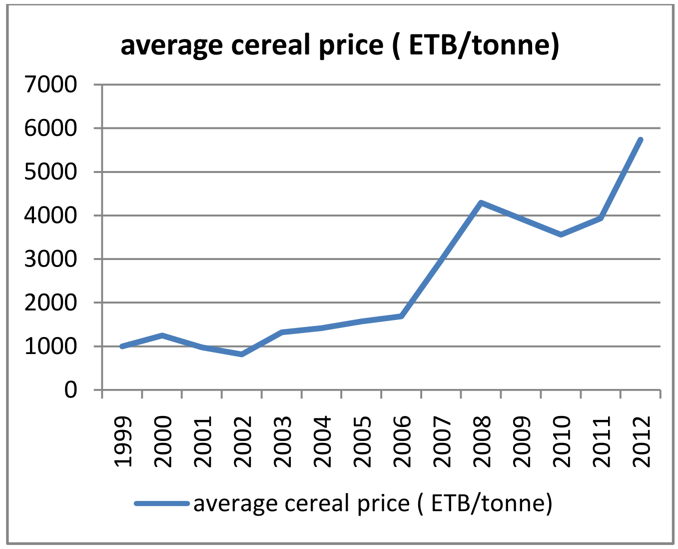
The trend in the land use and bio-fuel yield in Ethiopia shows that around 700 liter of ethanol per hectare of sugar cane land (Bio-fuel Enterprise Ethiopia, 2015). Whereas, the world average bio-fuel yield shows that 3000-6000 l.g.e. per hectare of land used (IEA, 2007).

The stock of sugar cane land for bio-fuel is adjusted to the desired land requirement with an adjustment time delay. The source of the time delay is the gap between identifying the desired land for the year compared to the actual (existing) land and the time it takes from land preparation to harvesting of the feed stock. (Hagos et al., 2014), a research made on one of the newly established sugar factory, TENDAHO, to determine the optimum harvest age of sugar cane suggests that even though it may take up to 20 months to harvest sugar cane, 12 months of harvesting time is optimal for most of sugar cane verities specially in tropical areas. Therefore, for this research purpose, a total of 3 years of adjustment time is used by considering the maximum harvesting time of 18 months plus land preparation time of another 12 months.

The need to know the adjusted sugar cane land for bio-fuel is to determine the effect of land cost related to bio-ethanol production as if sugar cane is grown mainly for bio-fuel production, in other words, it is important to understand the relationship between feedstock cost and land cost. Land cost is the opportunity cost of using the land when the land has an alternative use; that is, the cost is the forgone return from that land in its best alternative use (Raineri et al., 2015). In this research, land cost is considered as the only cost of feedstock that has an effect on bio-fuel production cost. This is based on the assumption that although there are various feedstock costs that could be attached to the cost of bio-fuel production, most of them (e.g. Labor cost) are relatively stable over time in the country and hence, their impact on feedstock cost is assumed to be insignificant but needs further research, rather, the opportunity cost of sugar cane land for bio-fuel is estimated based on the productivity (performance) of the land, had it been used for other cereals. Average cereal price (real) and cereal yield are considered to calculate the opportunity cost as:

*Opportunity cost of land = Sugar cane for bio-fuel * cereal yield * average cereal price*





Source: FAOSTAT

Source: Author computation from FAOSTAT

Figure 11: Cereals yield and price

Taking the initial unit cost of bio-fuel production, 2500ETB/TOE in 1999(Sugar Corporation), the change in the cost of bio-fuel production is caused by the relative effect of the opportunity cost of the land used to grow the feedstock with an elasticity of 0.2666. Elasticity of bio-fuel production cost to relative land cost is not properly studied in Ethiopia, therefore, for this research purpose a proxy is used to estimate the figure. (Raineri et al., 2015) a research on elasticity analysis of lamb production cost stated that a 1% increase in land cost will result in a 0.2666% increase in the production cost of lamb and added that the opportunity cost of land is the item to which production cost is more sensitive. The unit cost of bio-fuel production suggests the level of bio-fuel price, which is referred as indicated producer price; the most recent price that considers the recent costs related to production. The previous year's selling price is constantly adjusted towards the indicated selling price with a price adjustment time which literally mean the production cycle, a one year production cycle is considered for this research purpose.

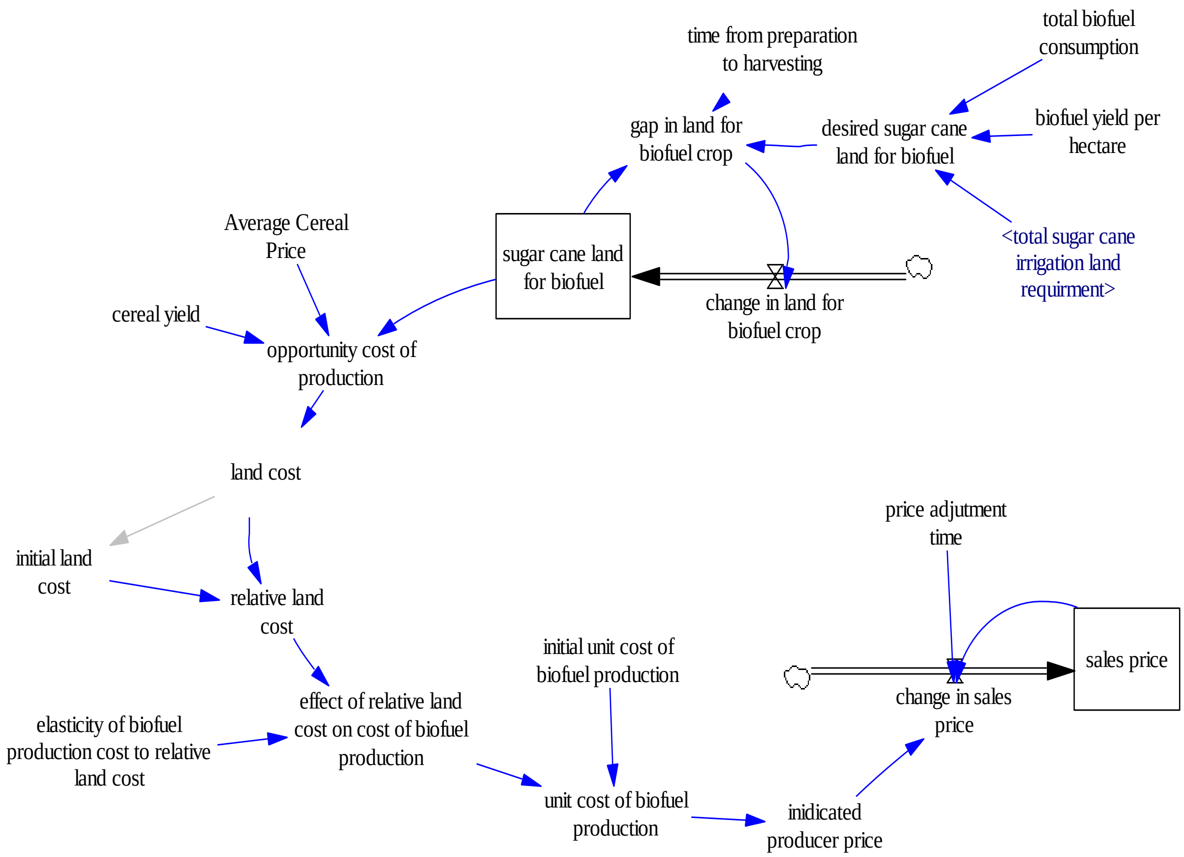


Figure 12: Stock and flow structure of ethanol production cost

Unit cost of production was also checked against international costs; in 2007 the cost of bio-ethanol from sugar cane was estimated between 0.3-0.5usd per l.g.e. (IEA, 2007) which is nearly 3600 birr/lge. The price of bio-fuel from domestic production source is compared to the average price of fossil fuel in the market and a price ratio is set. The price ratio is changed to relative values as a normalization step. The share of transport fuel consumption from bio-fuel is formulated from its initial value and the effect of the price ratio on the desire to consume bio-fuel.

Price ratio = average oil market price / retail price bio-fuel

After calculating the price ratio, its effect on bio-fuel consumption is expressed in terms of elasticity.

$$\text{Effect of price ratio on bio-fuel consumption} = \text{relative price ratio}^{\text{elasticity of bio-fuel consumption to price ratio}}$$

Therefore, the share of transport fuel consumption from bio-fuel is the result of the initial value and the effect of the price ratio. If the price of bio-fuel increases, the value of the price ratio declines and hence, it decreases the value of the share of transport fuel consumption from bio-fuel and results in lower bio-fuel consumption. On the other hand, if by any means the fuel consumption of transport sector decreases or increases, the bio-fuel consumption trend will change similarly as share of bio-fuel consumption is multiplied with the total transport sector fuel consumption.

(Labandeira, X. et al., 2016; GIZ, 2013) estimated the relative change in fuel consumption with respect to the relative change in fuel price as -0.7. However, elasticity of 0.7 (positive value) is used; although, normally, elasticity of fuel consumption to fuel price is negative, the context in this study relates the fuel price, which is the difference between market fuel price and bio-fuel price, with bio-fuel consumption. As the gap increases, the price ratio increases and this could be the result of either the increase in market price or a decrease in bio-fuel price, consumption of bio-fuel increases too and vice versa. Therefore, the direction of the elasticity (the relative change) is in a similar direction.

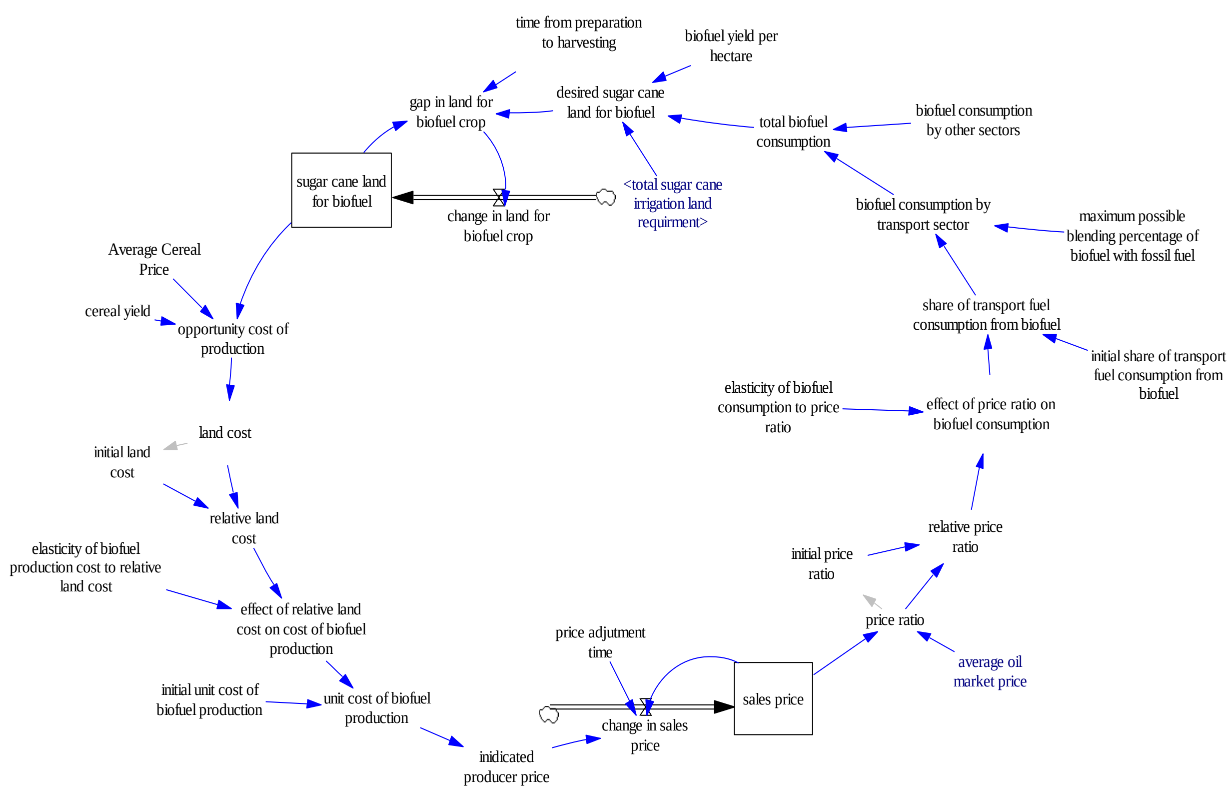


Figure 13: Stock and flow structure showing the effect of production cost in ethanol consumption

3.2.1.5. Production capacity

Ethanol production is dependent not only on total bio-fuel consumption of the transport sector, but it also considers the production capacity of the sugar factories.

Ethanol production = MIN {maximum ethanol production rate, total bio-fuel consumption}

Maximum ethanol production rate is based on the available molasses fermentation rate that can be transformed in to ethanol and the ethanol conversion factor, which is ethanol yield of the molasses over a production period.

*Maximum ethanol production rate = molasses fermentation rate*ethanol yield of molasses*

Currently, the trend in Ethiopia shows that one ton of transformable molasses containing about 45% fermentable sugar gives 0.2208 TOE ethanol yields which is equivalent to 230 lge (Sugar Corporation).

Molasses fermentation rate in its turn represents the delayed function of molasses production over a production period. This formulation assumes that the molasses or portion of the molasses produced, which is left during the fermentation process in the stock of 'transformable molasses', is considered as a waste (by-product) and it is not considered in the following years calculation of molasses fermentation rate

Molasses fermentation rate = DELAY1 (molasses production, production time)

Molasses is the by-product of the sugar industry, and according to Sugar Corporation, the production rate is estimated between 4%-5% of the amount of cane crushed during the process of sugar production.

*DELAY1 (crushing*molasses percentage of crushed sugarcane, production time)*

Before molasses production, the crushed sugarcane is used to produce sugar and from 10% - 12% of crushed sugar cane is believed to be raw sugar with 85% crushing efficiency of the plants. The outflow that represents sugar production is given as:

*Sugar production = DELAY1 (crushing*sugar percentage, production time)*

The rest of crushed sugarcane every year is excluded in the form of steam burning and other dry matter loss. This is represented by the outflow steam burning loss as:

*DELAY1 (crushing*steam burning loss and other dry matter percentage, production time)*

The loss percentage is calculated as the excess of sugar and molasses percentage of the crushed sugarcane every year and is given as:

1-(sugar percentage + molasses percentage of crushed sugarcane)

In the process of making sugar cane juice, sugar and ethanol, there are multiple steps and procedures but for this study purpose, it is put in a simplified manner. The following stock and flow structure represents a simplified version of the process.

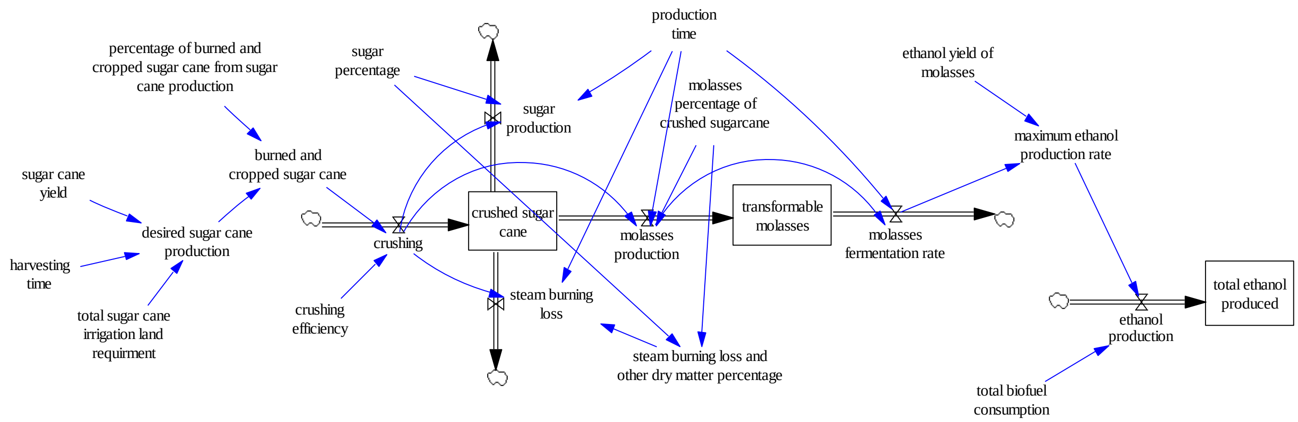


Figure 14: Stock and flow structure of ethanol production process

The sugar cane plant that is used as a feedstock should be burned and cropped before it is delivered to the processing plant. The reason for this is that the stalks are separated from the leaves, which are burned and whose ashes are left in the field as fertilizer, and from the roots that remain in the ground to sprout for the next crop. Research from Brazil show that 77% of the mass of the raw can represents burned and cropped cane that is ready for further processing (Rosa, 2005).

The amount of sugar cane production depends on a) size of sugar cane land b) sugar cane yield c) harvesting time. The size of sugar cane land (total sugar cane irrigation land requirement) refers to the amount of land (ha) assigned to each sugar factories; the existing and the newly built, and includes the extra land given for expansion projects. This size doesn't exceed the maximum available sugar cane land which is already identified as suitable for cane plantation. Sugar cane yield represents the quantity of cane plant parts measured in ton per area and time unit, harvesting period in this case. The following figure shows sugar cane yield in the country from 1999-2014.

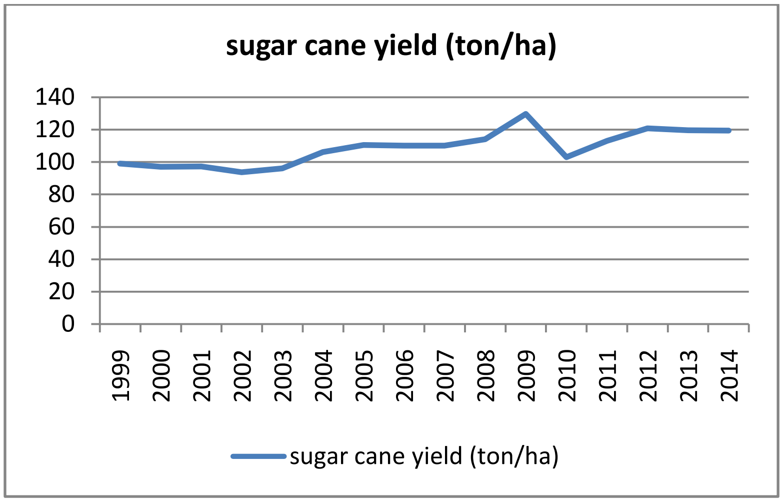


Figure 15: Sugarcane yield

Source: FAOSTAT

The capacity of ethanol production is the sum of individual sugar factories ethanol production capacity. Ethanol is produced as a byproduct in the sugar factories. The demand for new sugar plants, desired number of sugar mill, is based on the countries response to address the progressive sugar consumption every year. The initial per capita sugar consumption of the country is taken as a reference and this consumption level increases following the population change. The population estimation and projection until the year 2050 is used based on the World Bank.

As mentioned above, desired number of sugar mill is assigned based on yearly sugar consumption and the average sugar production capacity of each sugar mill. Average sugar production capacity of sugar mills is calculated based on the maximum yearly production capacity of sugar mills that are already built and using the planned capacity of those to be built in the future. The following table shows the number of sugar mills, existing and on a project phase, including their sugar and ethanol production capacity.

NO	sugar mill	sugar production capacity(ton/year)	ethanol capacity(toe/year)	sugar cane area(ha)	cost (ETB)	power cogeneration(MW)
1	Tendaho-2factories	619,000	63,000	50,000	na	60
2	Omokuraz-4factories	1,390,000	130,810	100,000	6.7billon	415
3	Wolkayit	484,000	41,654	50,000	20 billion	
4	Wonji Shoa	220,700	12,800	12,800	na	31
5	Metehara	136,692	12,500	10,000	na	9
6	Finchaa	270,000	20,000	21,000	na	31
7	Arjo-Dediessa	na	na	20,000	na	
8	Kessem	260,000	30,000	8,413	na	26
9	Belles-two factories	484,000	41,654	50,000	20 billion	
total	**14**	**3,864,392**	**352,418**	**322,213**		**572**

Table 2: Number of sugar factories and their respective capacity

Source: compiled from Sugar Corporation

There were three sugar mills in 1999 which are used as an initial number of sugar mill foe completed sugar mill stock. Comparing sugar mills that are completed and those under construction with the desired number, new sugar mills are considered in order to fill the gap. Identifying the gap and studying new sugar mill projects takes an average of 3 years which is considered as construction start time that includes identifying sugar consumption pap, land selection, preparation, financing decision and auction processing time. Sugar mill gap adjusted with construction start time gives us a new sugar mill construction start rate, the inflow for under construction sugar mill stock; it also considers the degradation rate of sugar mills that are already completed in order to avoid steady state error. On average 4 years of construction delay time is required to complete a sugar mill project; this delay time is a deterring factor in the conversion of under construction sugar mill to completed ones'. This completion rate is the base for calculating the size of total sugar cane irrigation land requirement which is also an input to desired sugar cane production; average irrigation land requirement per sugar mill, which is calculated by adding the total irrigation land size owned by sugar mills and dividing it by the total numbers of sugar mills.

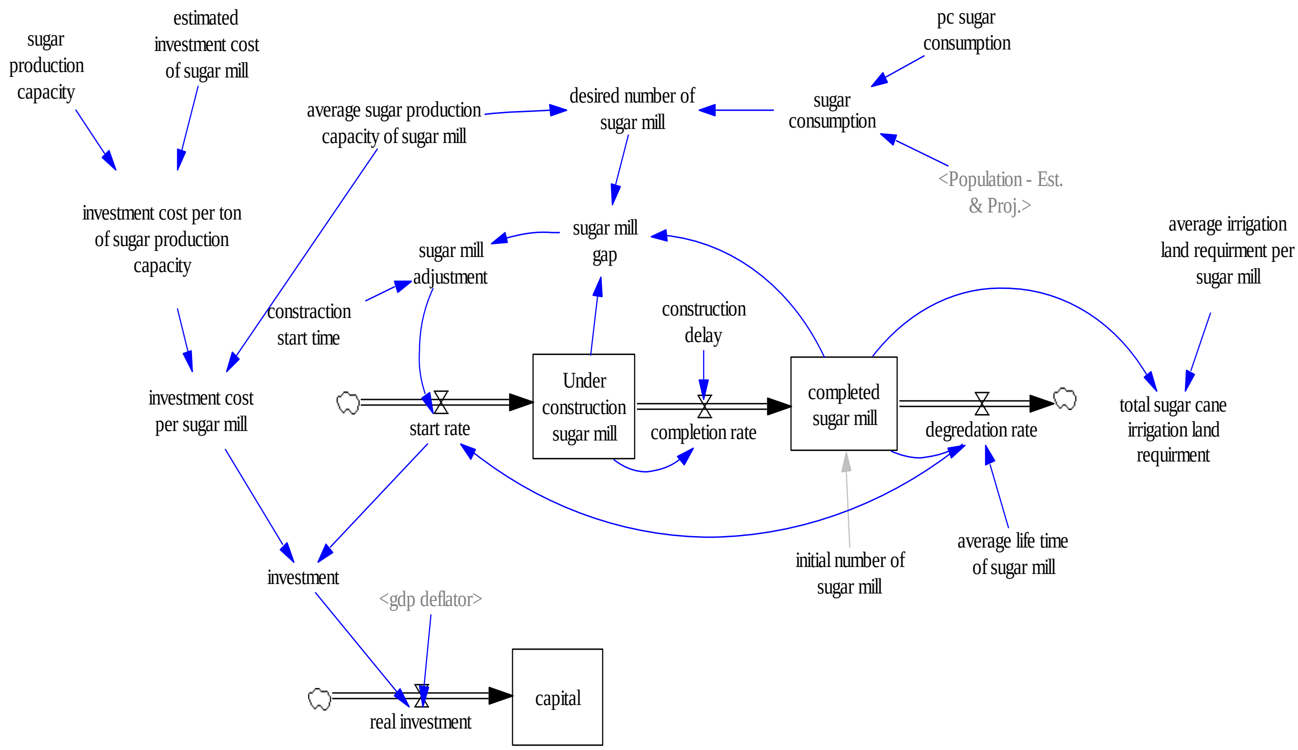


Figure 16: Stock and flow structure showing construction of sugar factories

3.2.1.6. Investment cost

Based on table 3, investment cost of only two sugar factories are recorded and the attempt to dig extra information was not successful as financial affairs are of confidential in the country. Therefore, the assumption of investment cost of establishing a sugar mill with a certain capacity is based on the available information only and hence the values are subject to vary.

According to the available data, the estimated investment cost of a sugar mill with sugar production capacity of 484,000 ton/year and ethanol production capacity of 41,654 TOE/year is estimated to be around 20 billion ETB. Investment cost per ton of sugar production is calculated by dividing the total investment cost with sugar production capacity per year.

Investment cost per ton of sugar production capacity = Estimated investment cost of sugar mill/Sugar production capacity

Then, the result is multiplied by average sugar production capacity of sugar mills. The result shows an estimated investment cost per sugar mill. Therefore, the government invests a total sum of investment cost per sugar mill multiplied by the number of sugar mills to be constructed each year (start rate) and the value is adjusted by the country's GDP deflator to calculate the real investment cost per year, the inflow for the cumulative money invested so far (capital stock).

*Investment cost per sugar mill = investment cost per ton of sugar production capacity*average sugar production capacity of sugar mill.*

*Therefore › Investment = investment cost * construction start rate*

It is clear that the smooth handling of sugar factory projects is an essential and determinant factor to plan a continues production and supply of both sugar and its byproduct ethanol as both rely on government performance and commitment towards making timely financial decisions and monitoring the status of the projects. A delay on the projects would disrupt the whole system of production process.

3.2.1.7. Land and water resources

Sugar Corporation is working vigorously to raise the nation's current sugar production capacity remarkably so that the nation will greatly benefit from the sector. According to a survey conducted at a national level on the water resource and canal development opportunities, it is proved that the country has a potential of more than 500,000 hectares of land suitable for sugar cane plantation (Sugar Corporation; Ethiopian Investment Agency, 2012). The survey identified upper and lower areas of Beles river, areas of south-west of Lake Tana called upper Dinder, areas along Tekezzie river and its tributaries around Wolkayit and Humera, valleys of Anger river-Negiesso, central Genallie river and Baro-Gillo rivers of Gambella as among some of the areas suitable for star cane production. The corporation is currently building 10 new sugar factories at various regions of the country following the survey by Ethiopian investment Agency (EIA, 2012).

Sugar cane irrigation land increases progressively as the number of sugar mills increase but it can't exceed the maximum available sugar cane land mentioned above. This portion of land is the part of total irrigable land in the country. Ethiopia ha a potential of vast cultivable land (30-70 m Ha), but only one third of that is currently cultivated (approximant 15mHa), with current irrigation schemes covering only about 640000 ha across the country in 2015 and this area of land developed with high and medium irrigation schemes will be expected to reach 954,000ha during 2020(EPRDF GTPII, 2015-2020). However, the study estimates that total irrigable land potential in Ethiopia is 5.3m ha assuming use of existing technologies, and the irrigation trend according to (Nata et al., 2008;

Bekele et al., 2012 sighted by Haile, G.G., & Kassa, A.K., 2015) shows that less than 2000 ha of land (1,090-1,150 ha per year) were developed by irrigation for the last 12 years. This figure is represented as an average current irrigation land development per year and it is compared to total irrigation land potential to calculate the irrigated land fraction. This fraction helps us identify the amount of non-sugar cane irrigated land added each year from the maximum irrigable land potential.

Maximum irrigable land potential = total irrigated land potential – sugar cane irrigated land

This classification of land will help us to estimate the water needs for each irrigation type.

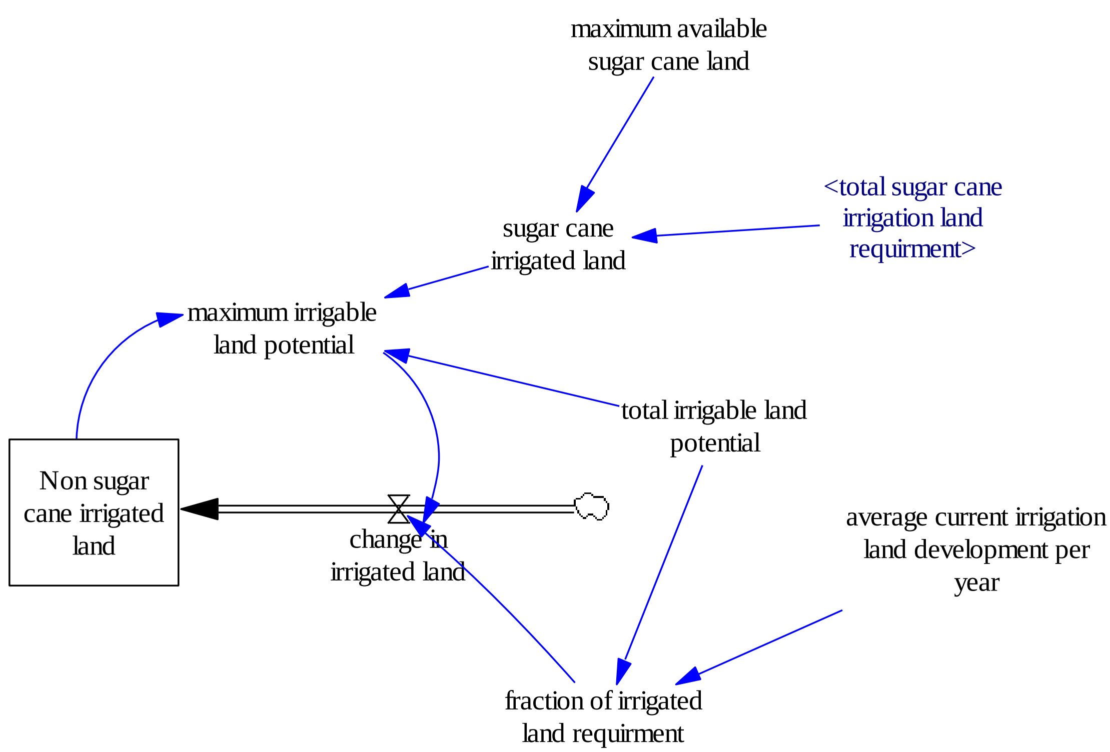


Figure 17: Model structure showing Irrigation trend and potential

Total water demand for irrigation arises from both sides of non-sugar cane and sugar cane irrigation land. These two are separated because their water intake (consumption) pattern is different.

Water demand for sugar cane crop is based on the size of sugar cane irrigation land and sugar cane water foot print. Water foot print is the volume of water consumption per unit of feedstock crop. Water required for producing a kg of sugar cane in china is estimated around 0.12 m^3 (H.Yang et al., 2009); 0.12m^3 per kg is approximately equivalent to 120m^3 water per ton of sugar cane and considering an average sugar cane yield of 100 ton per hectare of land in Ethiopia (FAOSTAT), it requires 12,000m^3 of water to cultivate a hectare of sugar cane land. The water requirement only considers evapo-transpiration, i.e., the water actually consumed for growing the crop. It doesn't consider the loss of water to percolation and direct evaporation from soil surface due to the lack of detailed information on irrigation water use efficiency across regions and for different crops.

The water consumption demand for non-sugar cane irrigation land depends on the size of non-sugar cane irrigated land and the water demand per hectare of non-sugar cane land. According to (Awulachew, S.B., 2010), water consumption for non-sugar cane irrigation is classified in to three categories; high rainfall area, moisture deficit area and pastoralist area. Sequentially, the water consumption per hectare is assumed to be 5000, 6000 and 7000m^3. For this study purpose, these three categories are averaged and 6000m^3 per hectare is used. In addition, it is assumed that irrigation could on average be take place twice a year and since the 6000m^3 per hectare is the consumption per hectare at a certain growth period, 2*6000m^3/ha/year (12000m^3/ha/year) is considered as the water demand for non-sugar cane irrigation. Therefore, the total water demand is given by:

Irrigation water demand for non-sugar cane land + sugar cane crop water demand

Now, the question is where we can get the water to satisfy this water consumption level.

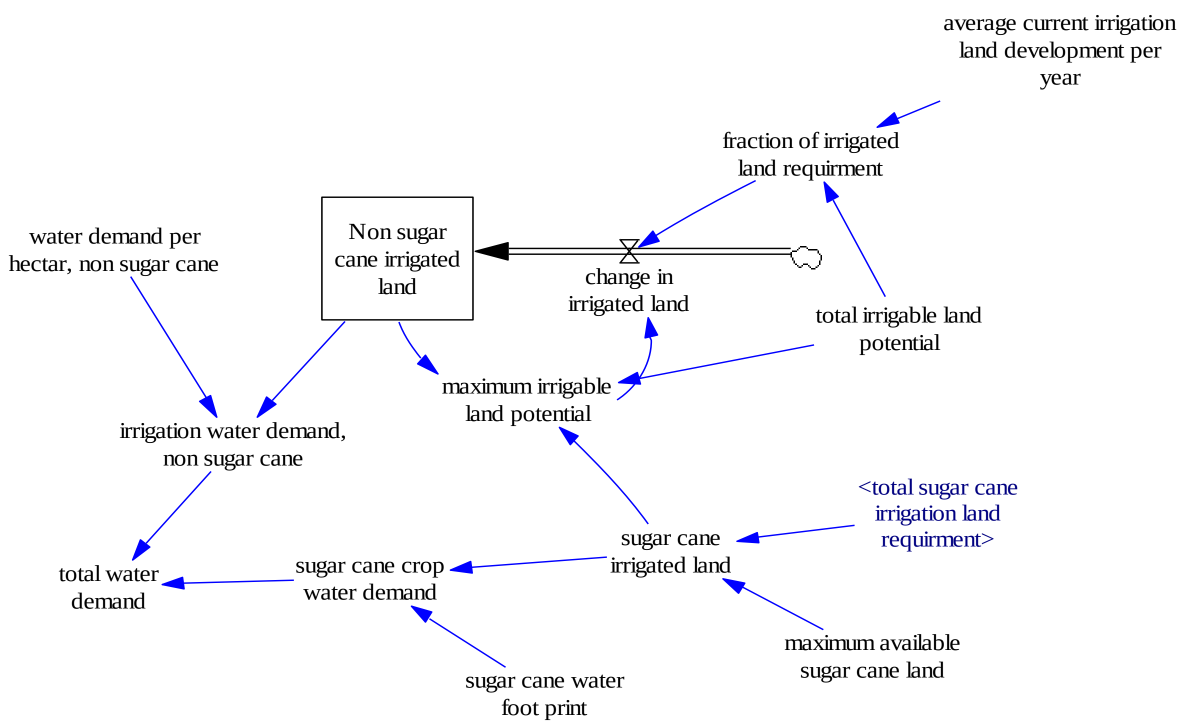


Figure 18: Model structure showing land and water footprints for irrigation

Well, Ethiopia has river basins that provide an estimated annual run-off of 125bm^3 which is equivalent to 3,731,222 ha irrigation potential; of which, 85% of surface water potential is estimated to be in large scale schemes. In addition to this capacity, the country has a ground water potential of 6.5 bm^3 and this is equivalent to irrigation potential of 1,165,881ha (Awulachew, S.B., 2010). However, according to (Awulachew, S.B., 2010), the country's per capita water storage capacity for irrigation remains low at 160m^3 (20% of South Africa's capacity). This may indicate that even though water is physically available, the country lacks the infrastructure to properly utilize the resource.

Based on the aforementioned estimates, this study considers surface water as the primary source of water for irrigation purpose. After calculating the water level consumed by non-sugar cane irrigation every year, surface water usage ratio is determined to justify the trend in water usage from the annual surface water run-off potential. And then, this figure is compared against the maximum water storage capacity of the country that is calculated based on per capita irrigation water storage capacity (assuming this capacity grows smoothly as per the population size). The minimum value of surface water irrigation potential or maximum water storage capacity is considered as the available water for irrigation.

Finally, the available water for irrigation is compared to total water demand for irrigation. If the available water exceeds the consumption, then there is no need to look for other options. But, if the water consumption level exceeds the available water, a gap in capacity is created. This capacity gap can be adjusted either by improving the storage capacity of surface water run-off or by extracting a certain level of water from ground water potential.

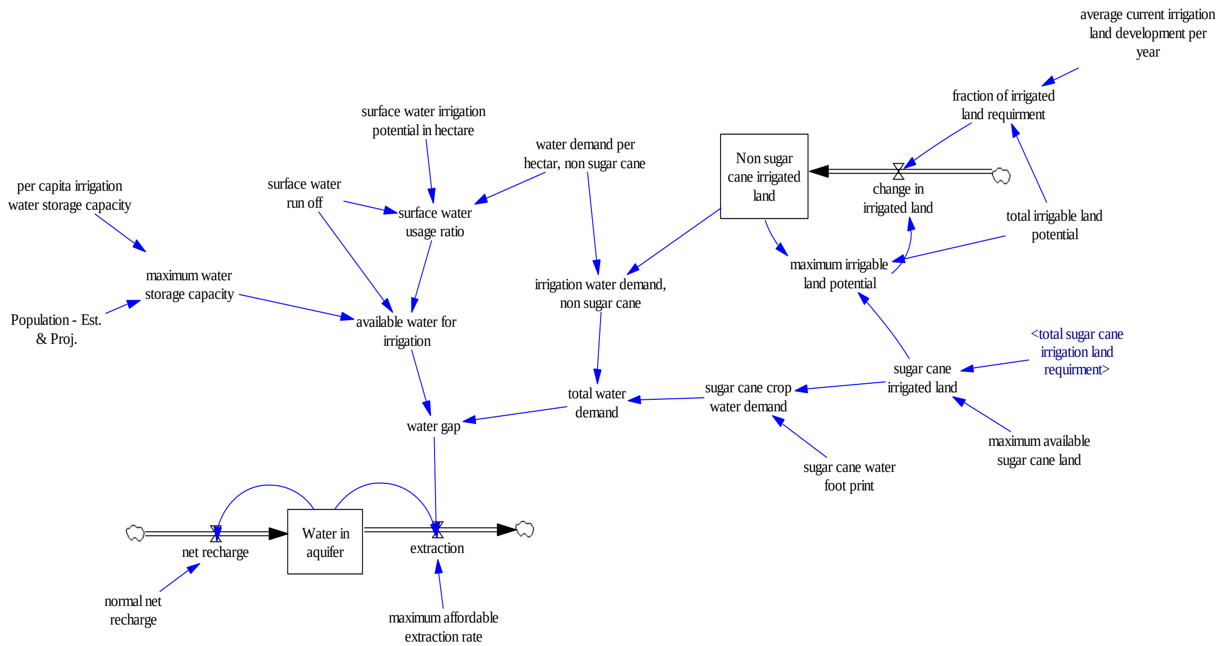


Figure 19: Model structure comparing land and water demand against availability

3.2.1.8. GHG emission

One of the objectives of producing ethanol as a renewable energy source for the transport sector is to reduce the GHG emission level of the sector; how much can the GHG emission level be reduced by substituting bio-ethanol with fossil fuel, which is referred as Net Emission Reduction.

Net emission reduction refers to the difference between the emission reduced by substituting ethanol with fossil fuel in the transport sector and the emission that is created due to additional land use to produce the ethanol. In other words, net emission reduction is the marginal benefit that we could get from producing extra ton of ethanol in the process of blending it with fossil fuel.

Emission reduction is calculated by considering the GHG emission saving achieved by using ethanol instead of fossil fuel. Based on the report (IEA, 2007), using a liter of sugar cane ethanol enables 90% co_2 reduction that could have been emitted in a liter of gasoline; using one liter of gasoline results in2.8 kg of co_2. The rest 10% emission is caused due to the use of fossil fuel during the harvesting, production and distribution period and this of course could be avoided by using ethanol in this process too. Therefore, total emission reduction is equivalent to GHG emission saving arises from the total ethanol production (assuming all ethanol produced is to be consumed by the transport sector).

The emission from additional agricultural production arises from the additional sugar cane production as a feedstock to ethanol. The amount of the feedstock in its turn depends on the size of the land assigned to it and its yield per hectare. On the process of growing sugar cane feedstock and harvesting, the release of GHG emission during cane field burning, release of N_2O from the soil due to fertilizer decomposition are considered as the major sources of GHG emission (Alckmin G, 2004).

The ultimate goal for net emission reduction is to affect the rate of GHG emission resulted from transport sector fossil fuel combustion and as a result it reduces the cumulative GHG emission over time.

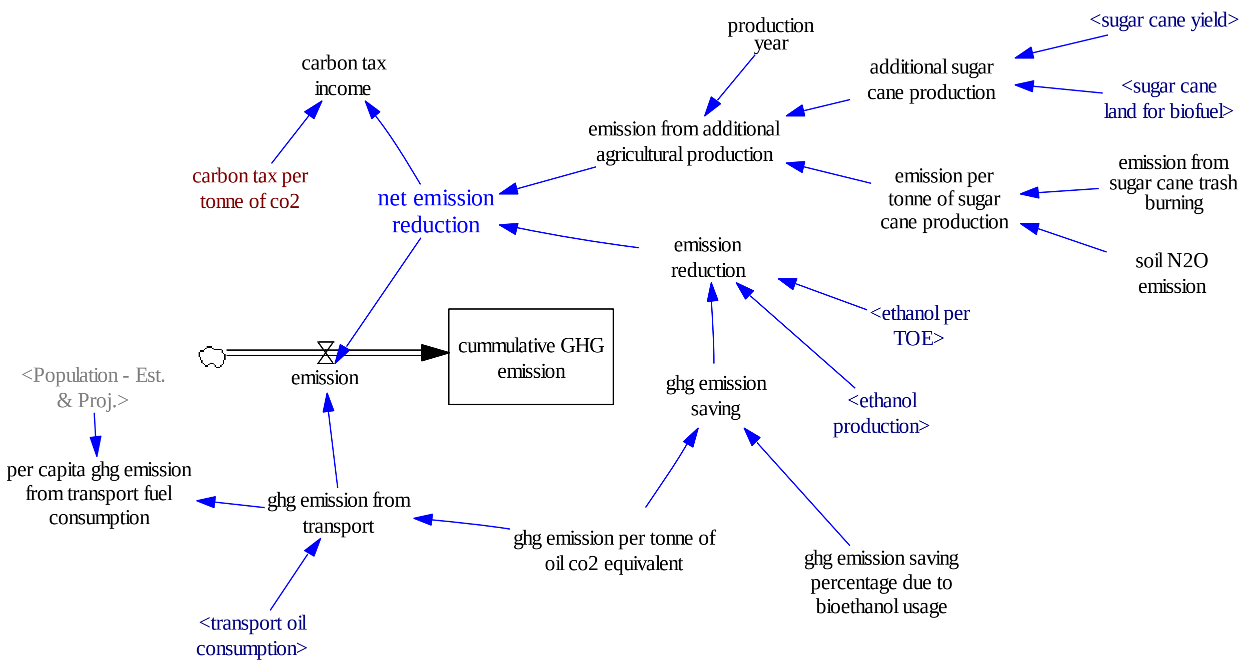


Figure 20: Model structure showing transport sector GHG emission and GHG emission saving due to ethanol blending

Chapter 4: Model Validation and Behavioral Analysis

4.1. Model Structure Test

Model structure test help us assess the structure and parameters of the model without studying the relationships between structure and the resulted behavior. Various tests can be carried out to assess the structure of a model, for this research, structure and parameter verification tests, dimensional (unit consistency test) and extreme condition test are carried out to build confidence on the structure of the model (Forrester and Senge, 1978)

4.1.1. Structure and Parameter Verification Test

This test is carried out to compare the structure of the model against the structure of a real system, whereas, parameter verification test is carried out to evaluate the constant parameters against knowledge of a real system (Forrester and Senge, 1978).

Under hypothesis section of model description, chapter 3, we have presented the stock and flow structure of the model, with which we described the systematic interaction between various parameters resulting in the problematic behavior. We have also presented the constant parameters we used in the model. Hence, the validity of the model depends on the validity of the model structure representing the hypothesis and the validity of the parameters used in the model. (Forrester and Senge, 1978) recommends that these verification tests should be made based on practitioner's knowledge and literature.

The structure of the model and estimations of the values of the parameters are conceptualized and on the basis of expert knowledge in literatures and discussions with field experts. As documented under the model description, researches, web pages of related organizations, surveys, and document analysis are used in the development of the model structure and determination of parameter values.

4.1.2. Dimensional Test

Consistency of units in the process of building a model can be used as a means of model validation test. The units must be consistent throughout the model and must exactly represent the intended variables. The consistency of all the units is checked in the model and some of the variables along with their units are presented below.

Units of some variables	Type of variable	Unit
Sugarcane land for bio-fuel	Stock	hectares
Crushed sugarcane	stock	tone
Transformable molasses	stock	tone
vehicles	stock	car
Completed sugar mill	stock	Sugar mill
Construction start rate	flow	Sugar mill/year
Completion rate	flow	Sugar mill/year
Vehicles growth rate	flow	Car/year
crushing	flow	Tone/year
Molasses production	flow	Tone/year
Ethanol production	flow	Tone/year
Transport oil consumption	auxiliary	TOE/year
Oil products import	auxiliary	TOE/year

Table 3: Units of selected variables

4.1.3. Extreme Condition Test

One of the model structure tests in system dynamics is extreme condition test. It is a technique that helps us assess the model's response for extreme values of parameters, shocks and extreme policies, and comparing the model-generated behavior to the observed or anticipated behavior of the real system under the same extreme conditions. However, the extreme condition test doesn't necessarily imply the conditions exist in real situation (Sterman, 2000)

In this section, we test the response of the model to extreme values for some selected variables and the resulted behavior following the change. The variables selected for this test are "share of transport fuel consumption from bio-fuel".

Let us assume that there is no need for ethanol use in the transport sector fuel consumption, that is, the "Share of Bio-Fuel in Fossil Fuel Consumption in Transport Sector" is zero, which implies that there is no ethanol consumption. From our discussion in chapter 3, we learn that the need for ethanol production arises from the demand for consumption of ethanol in the transport sector, therefore, no ethanol consumption infers there is no need to produce ethanol; assuming other sectors ethanol consumption is set to zero. If there is no ethanol production, we expect the cost related to production, including opportunity cost of land, to be zero; there will be no land assigned to ethanol production,

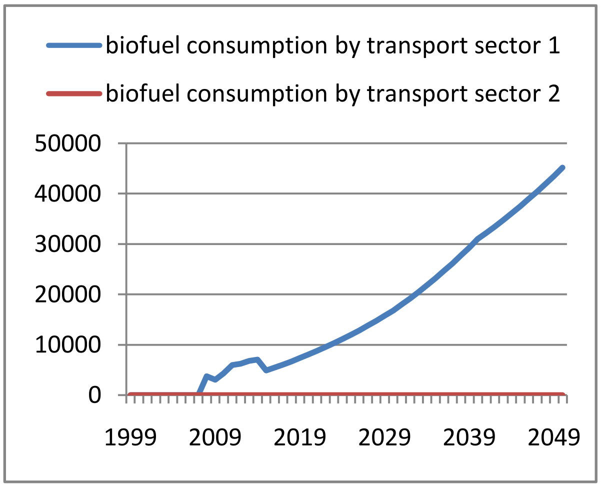


Figure 21 (a): transport sector ethanol consumption

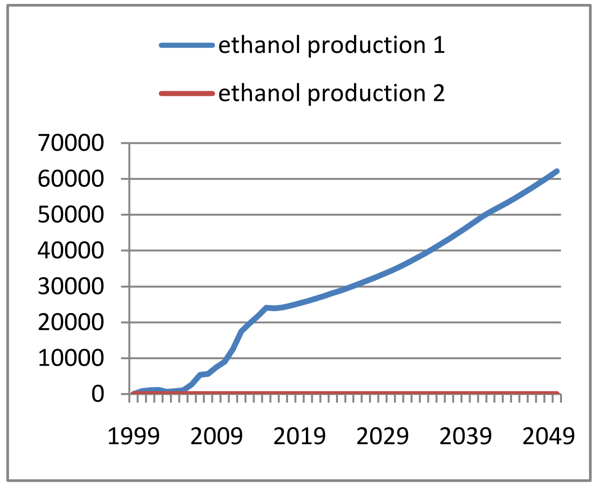


Figure 21 (b): ethanol production

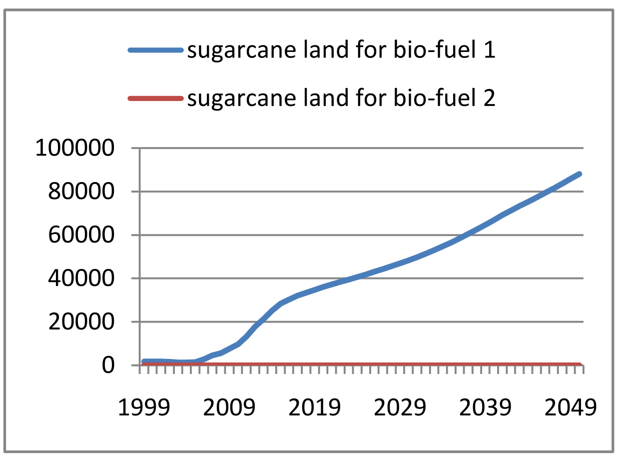


Figure 21(c): land size assigned to feedstock

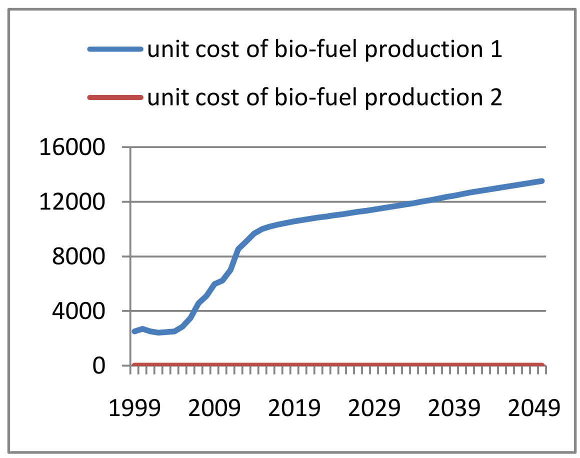
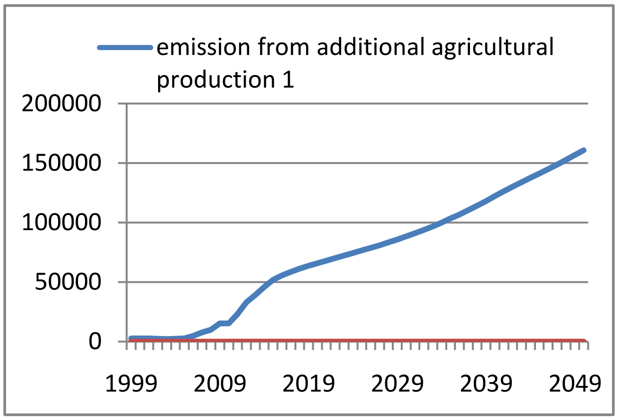


Figure 21(d): bio-fuel production cost

Figure 21: Simulation results of ethanol production, consumption, land and production cost with the extreme condition test of share of bio-fuel from transport sector (blue-base run and red- share value= 0)

Therefore, the emission that could have been added from agricultural production due to the land shift should remain nil (figure 22.a). In addition, the level of emission that could have been saved (figure 22.b) due to ethanol must remain zero and the result as shown in Figure 22 (A-D) with the red curve confirms our expectation.



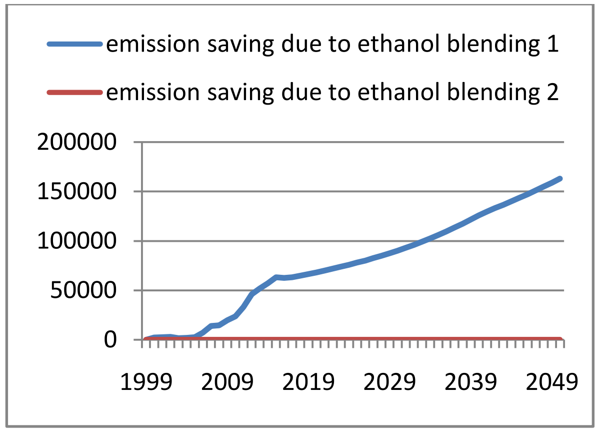


Figure 22(a): emission from land use shift

Figure 22(b): emission saving from ethanol use

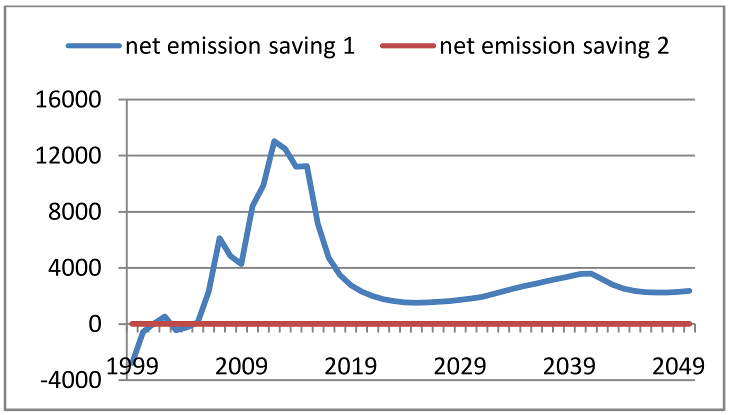


Figure 22 (c): net emission reduction

Figure 22: Simulation results of GHG emission from land use, emission saving from ethanol use and net emission saving with the extreme condition test of share of bio-fuel from transport sector (blue-base run and red- share value 0)

The negative values in the net emission reduction, figure 22.c, indicates that ethanol was produced starting from 1999, meaning there was an increase on GHG emission from the land used to grow the feedstock, however, ethanol blending was started at 2008 and we couldn’t get as much benefits of emission saving from ethanol blending in the years between 1999- 2008.

Of all, the amount of fossil fuel consumed by transport sector and oil products import remain as they were, meaning no substitution of ethanol. Consequently, the benefits related to ethanol blending will no longer be available; there will not be GHG emission saving, as there is no reduction in the amount of fossil fuel consumption. This in turn tell us that the import of oil products keep on growing in the same trend as before.

Now let us assume a 100% ethanol use in the transport sector, that is, the "Share of Ethanol in Transport Sector Fuel Consumption" is one. This implies that total transport fuel consumption is covered by domestically produced ethanol, meaning fossil fuel consumption in the sector stays nil; we assume the maximum possible blending percentage of bio-fuel with fossil fuel to be 1 considering no technological constraints to use ethanol for vehicles. If fossil fuel is to be fully substituted by ethanol, a huge increment on both the consumption and production level is inevitable as it can be seen on the following figure:

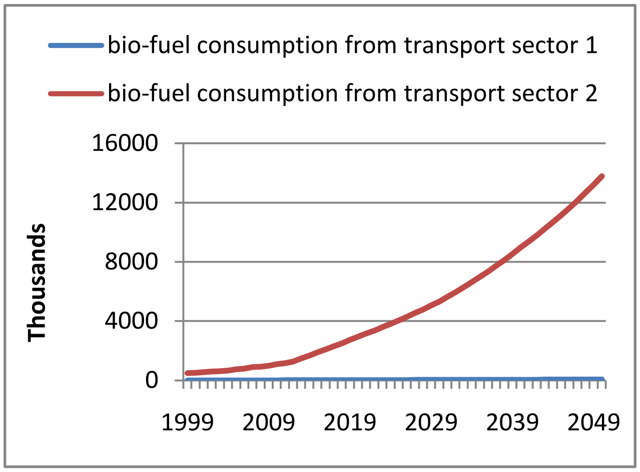


Figure 23(a) ethanol consumption

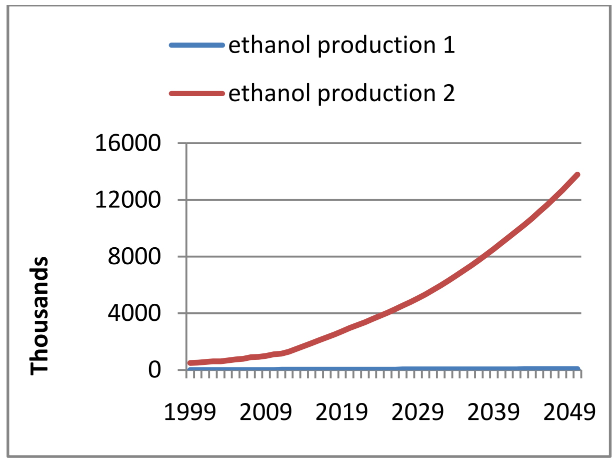
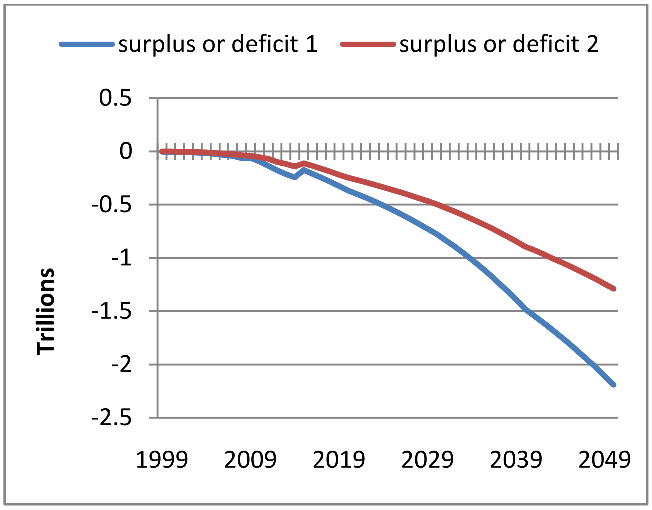


figure 23(b) ethanol production

Figure 23: Simulation results ethanol production and consumption with the extreme condition test of share of bio-fuel from transport sector (blue-base run and red- share value of 1)

The amount of fossil fuel to be saved due to ethanol use results in a huge reduction in the amount and value of oil products import, figure 24.a, meaning a large amount of foreign currency will be saved and ultimately the country will be benefited from trade deficit reduction as shown in the figure 24.b.



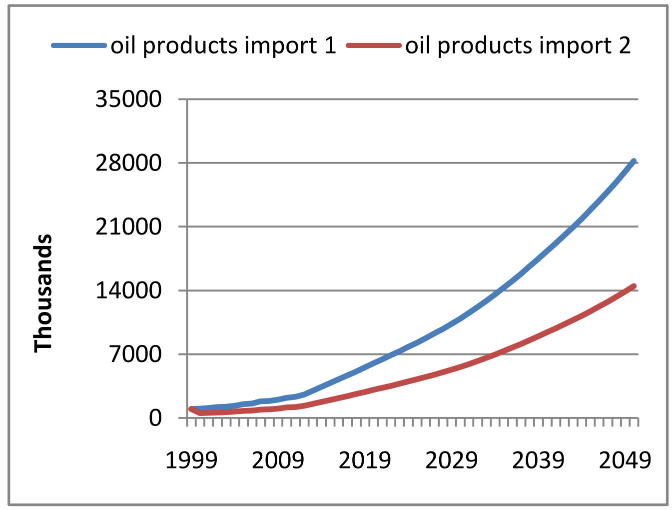
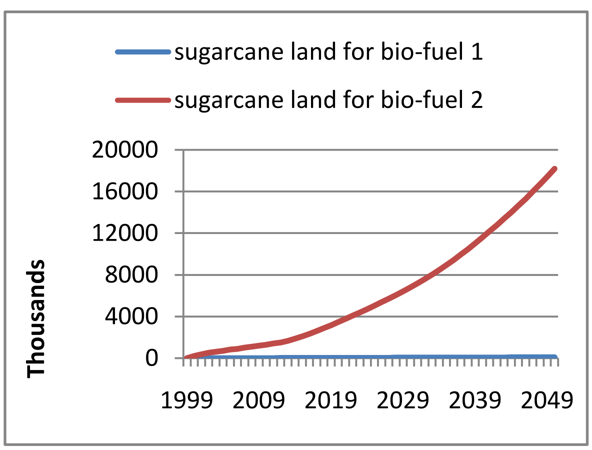


Figure 24(a) oil products import

Figure 24(b) trade surplus or deficit

Figure 24: Simulation results of oil products import and trade deficit with the extreme condition test of share of bio-fuel from transport sector (blue-base run and red- share value of 1)

On the other hand, it requires a huge effort to access resources used to produce this large amount of ethanol which will be an independent source of fuel consumption need to the transport sector. For instance, the size of land required at the end of the simulation period (2050), figure 25.a, will exceed 18 million hectares, which is far more than the size of crop land the country is utilizing for crop production today (FAOSTAT). The increase in resources will result in an increase on feedstock production costs and consequently, cost of ethanol production will reach to the point that the country can't afford as indicated in figure 25.b.



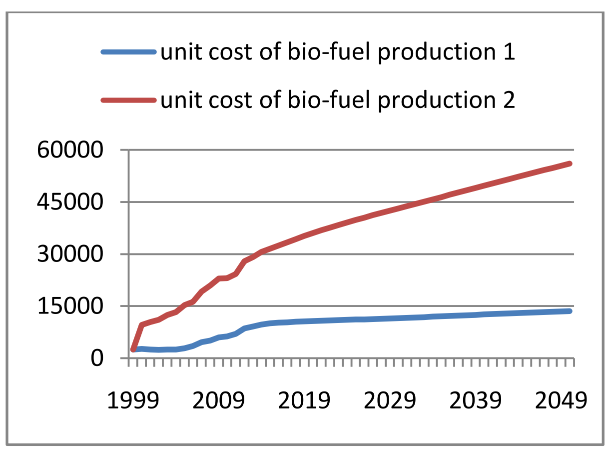
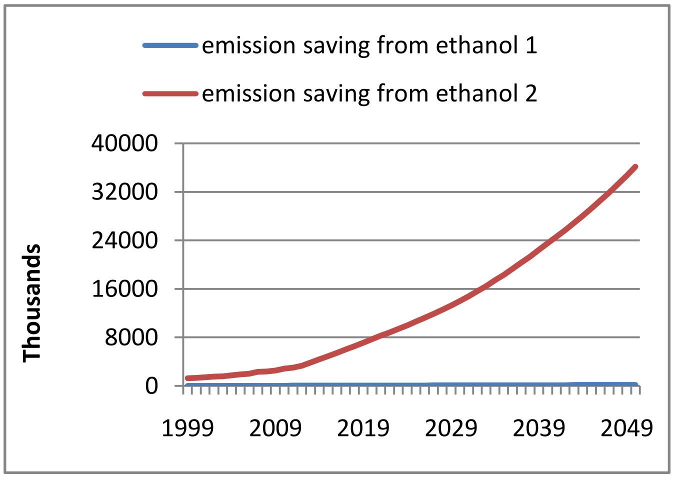


Figure 25(a) land use for feedstock production

Figure 25(b) ethanol production cost

Figure 25: Simulation results of land use and unit production cost with the extreme condition test of share of bio-fuel from transport sector (blue-base run and red- share value of 1)

If the size of the land assigned to ethanol production increases, the emission from feedstock production increases too as shown in figure 26.b, however, since the level of emission saving from ethanol use is higher, figure 26.a, the net emission reduction remains positive and the resulting carbon tax income increases.



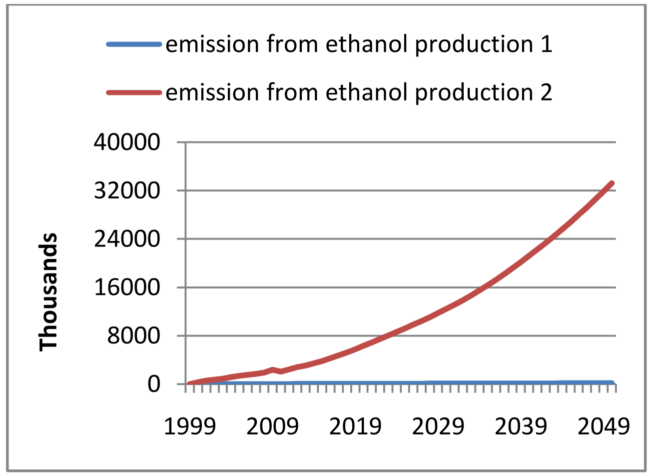


Figure 26.a emission saving from ethanol use

Figure 26(b) emission from ethanol production

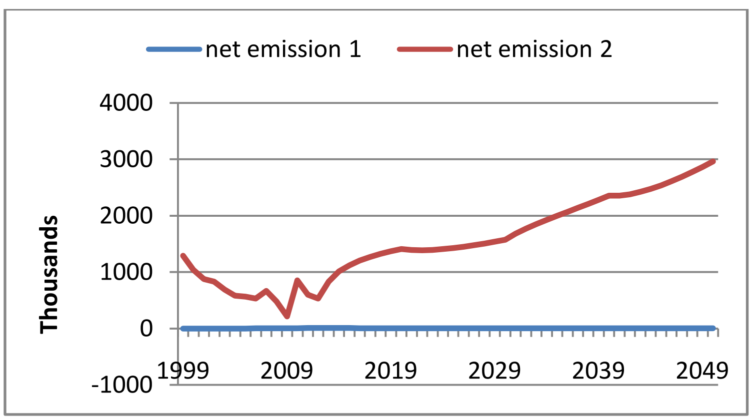


Figure 26(c) net emission (emission saving – additional emission) due to ethanol

Figure 26: Simulation results of net emission saving from ethanol production and consumption with the extreme condition test of share of bio-fuel from transport sector (blue-base run and red- share value of 1)

4.2. Model Behavior Test

Testing behaviors generated by the structure of a model help us evaluate the adequacy of the structure ((Forrester and Senge, 1978). In this section, among the various tests of model behavior, we consider mainly two of them: behavior reproduction (comparison between simulated and reference behavior) and sensitivity analysis.

4.2.1. Reference and Model Simulation Behavior Test

Model validation process includes the comparison of the simulated model behavior with the historic behavior. The objective of this test is to evaluate the model's ability to replicate the reference (historical) behavioral patterns. The model simulation result against which the historical behavior is assessed called the base run, and the assumptions set for the base run is called base scenario. In the following sections, we discuss the base scenario and the simulation results (base run) under this scenario.

4.2.1.1. Base scenario

Different assumptions that are made for the exogenous variables should be set in order to run the model in to the future. Simulation begins from 1999 and ends in 2015. Assumptions and analysis for the future begin after 2018.

The following assumptions were made for the base run: population projections and estimations are made according to The World Bank. Average oil market price estimation is based on OPEC oil basket price; the estimation assumes (predicts) the price of oil will reach the level of around $92(in real $ 2015) in 2040. One USD is equivalent to 21.6271 birr in 2015 (NBE). Therefore, a tone of oil will approximately be sold 14,803.32 birr in 2040. The reference scenario then assumes the price will continue until 2050, the reference time horizon, as there is no data source indicating the price of oil after 2040.

Vehicles growth rate assumption is made by assessing the fact that the resulting number of vehicle per 1000 people at the end of the time horizon doesn't exceed the values observed in middle income countries today. Sugar demand is derived from average per capita sugar demand that changes with the size of the population and the values at the end of the time horizon are compared to today's per capita sugar consumption in middle income counties in order to be realistic.

4.2.1.2. Base run

To recall, the key issue we are addressing is that Ethiopia imports oil products for its fuel requirements, and the demand for fuel is rapidly increasing, which is associated with its growing economy and expanding infrastructures. Imported fuel accounts for the lion's share of the total import expenditure and absorbs much of the total export earnings. As stated in chapter 3, under hypothesis section, the basic assumption taken as a cause for the problem is an increasing fossil fuel demand in the transport sector due to the growth in road network and number of vehicles following a continues GDP growth the country is witnessing. On top of its effect on the country's trade balance, the GHG emission released from fossil fuel combustion in the sector is also another area of concern that should be addressed systematically in a way that the country would be benefited.

In order to reduce oil import dependency and support the green economy effort in the country, ethanol production and blending has been started but not at the level of the country's interest. Hence, bio-fuel accounts for a small share in the transport sector and lags far behind to be considered as one of a successful mitigating mechanism at this stage.

Under the base scenario, the following figures provide an overview of key variables comparing the base run to data points during the reference period from 1999 to 2015, as well as of simulations until 2050 under the assumptions of the base scenario.

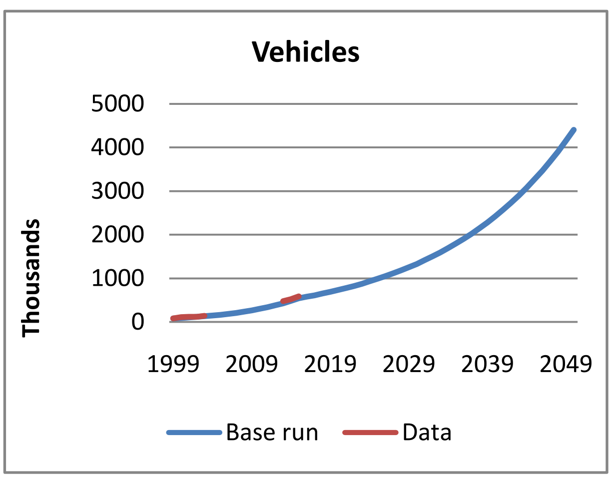


Figure 27(a): number of vehicles

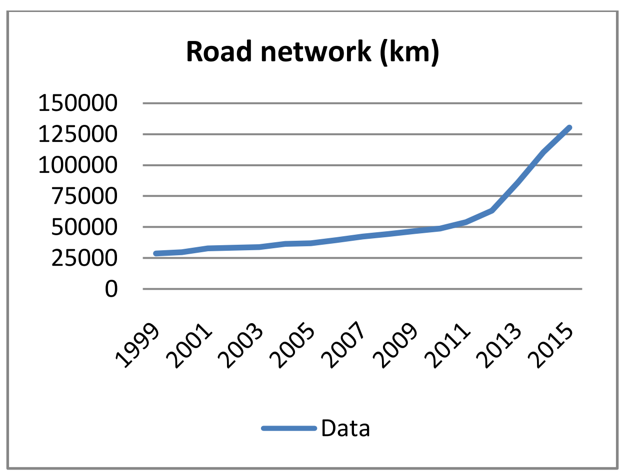


Figure 27(b): road network in km

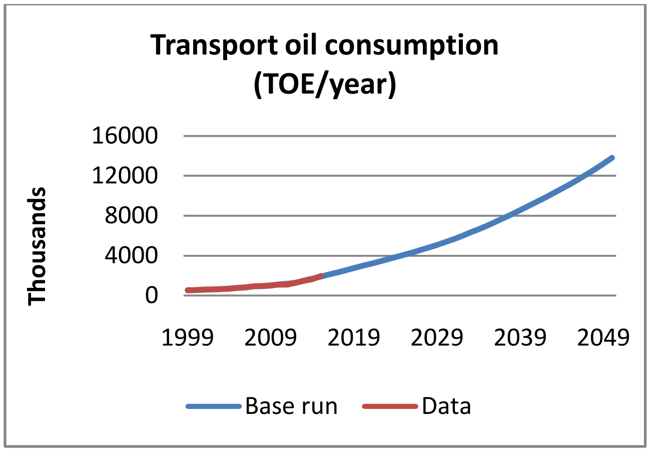


Figure 27.c: transport sector fuel consumption

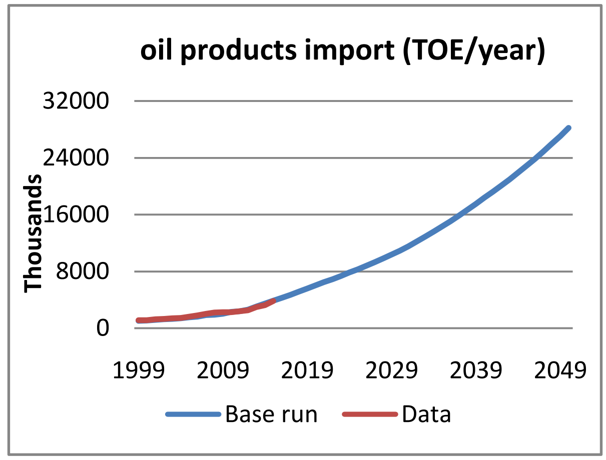


Figure 27d: total oil import quantity

Figure 27: Simulation results and data (if available) for key variables during the reference period from 1999 to 2015 and the base run up until 2050

The following figure indicates the causal loop diagram that represents the base run scenario.

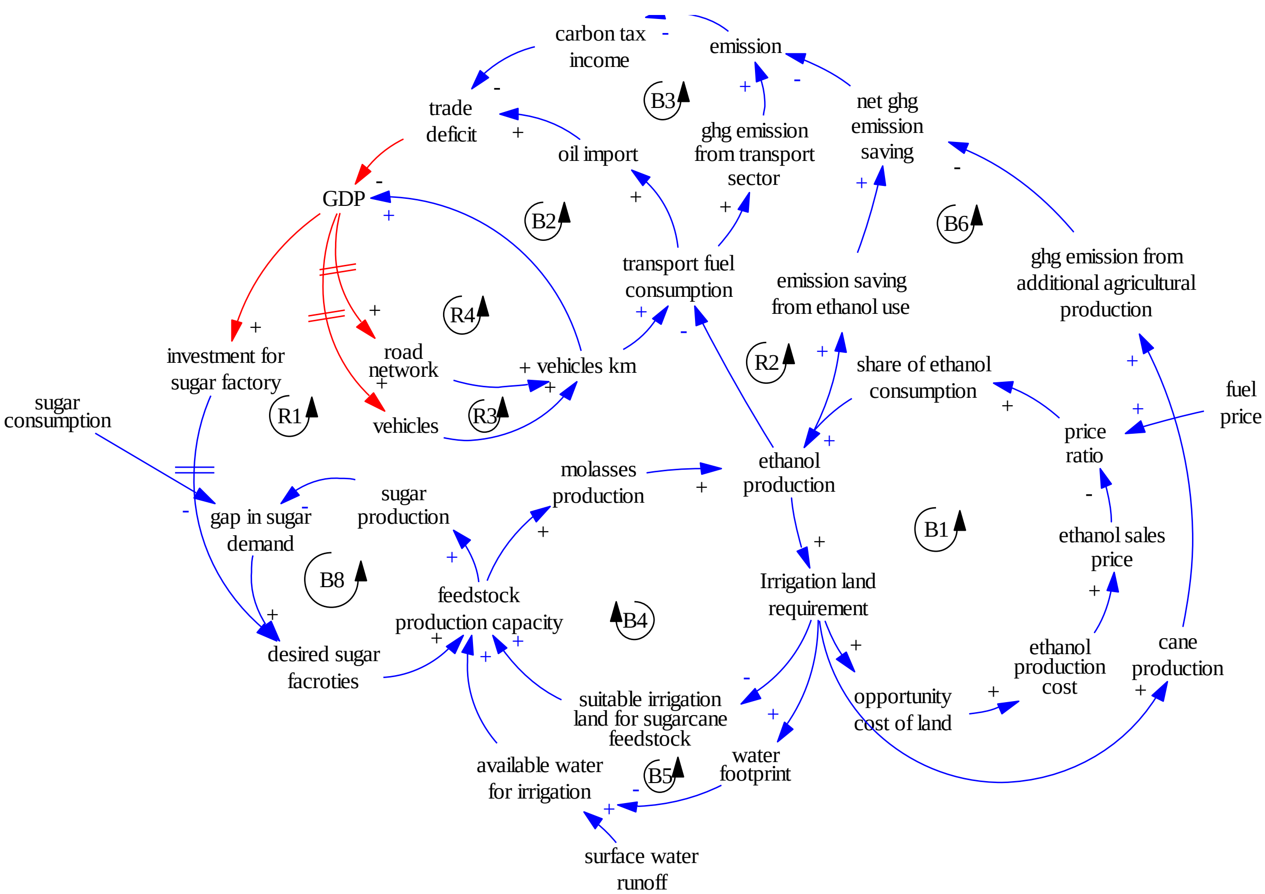


Figure 28: Causal loop diagram constitutes the underlying structure that created the problematic behavior:

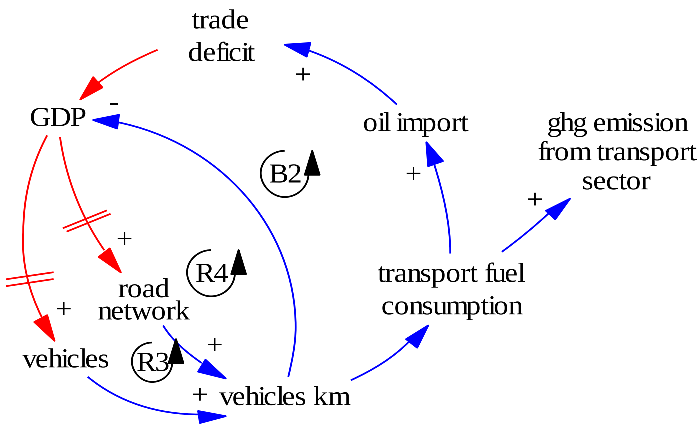


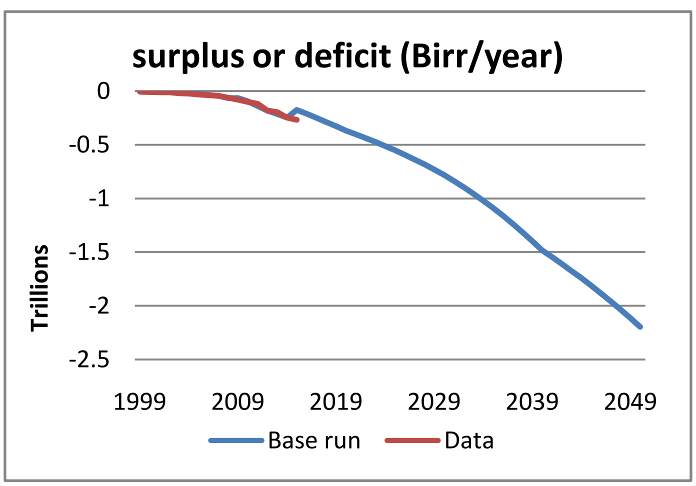
Figure 29: Oil consumption loop

In the base run, transport sector fuel consumption is dependent on the number of vehicles available in the country as well as the growth in the road network, figure 29(R3 and R4). Number of vehicles is increasing during the reference period where as road network shows a steady increase until 2010 and then follows a rapid growth, figure 27 a and b.

This results in relatively higher fuel consumption in the transport sector. The amount of fuel consumed by the transport sector within 10 years (1999-2009), as shown in figure 27.c, has increased from 500,000 TOE to 1M TOE respectively, almost doubled. However, it took only five years since 2010 for the amount to be doubled, from 1M to 2M TOE; this corresponds to the behavior shown in figure d where road network has witnessed a substantial increase starting from the year 2010.

Given the increasing level of fuel consumption in the transport sector, the level of oil products import in each year is increasing too. Oil products import has also shown a rapid growth after 2010 in a similar fashion with road transport fuel consumption, figure 27(d).

Figure 30: Trade balance simulation result

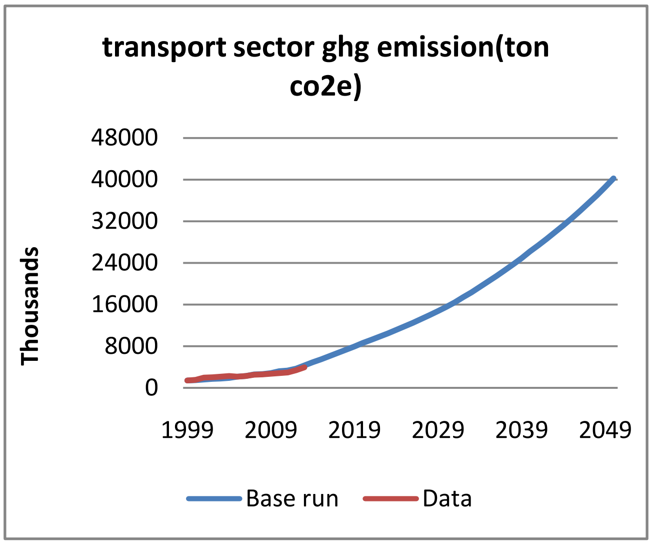


Following the rapid increase in oil products import, the country's trade deficit was increasing over the reference period, figure 30. During the periods 2008-2009 and 2014-2015, the deficit has shown a substantial decrease in value. This is because; the average oil market price during those years has shown a significant reduction (figure 8 section 3), especially during the later period.

In the simulation, trade deficit is sensitive to oil import values and amounts; when the price of oil or the amount of oil import changes, the trade deficit also changes in a similar pattern, but the data values of the trade deficit in the country don't capture such dynamics and this is may be due to other factors that are beyond the model boundary.

GHG emission from transport sector is increasing during the reference period as fuel consumption is increasing too, especially after 2010, figure 31.

Figure 31: Transport sector GHG emission simulation result



The emission level has reached around 5 million ton of co2 e per year during 2015 from 1.5 million ton of co2 eq per year in 1999, figure e. Given the base run scenario, the level will reach above 15 million ton of co2 e by 2030, is almost three fold compared to 2010 level, which is not in line with the country's objective to limiting net GHG emissions in 2030 to below today's (2010) 150 MT of co2 e which is around 250 MT co2 e reductions from estimated

Ethiopia's contribution to GHG emission is very low on a global scale. However, the projected environmental impact of conventional economic development in Ethiopia risks following the pattern observed around the globe. If current practices prevail, GHG emission in Ethiopia will more than double from 150 MT co2 e to 400MT co2 e in 2030. On a per capita basis, emission are set to increase by more than 50% to 3 ton co2e- and will thus exceed the global target to keep per capita emissions between 1 to 2 ton in order to limit the negative effects on climate change (CRGES).

In order to reduce oil import dependency and support the green economy effort in the country, ethanol production and blending has been started but not at the level of the country's interest. Hence, bio-fuel accounts for a small share in the transport sector and lags far behind to be considered as one of a successful mitigating mechanism at this stage.

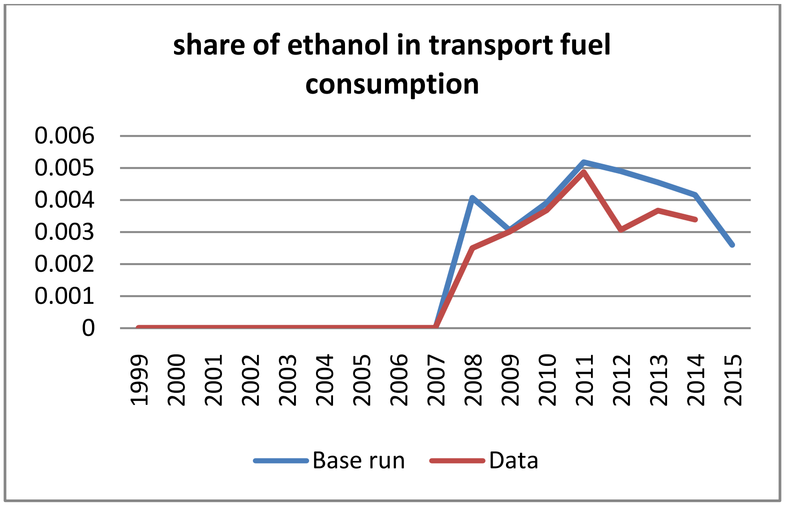
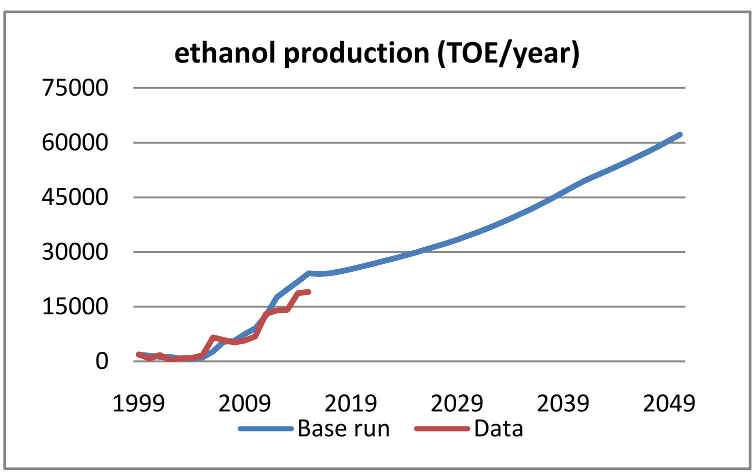


Figure 32: Share of bio-fuel from transport sector fuel consumption

22,500 TOE of ethanol in 2015 provided an annual GHG savings of 12,000 ton of co2 e. This is equivalent to a 0.24% of GHG emission reduction from same year's transport vehicles emission. If the saving had been invested with a minimum carbon market value of 15$ per ton of co2 e (minimum CO_2 quota value set by Carbon Trade Exchange, CTX), the country would have earned 225 million birr till 2015.

Figure 33: Ethanol production trend simulation result



When ethanol was introduced, the production cost was lower than its substitute fossil fuel market price. Therefore, in the first years the production of ethanol was increasing up until 2014. As a result, the share of bio-fuel compared to total fossil fuel consumption increases and causes an increase in the production of ethanol as indicated in figure 28 balancing loop B1, and ultimately, the loop is closed by reducing the amount of fossil fuel used in the transport sector. Afterwards, market value of fossil fuel has declined in international market and the resources required to produce ethanol has been increasing too and causes the balancing loop B1 to be stronger and increase ethanol production cost, consequently, the price ratio (ethanol price compared to fossil fuel price) decreases, which indicates lower price difference. Therefore, since fuel consumption is elastic to price, the consumption of ethanol (ethanol preference) decreases, either the price should be subsidized or the production level should be lowered, which is another indication for policy test.

The production of bio-ethanol reaches above 60,000 TOE per year in 2050 and as a result the annual net GHG emission savings are expected to increase, but the simulation result shows a decline.

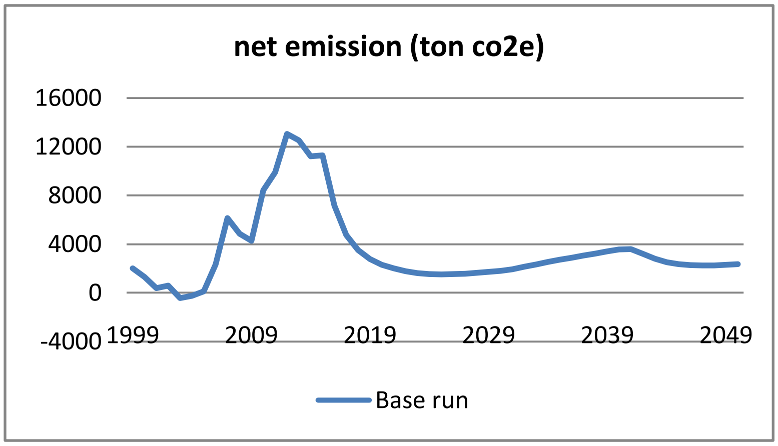


Figure 34: Net emission saving

This is due to the fact that the emission level from additional agricultural production in the bio-ethanol making process is higher than the emission reduction level due to bio-fuel consumption in vehicles. In other words, the net emission reduction level is not increasing after 2015, and this is because the amount of bio-ethanol production and consumption is not increasing as fast as the previous years (share of ethanol in transport has declined). On the other hand, the amount of land used for bio-ethanol crop which is the source of additional emission, is increasing with a lower bio-ethanol yield ; 700 litter of bio- ethanol per hectare where as the world standard is on average 3000 – 6000 litter of bio-ethanol per hectare (IEA, 2006).

Simulation result summary table				
variables	**2020**	**2030**	**2040**	**2050**
vehicles	791,313	1,440,249	2,621,360	4,771,070
road network	190,000	275,000	395,000	480,000
transport oil consumption	3,030,974	5,482,485	9,255,668	14,254,350
oil products import	6,241,818	11,276,823	19,027,278	29,290,000
transport sector GHG emission	8,913,304	16,085,083	27,125,990	41,738,968
ethanol production	26,973	35,933	50,628	65,318
net emission saving	4,318	4,716	8,299	6,945
surplus/deficit	-377.1B	-799.3B	-1.527T	-2.266T

Table 4: Summary table of simulation results in the business as usual scenario

4.2.2. Sensitivity Analysis

One of the behavior tests that help us study whether or not reasonable shifts in the model parameters can cause a model to fail behavior test previously passed (Forrester and Senge, 1979). Sensitivity analysis is conducted on parameter values that are estimated based on statistical data, expert knowledge and other research results. In addition, sensitivity analysis is crucial in examining whether the real system would exhibit similar sensitivity to the corresponding parameters (Barlas, 1994). In this section, we examine the sensitivity of our model behavior to the variable bio-fuel yield per hectare compared to the base run:

Bio-fuel yield per hectare is the quantity of bio-ethanol produced in a given hectare of land size. As mentioned in the model description, the sugarcane land for bio-fuel is directly dependent on its yield. The land size on the other side has a causal relationship with ethanol cost of production and share of bio-fuel from transport sector fuel consumption and ultimately to ethanol production. The higher the yield causes to decrease the land size used to grow feedstock which in turn results in a decrease in the opportunity cost of land that directly influences the cost of ethanol production and determines the share of bio-fuel in transport sector fuel consumption, as the value of the share is set by comparing cost of ethanol production to the price of fossil fuel in the market in the same period.

Figure 35 shows the sensitivity analysis of sugarcane land, cost of ethanol production, share of bio-fuel in transport sector fuel consumption and ethanol production with the change in bio-fuel yield per hectare. We refer the simulation behavior of the variables with the value replicating the reference behavior, blue color simulation graph, as the base run. The simulated behavior, with a 50 % of the parameter below the base run value, is represented by the red color and the simulated behavior, with a 50 % of the parameter above the base run value, is represented by the green color. We considered the parametric values above the reference values as pessimistic values and those below the reference as optimistic values.

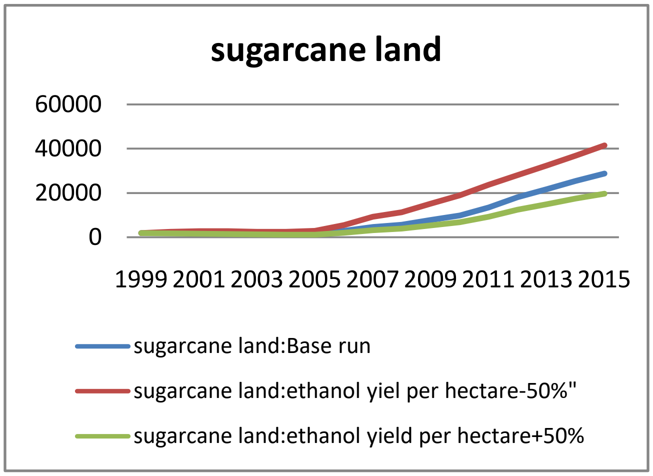


Figure 35.a: land for ethanol feedstock

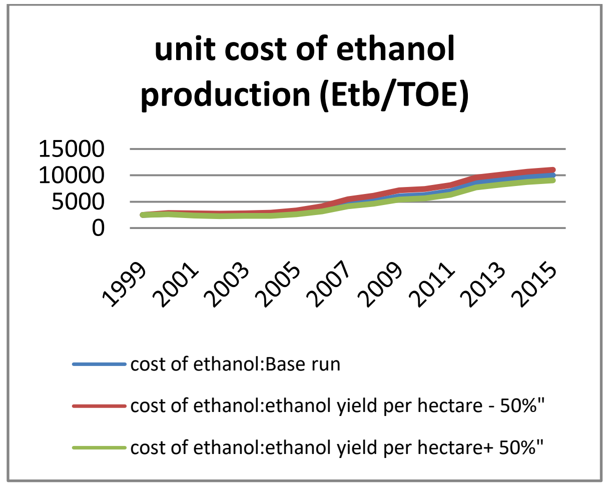
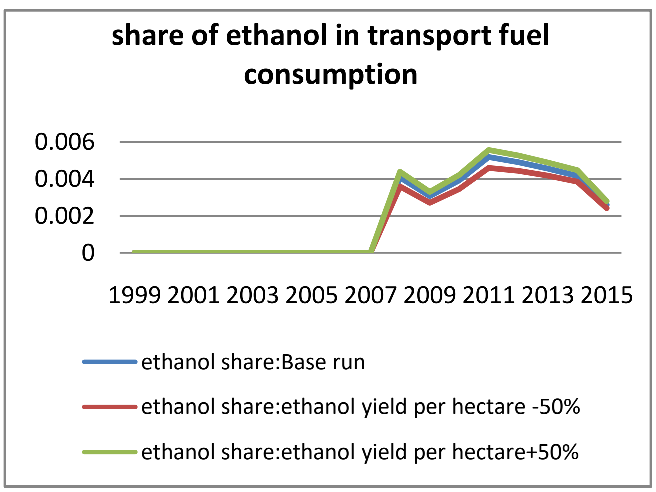


Figure 35.b: Unit ethanol production cost



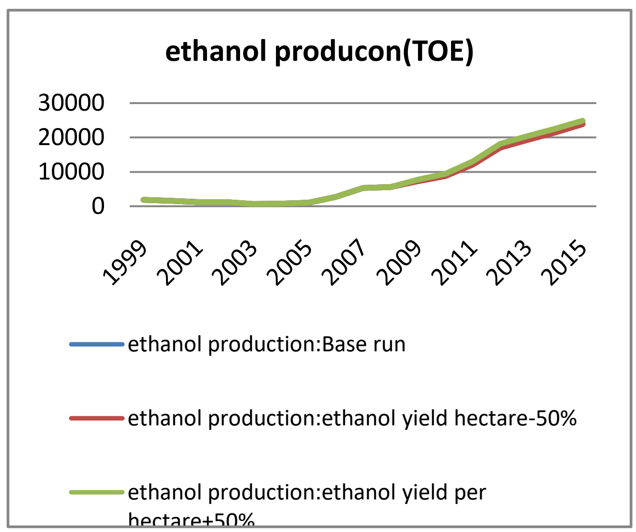


Figure 35.c: ethanol consumption

Figure 35.d: ethanol production quantity

Figure 35: The sensitivity analysis of sugarcane land, unit cost of production, share of ethanol consumption and production with bio-fuel land yield per hectare

variables	Sensitivity test summary table					
	2010			2015		
	bio-fuel yield +50%	Base run	bio-fuel yield -50%	bio-fuel yield +50%	Base run	bio-fuel yield -50%
sugarcane land for bio-fuel	6,678.3	9,795.7	18,923	19,556	28,712.3	41,443
unit cost of ethanol production	5,643	6,250	7,449	9,055	10,032	11,063
share of ethanol in transport	0.0042	0.0039	0.0035	0.0028	0.0026	0.0024
ethanol production	9,368	9,051	8,673	24,806	24,102	23,616

Table 5: Summary table of the effect of bio-fuel yield per hectare on variables in the feedback loop

As shown in figure 35.a, the decrease in bio-fuel yield per hectare causes a more rapid increase on the land size than the increase in land size that actually happens when the yield increases; this may suggest that the parameter value for bio-fuel yield per hectare is below the average value. As a result, the effect of the land size on cost of ethanol production is more significant in case of 50% lower bio-fuel yield.

Sugarcane land for bio-fuel figure 35 (a) is more sensitive than the other three for the parameter bio-fuel yield per hectare shown in the figure 35 (b), (c), and (d). The general model behavior is less sensitive to this parameter implies that the model is robust with this parameter.

Chapter 5: Policy Analysis

In the previous sections, we discussed that the increasing oil products import, both in quantity and value, has become a burden for the country. This is majorly caused by the increasing amount of fossil fuel demand in the transport sector coupled with other sectors fuel consumption, due to the growth in road network and number of vehicles following a continues GDP growth the country is witnessing. Increasing ethanol consumption in the transport sector (share of bio-fuel from transport sector fuel consumption) and mitigating GHG emissions are of the major concern in the process of minimizing the burden of fossil fuel import and the release of resources for investments on other sectors.

In this section, we will mainly focus on examining future policy options and analyzing scenarios on selected variables that could help in reducing the problem. Two policy options: progressive blending policy and green harvest system, target share of ethanol in transport sector fuel consumption are the major policy scenarios that we will focus in this study. The causal loop structure of the new policy scenario is presented in the figure below.

5.1 Progressive Mandatory Blending Scenario

The main challenge in the process of substituting bio-fuel with fossil fuel is the decision of blending; the ratio of ethanol and gasoline in a unit of energy. Blending decision requires a consistent and critical review of the resources available, in this case, the amount of ethanol produced at a unit of time, and proper estimation or projection of future capacity. In addition, studying the consumption trend compared to the market price of other substitutes is a crucial procedure. In the model explanation section, we have examined that despite the presence of arbitrary assumption of E10 blending, 10% ethanol and 90% gasoline, ethanol consumption trend remains low because the figure was assigned arbitrarily and was not supported with detailed research and analysis. As a result, the share of bio-fuel from transport fuel consumption remains insignificant against the interest of the government.

The objective of this policy option is to set an appropriate blending strategy and ultimately improve the share of ethanol in the transport sector fuel consumption without major interruption in the production and distribution of ethanol; the blending limits provide a very good basis for the production of significant volumes of bio-ethanol. Methods of improving consumption may include: subsidy, tax exemptions and blending targets (mandates). Various techniques has been applied to improve bio-fuel consumption in various counties depending on their goal, the resources they have, the expert knowledge, priority of finance allocation. The application of a particular improvement method, or a combination of them could be possible and should be decided based on expert knowledge.

The objective of this section is to analyze which policy option is suitable for a smooth interaction of resource availability, production capacity and the consumption level that enables the country achieve its goal and for simplicity, we consider a progressive mandatory blending target.

5.1.2 Stock and Flow Diagram of Progressive Mandatory Blending Scenario

The assumption of this policy option is that the application of progressive mandatory blending target will enable and encourage vehicles to use bio-fuel ethanol together with fossil fuel so that the share of transport fuel consumption from bio-fuel gradually increases and, as a result, the amount of ethanol produced increases. Consequently, the amount of fossil fuel consumption reduces, and as a result, the level of fossil fuel import declines, and ultimately enables experience the benefits from foreign currency saving and GHG emission reduction mentioned in the behavior analysis.

However, decision should be progressive and mandatory that requires continuous and timely review of production capacity, the level of transport fuel consumption, specifically gasoline consumption, on which the substitution depends on.

We made estimation on the proportion of gasoline in transport fuel consumption based on a data from (IEA yearly world energy balances; Mekuria, T., 2015; Ethiopian Petroleum Enterprise) that the proportion of gasoline consumption in the transport sector compared to other oil products ranges from 10% to 14%. Based on this, we take the maximum value 14% of fuel in the transport sector is consumed by gasoline vehicles. Therefore, we consider the proportion of gasoline in transport fuel to be 0.14.

*Gasoline = transport fuel demand * proportion of gasoline in transport fuel*

Once the amount of gasoline is determined, we set a blending percentage decision that will give us the desired level of ethanol to add up to a (1- blending percentage) of gasoline. The desired share of transport fuel consumption from ethanol is given by:

Desired ethanol / transport fuel demand

A stock of new share of transport fuel consumption from ethanol is set to show the delay that the initial share of transport fuel consumption from ethanol in 2017 adjusts itself towards the desired level with an adjustment time of two years. And finally, the value of the stock is linked to the existing system by multiplying it with the effect of price ration on bio-fuel consumption:

*New share of transport fuel consumption from ethanol * effect of price ratio on bio-fuel consumption*

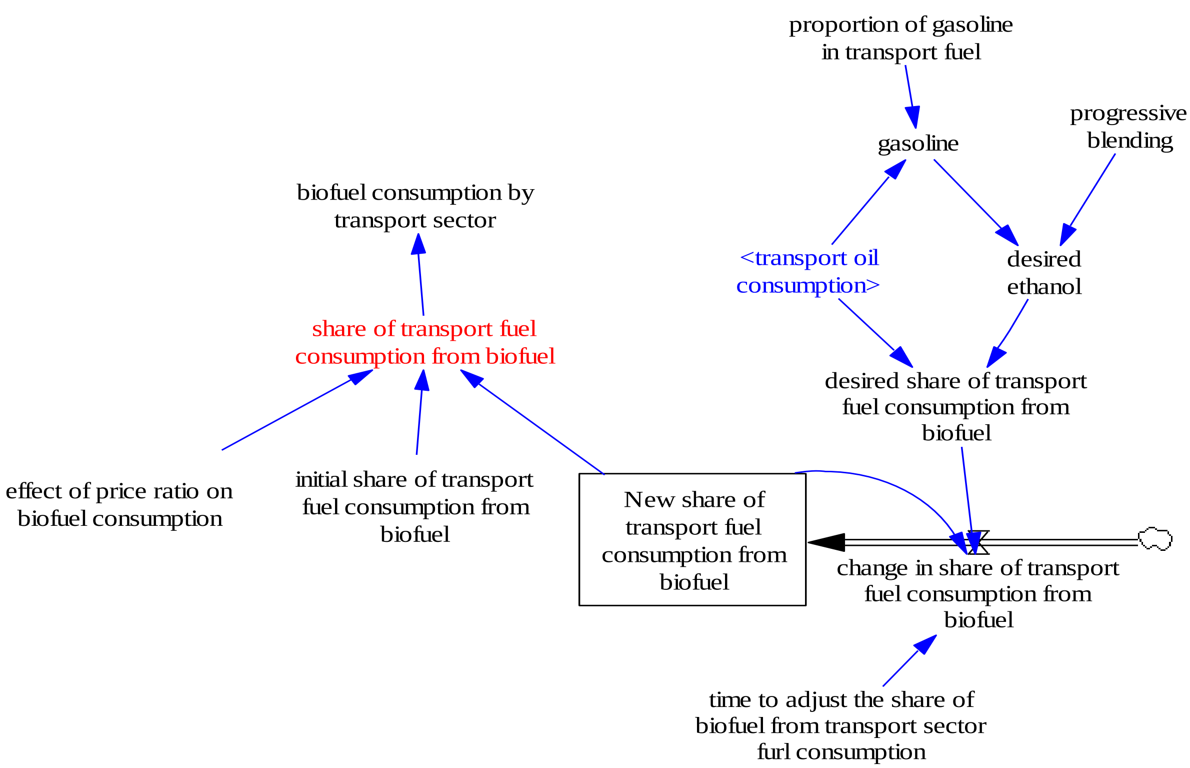


Figure 36: Stock and flow structure of progressive mandatory blending policy

5.2 Green Harvest Scenario

Traditionally, sugarcane has been burned prior to harvest in order to eliminate leafy non-sugar containing material. This process has been a cause for the increase of GHG emission level during sugar and ethanol production. On the process of growing sugar cane feedstock and harvesting, the release of GHG emission during cane field burning and the release of N_2O from the soil due to fertilizer decomposition are considered as the major sources of GHG emission (Alckmin, G & Goldemberg, J., 2004).

A study (de Figueiredo et al, 2010) on greenhouse gas emission associated with sugar production in southern Brazil indicates that most important reduction in green house gas emissions from sugar cane area could be achieved by switching to a green harvest system, which means harvesting the leaves and roots without burning it on the field. The study reveals that it is possible to reduce the major part of the total emission (44%) by switching to green harvest without causing significant variations on productivity and yield compared to field burning.

The objective of this policy is to reduce GHG emission resulted from burning. . Methane and N_2O emission from this process of burning sugar cane trash is equivalent to 9 kg CO_2e per TC (tone of cane)

Modern harvesting machines can separate trashes from the crushable cane efficiently and the challenge is how to manage the trash and what impact this residue left in the field will have on the soil and on subsequent crops. Retention of unburned residues can increase nutrient conservation, reduce weed growth, and conserve soil moisture. However, the retained residue makes tillage operation more difficult, interferes with fertilizer and herbicide applications (Wiendenfeld, 2009). But we suggest chopping and grinding the leaves; the harvesting machine could be enabled to chop and release the leaves on the field during harvesting time.

With the green cane approach, harvesting is still possible when wet weather prevents burning and there is no loss when heavy rain delays harvesting of burnt cane for long periods. Blocks of cane also can be cut as scheduled without worry about unfavorable wind conditions for burning.

5.2.1 Stock and Flow Diagram of Green Harvest Scenario

The basic assumption of this policy is that the application of green harvest method instead of burning during sugarcane harvesting decreases the GHG emission resulted from sugarcane trash burning. As mentioned above, it is estimated that 9 kg of CO_2e per ton of cane, that could have been saved, is released.

Based on the fact that it is possible to avoid emission from sugar cane trash burning, we introduced a green harvest policy. However, the emission level from sugar cane trash burning is not expected to drop to zero in 2018, rather it will decline slowly based on the capacity of green harvesting machine. Figure 2 shows the assumption reflecting the decline of emission from trash burning over a period of time.

Change in the emission level = (green harvest desired emission – new emission from sugar cane trash burning) / time to shift to green harvest

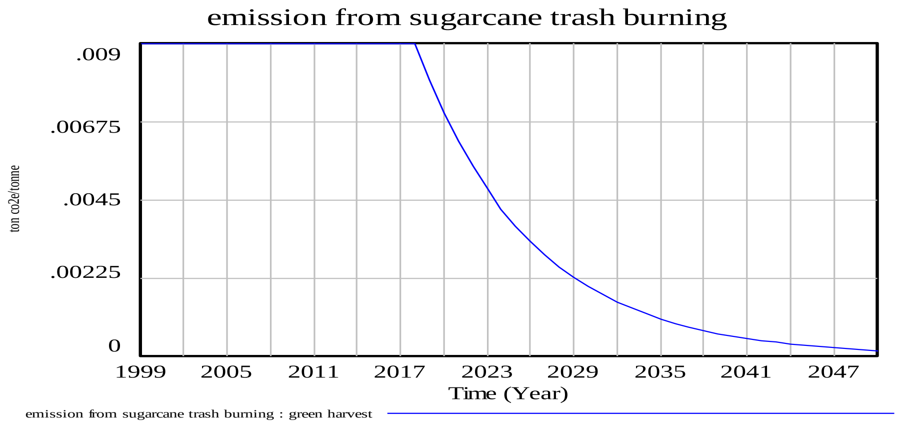


Figure 37: Emission from sugarcane trash burning reduction trend

Therefore, the shift from trash burning to green harvest is assumed to take 8 years of capacity building and improvements in technology innovations.

A stock of new emission level from sugarcane trash burning is set to show the time delay resulted from the policy shift. And finally, the value of the stock is linked to the existing system substituting the value of emission from sugar cane trash burning after 2018 and added to soil n2o emission to get the value of emission per ton of sugar cane produced.

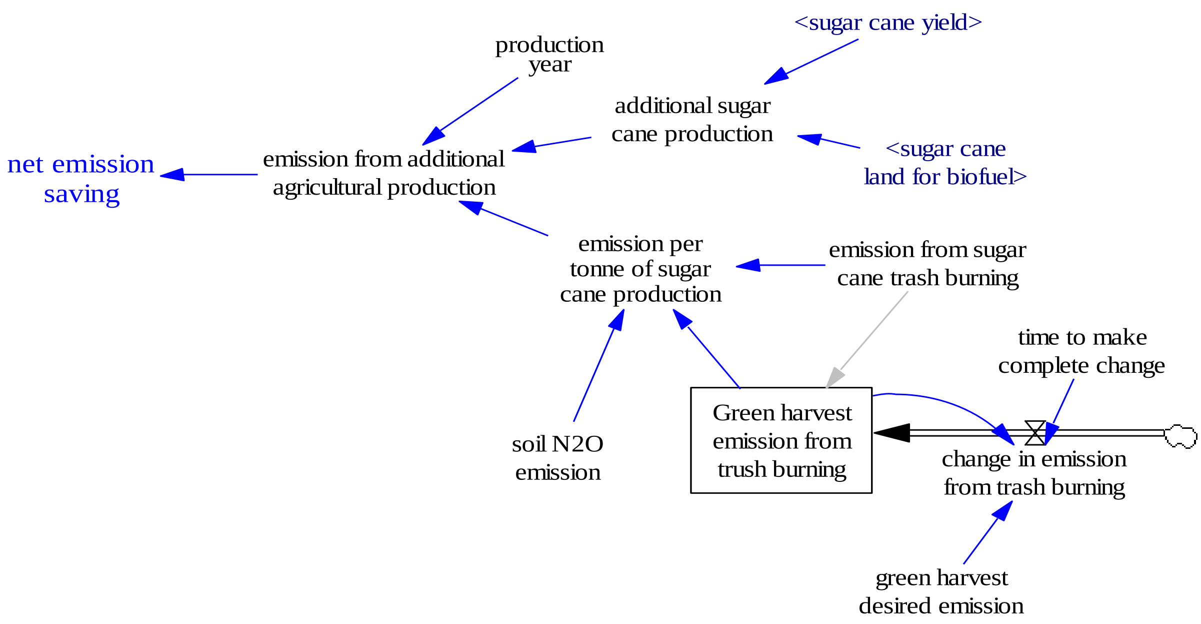


Figure 38: Stock and flow structure of green harvest scenario

5.3 Policy Testing

The objective of this section is to test the simulation results of the policy mechanisms and comparing them with the business as usual (base-run) case, and ultimately, interpret the implication for reality.

5.3.1 The Base Run

The base run is performed under base scenarios stated in section 4 and the exogenous variables continue their current development up to the end of the simulation period. The simulation results in the business as usual case runs from 1999 up to 2050.

Figure 39: Simulation results of the base run for some selected variables: oil import, transport fuel consumption, ethanol production, and share of ethanol from transport fuel consumption, trade deficit, and net emission reduction

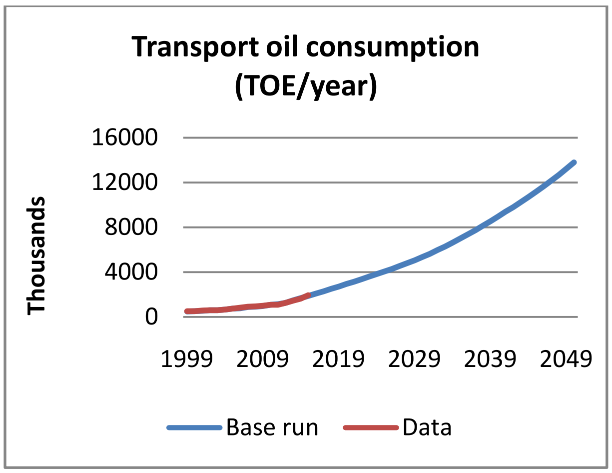


Figure 39.a. transport oil consumption

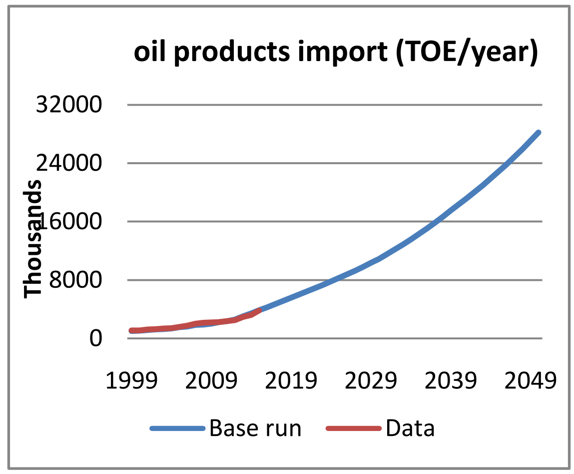


Figure 39.b. oil products import

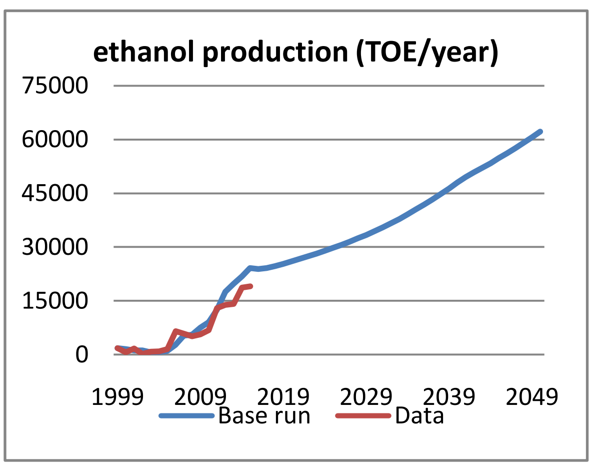


Figure 39.c. ethanol production quantity

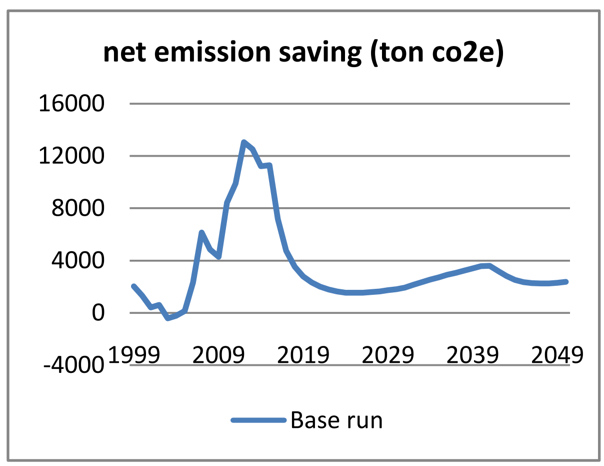


Figure 39.d. emission saving from ethanol use

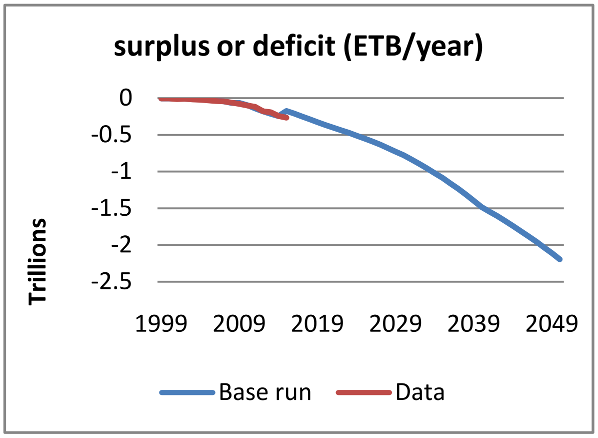


Figure 39.e. trade balance (net export)

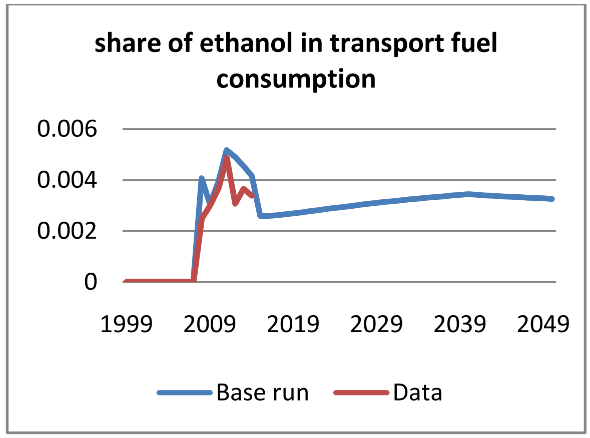


Figure 39.f. ethanol share in transport sector

Base run simulation result summary table

variables	2020	2030	2040	2050
transport oil consumption	3,030,974	5,482,485	9,255,668	14,254,350
oil products import	6,241,818	11,276,823	19,027,278	29,290,00
ethanol production	26,973	35,933	50,628	65,318
net emission saving	4,318	4,716	8,299	6,945
surplus/deficit	-377.1B	-799.3B	-1.527T	-2.266T

Table 6: Summary of base run simulation results

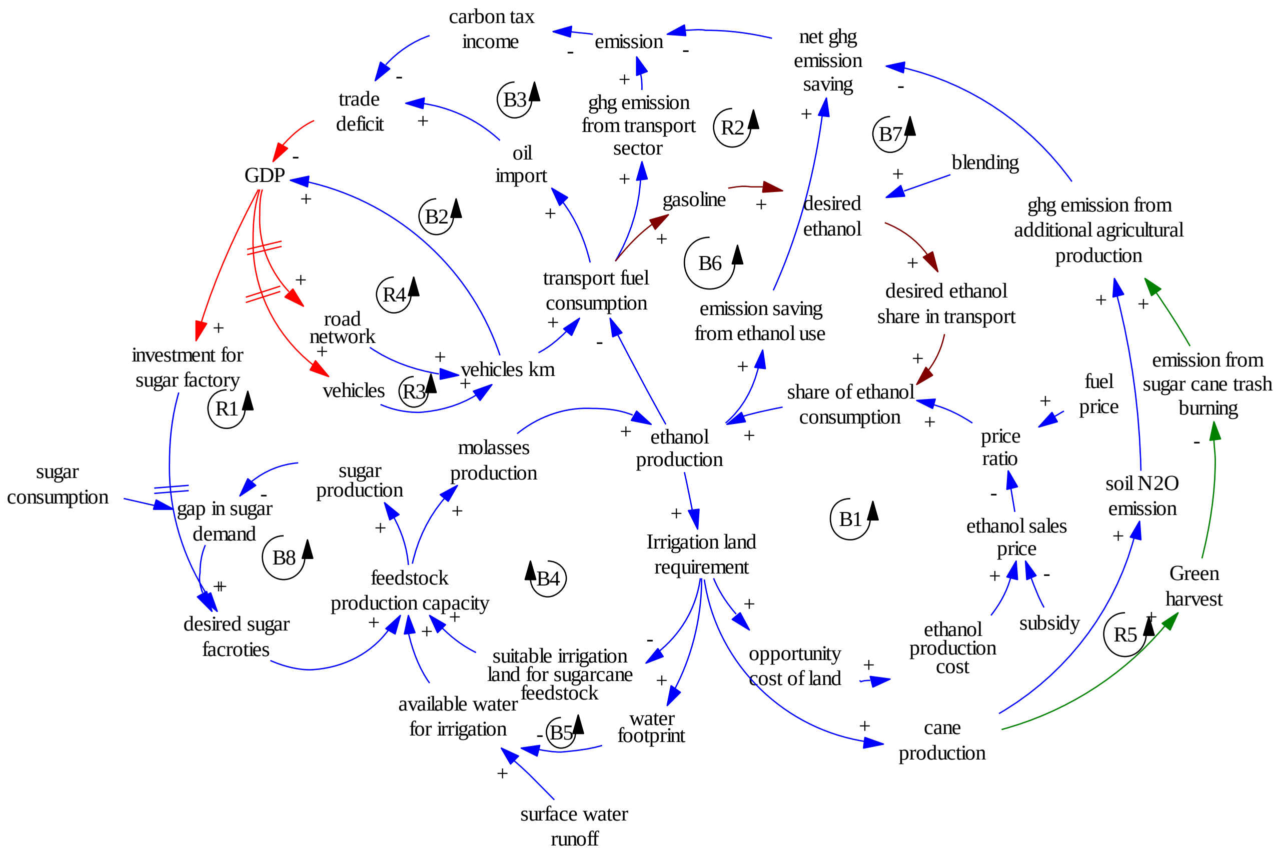


Figure 40: Main causal loop structure of the explanatory model (in blue and red) and the policy scenario (in green and brown)

Figure 39 and table 6 illustrate that how oil consumption in the transport sector will continue to grow and cause an increase in the amount of oil products import. As a result, the bills in oil products import have increased substantially over time as shown in figure 40 reinforcing loop R3 and R4. The high cost of oil imports has aggravated the country's balance of payments problem, figure 40 balancing loop B2. On the other hand, the GHG emission caused by the increasing transport sector fuel consumption continues to grow as indicated in figure 40 balancing loop B3.

Ethanol was being produced as an intervention for the existing problem as shown in figure 40 balancing loop B1, unfortunately, the production has not proceed as planned and the amount of ethanol used in the transport sector remained very small. Consequently, the net emission saving has declined due to the fact that compared to the sugarcane planted and harvested, and following a reduction on fossil fuel market price, very small amount of ethanol was produced and substituted after 2014. Therefore, the country hasn't been benefited from the sector as much as it was expected before. Hence, policy interventions that could improve the existing trend would be crucial.

5.3.2 The Progressive Mandatory Blending Policy Scenario

Progressive mandatory blending policy is the first option we want to test in the model. This policy replaces the already existing E10 blending policy and implements E5 in 2018 and progressively adjusts to increase to E10 in 2030 and finally the blending will reach E15 in 2050. The existing E10 policy was not applicable because of insufficient ethanol production and the policy was introduced without proper investigation of available resources and the inability to forecast future consumption and production capacity (EEA, 2007). The share of bio-fuel in transport sector fuel consumption is small, hence, a policy shock is introduced and the share is enabled to increase to a desired level, consequently, the policy causes an increase in ethanol consumption and opens room for an increase in ethanol production and gives indication for the resources that must be mobilized. The simulation results of progressive mandatory blending scenario compared to the base run are presented below in Figure 41(a-f).

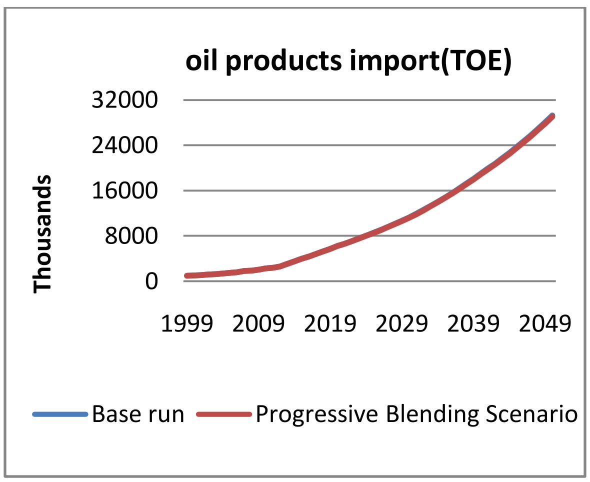


Figure 41.a. oil products import (quantity)

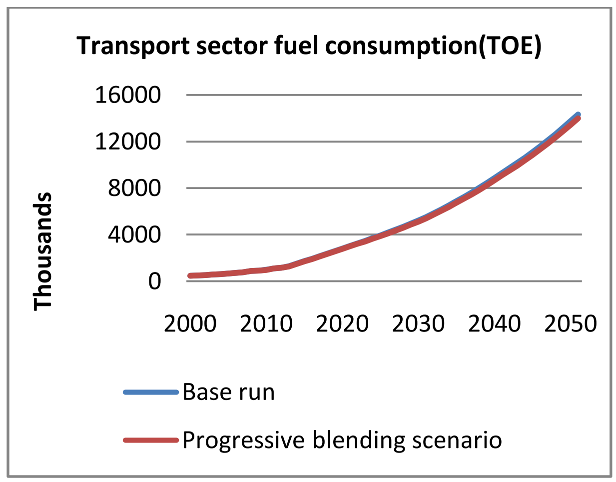
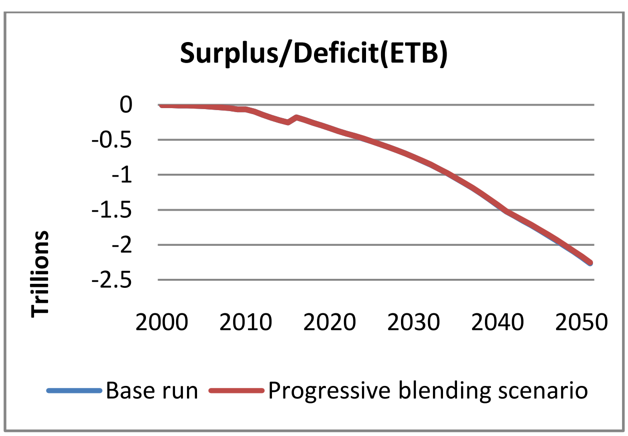


Figure 41.b. transport oil consumption



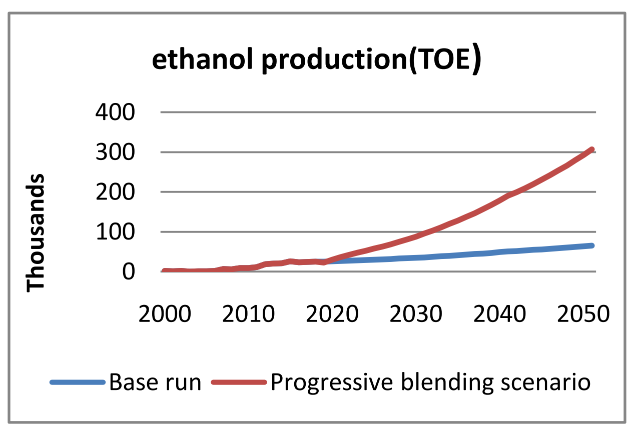


Figure 41.c. trade balance

Figure 41.d. ethanol production quantity

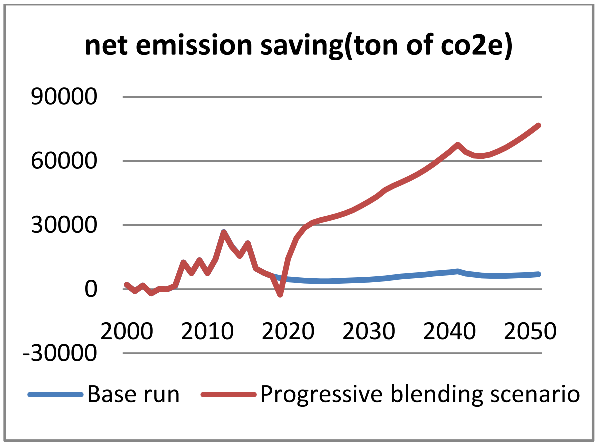


Figure 41.e.GHG emission saving

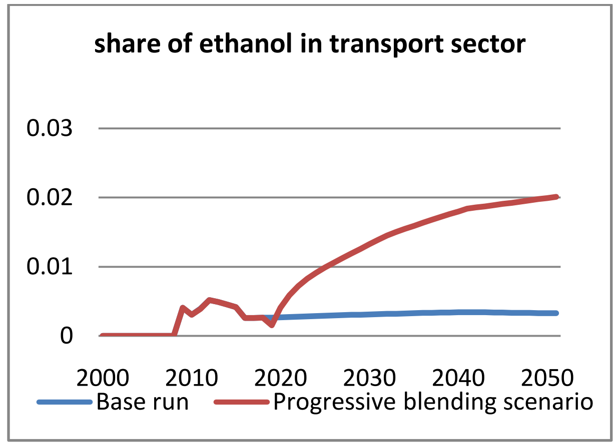


Figure 41.f. ethanol share in transport sector

Figure 41: The simulation results of progressive mandatory blending scenario compared to the base run

It is clear that some of the simulation results that have larger values seem to show of similar result, this is because, the changes observed due to progressive mandatory blending scenario are smaller compared to the trillion and billion values of some variables. Therefore, the simulation results are summarized in the following table 7 to clearly identify the change in the values.

summary table of progressive blending policy simulation results					
	variables	year			
		2020	2030	2040	2050
1	ethanol production	36,601	95,424	190,253	307,064
2	oil products import	6,232,191	11,217,332	18,887,652	29,048,256
3	transport oil consumption	3,021,346	5,422,994	9,116,043	14,012,604
4	surplus or deficit	-376.6B	-796B	-1.52T	-2.25T
5	net emission saving	24,007	43,430	67,720	76,690
6	share of transport fuel consumption from bio-fuel	0.0059	0.014	0.018	0.02

Table 7: Summary of progressive blending policy simulation results

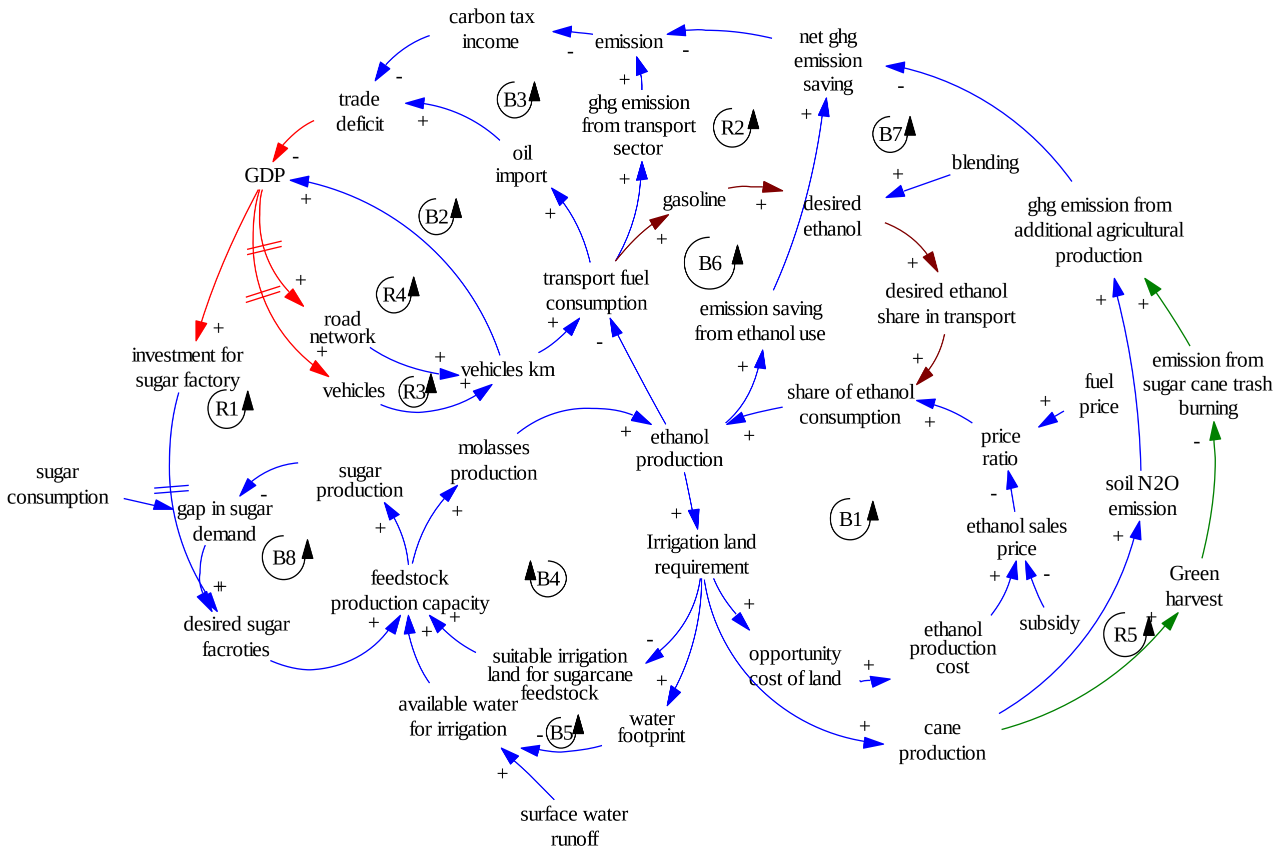


Figure 42: Main causal loop structure of the explanatory model (in blue and red) and the progressive mandatory blending scenario (in brown)

In figure 42 above, the loop B6 represents the new progressive mandatory blending policy structure. The loop represents the effect of mandatory blending in increasing the share of bio-fuel consumption. The increase in transport sector fossil fuel consumption causes an increase in gasoline consumption based on which ethanol blending is calculated. The effect of the increase in gasoline consumption on the desired blending mandates will have an increasing effect on the amount of bio-ethanol to be produced (desired bio-ethanol). As a result, the share of bio-fuel compared to total fossil fuel consumption increases and causes an increase in the production of ethanol, and ultimately, the loop B6 is closed by reducing the amount of fossil fuel used in the transport sector. However, if the blending mandate is beyond capacity and the production of ethanol increases, the resources required increases too and causes the balancing loop B1 to be more active and increase ethanol production cost, consequently, the price ratio (ethanol price compared to fossil fuel price) decreases, which indicates lower price difference. Therefore, since fuel consumption is elastic to price, the consumption of ethanol (ethanol preference) decreases, either the price should be subsidized or the production level should be lowered, which is another indication for policy test.

The introduction of the new progressive blending policy, figure 42 balancing loop (B6), triggers the amount of ethanol consumption and requires a higher ethanol production than the base run (36,601 TOE in 2020) compared to 26,170 TOE in the base run. This in turn, increases the amount of ethanol to be used in the transport sector fuel consumption as a substitute, consequently, the share of ethanol in transport fuel consumption increases to 0.59% (0.0059) in 2020 which in the base run was 0.00273 (0.28%) and continues to increase up until 2% in 2050. As a result the amount of fossil fuel import reduces following the decrease in transport sector fossil fuel consumption as shown in figure 42 balancing loop B2. Ultimately, the bills that could be paid to import those saved amount of oil plays its own role in the reduction of the country's trade deficit; a 447million, 3.2B, 9.3B, and 16 billion ETB reductions in 2020, 2030, 2040, and 2050 respectively. On the other side, apart from the role of balancing the net export to some extent, the level of GHG emission saving due to ethanol substitution increases and the carbon income tax related to the saving also increases as indicated in figure 42 reinforcing loop R2.

5.3.3 Green Harvest Scenario

This policy option is believed to avoid the GHG emission resulted from sugarcane trash burning during sugar cane harvesting in the process of sugar and ethanol production. As net emission reduction is the result of the surplus of emission saving over additional emission during ethanol production, avoiding the major cause of additional emission enables to increase net emission reduction, and ultimately, the carbon tax income related to emission saving increases and the country could benefit from it in the form of foreign currency earnings. The simulation results under Green Harvest scenario compared to the base run are presented below in Figure 43(a-f).

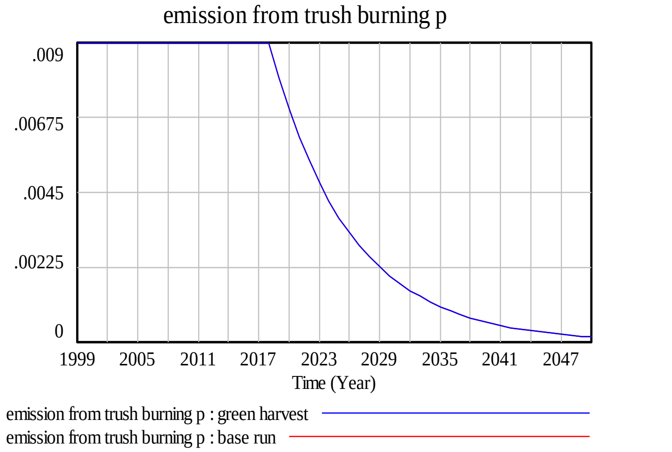


Figure 43.a. emission from trash burning after policy

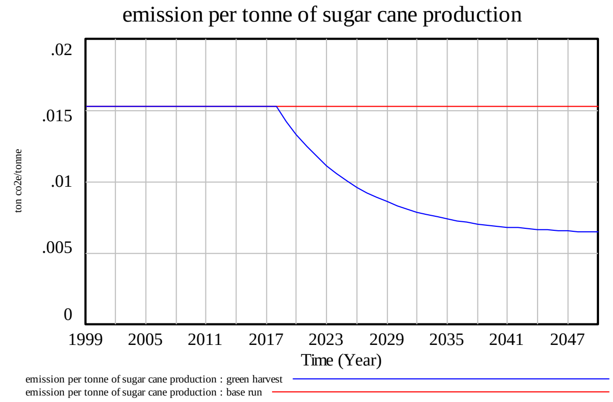


Figure 43.b. GHG emission in unit of sugarcane

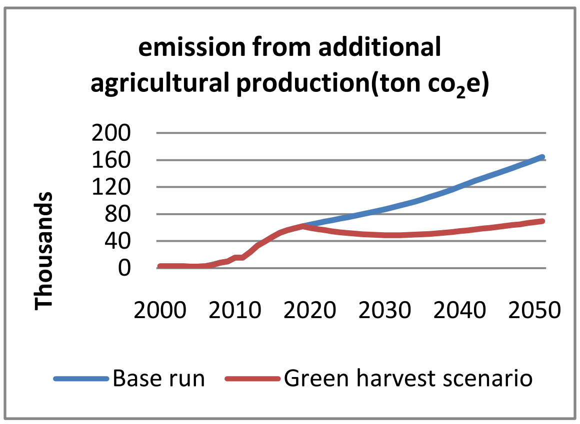


Figure 43.c. GHG emission during feedstock production

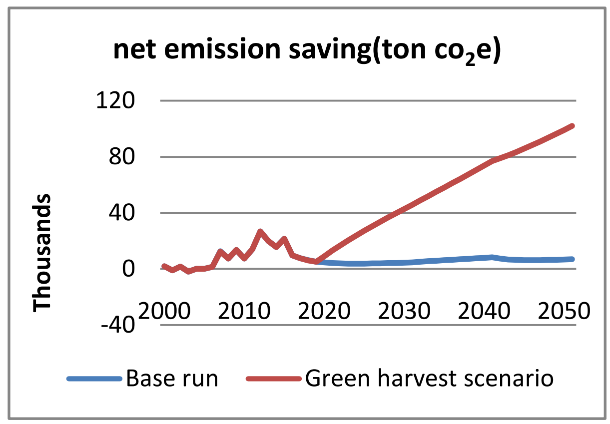


Figure 43.d. GHG emission saving

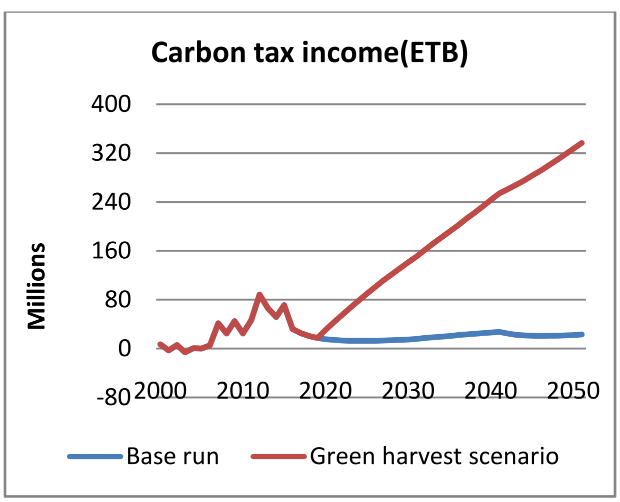


Figure 43.e. Income from carbon trade

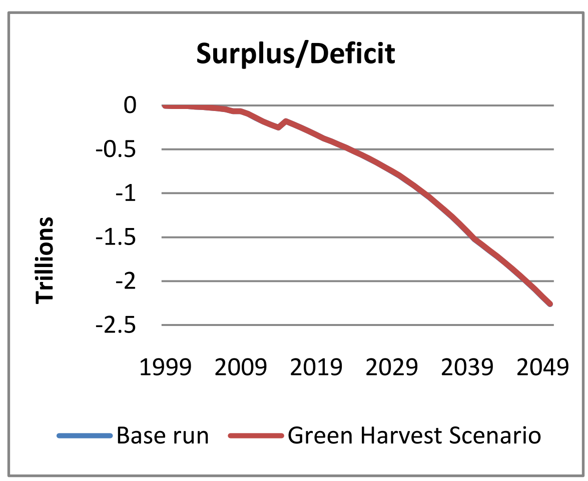


Figure 43.f. Trade balance

Figure 43: The simulation results under Green Harvest scenario compared to the base run

	Summary table of green harvest scenario simulation results				
	variables	year			
		2020	2030	2040	2050
1	Green harvest emission from sugarcane trash burning	0.007	0.00199	0.00056	0.00016
2	Emission per ton of sugar cane production	0.0133	0.00829	0.00686	0.00646
3	Emission from additional agricultural production	57,767	48,556	55,903	69,440
4	Net emission saving	12,993	45,706	76,910	101,910
5	Surplus or deficit	377B	799B	1.527T	2.266T
6	Carbon tax income	14,250,199	15,563,264	27,385,540	22,919,376

Table 8: Summary of green harvest policy simulation results

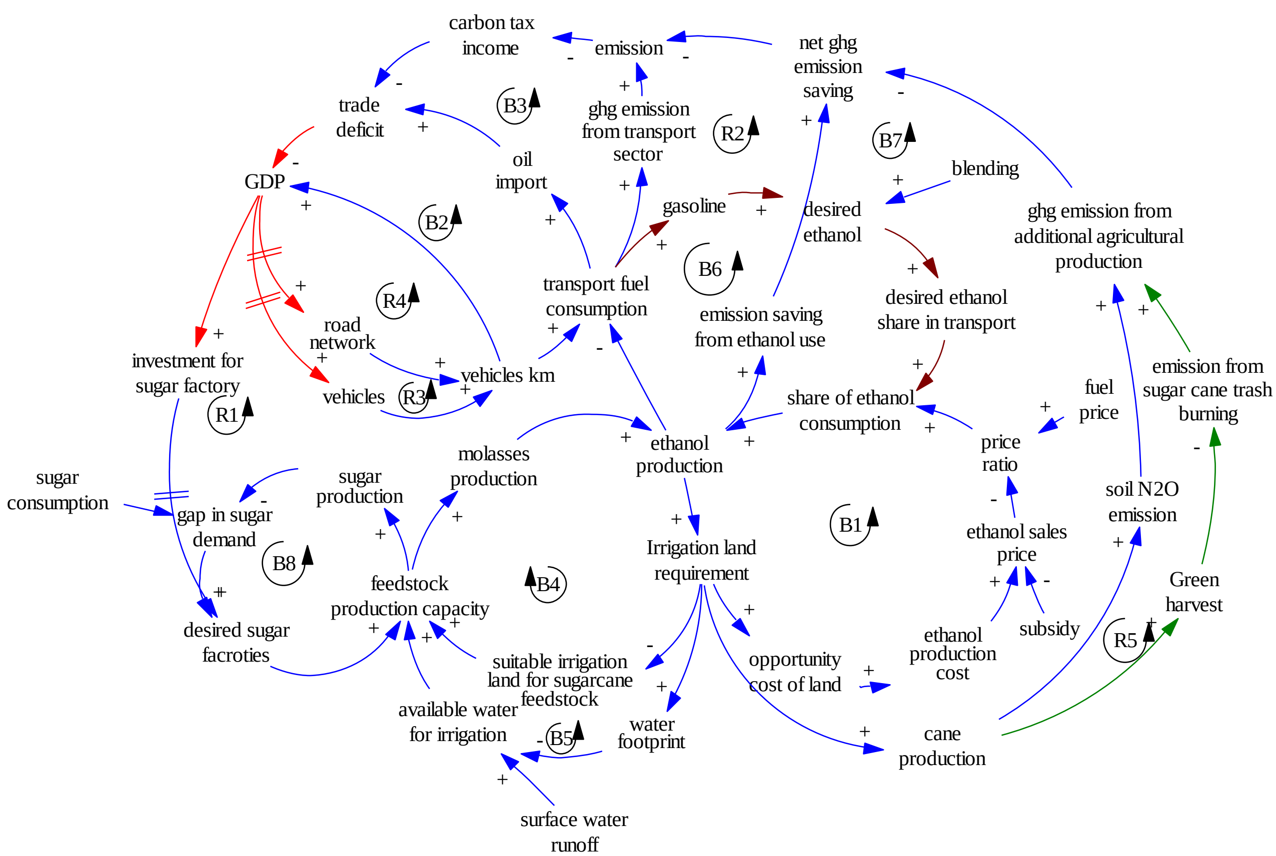


Figure 44: Main causal loop structure of the explanatory model (in blue and red) and the green harvest scenario (in green)

In figure 44 above, the reinforcing loop R5 represents the new green harvest policy structure. The loop indicates the effect of switching to green harvest in reducing the GHG emission level resulted from sugarcane burning during harvesting time in the process of ethanol production.

When ethanol production increases, the amount of land used to grow sugarcane feedstock increases, as a result, the sugarcane plantation and the level of harvesting increases too. The introduction of green harvest slowly avoids the emission resulted from sugar cane trash burning and ultimately reduces the total GHG emission from additional agricultural production and results in an increase on the net GHG emission saving; the difference between GHG emission saving due to ethanol substitution (reinforcing loop R2) and additional emission caused by the process of ethanol production (balancing loop B7). Therefore, the benefits that arise from GHG emission reduction increases and in the mean time, it motivates both the production and consumption of bio-ethanol in the country.

The introduction of green harvest policy enables to reduce the emission from trash burning over time (from 0.009 ton co2e to 0 until the end of 2050), figure 43.a. As a result, the total emission from a ton of sugarcane production starts to decline in the same fashion as shown in figure 43.b. As more sugar cane is produced in order to increase ethanol production, the emission released from additional agricultural production (feedstock) declines compared to the base run. Consequently, the net emission saved, the surplus of emission saving over the release of GHG emission caused by production increase, starts to increase increasingly resulting in an increase of carbon tax income from saving in a similar fashion. Ultimately, the income earned from carbon tax income slightly reduces the trade deficit. However, the effect of carbon tax income on trade deficit is very small due to the size of the surplus or deficit; a reduction of 28.6, 135.3, 226.4 and 313.5million ETB during 2020, 2030, 2040 and 2050 respectively.

5.3.4. Both Progressive Mandatory Blending and Green Harvest Scenario

When Progressive Mandatory Blending and Green Harvest Scenario are introduced together after 2018, the only changes that have been examined in the simulation results compared to the progressive mandatory blending scenario results are on net emission saving and the benefits related to it including trade deficit. This is because green harvest scenario has nothing to do with the change in ethanol production quantity; rather its impact is on the GHG emission levels related to the production.

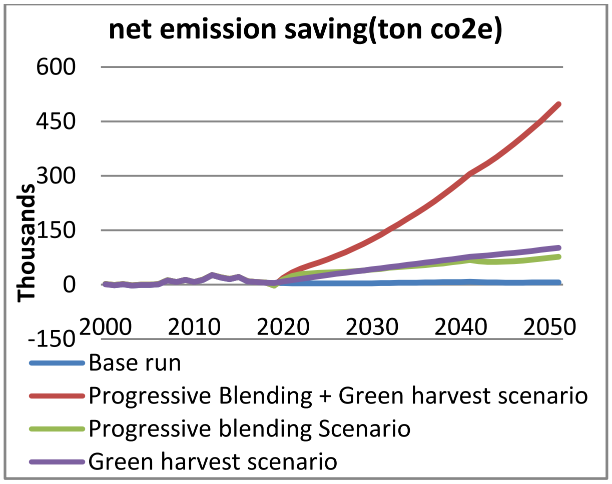


Figure 45.a. GHG emission saving

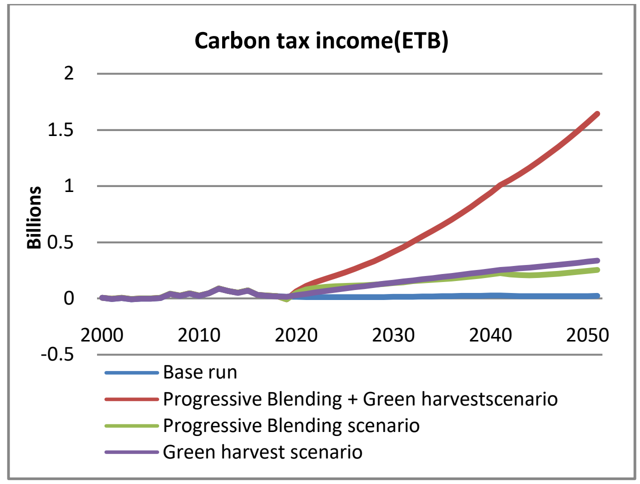


Figure 45.b. Income from carbon trade

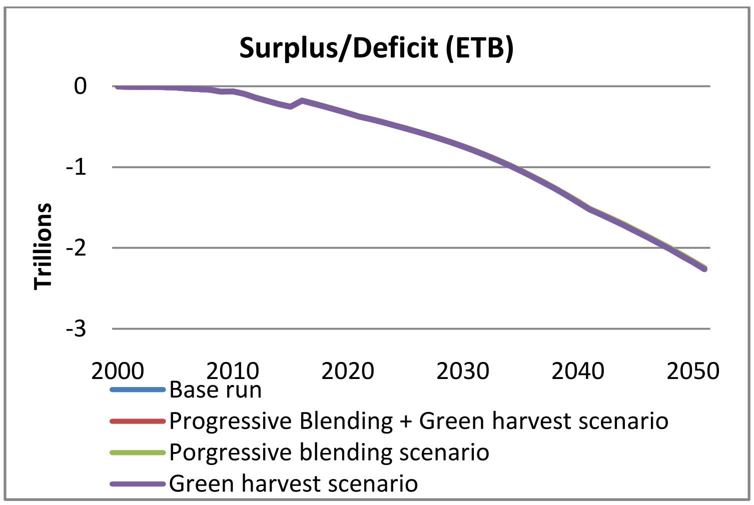


Figure 45.c. Trade balance

Figure 45: Simulation results of some variables under progressive blending plus green harvest scenario

It is clear the simulation results ‘surplus or deficit’ seem to show of similar result, this is because, the changes observed due to scenarios are smaller compared to the trillion value the trade balance. Therefore, the simulation results of progressive mandatory blending together with green harvest scenario are summarized in the following table 9 to clearly identify the change in the values.

summary table of simulation results when both policies activated					
	variables	**year**			
		2020	**2030**	**2040**	**2050**
4	Net emission saving	33,409	138,138	305,423	497,688
5	Carbon tax income	110.3M	455.9M	1.009B	1.64B
6	Surplus or deficit	376.6B	795.7B	1.52T	2.249T
	*M-million, B- billion, T- trillion				

Table 9: Summary table of simulation results

The introduction of progressive mandatory blending and green harvest scenario together increases the net emission saving to even a higher level, figure 45.a. This is because, the effects of blending policy has already increased ethanol substitution and saved a certain level of GHG emission. On top of that, the green harvest policy whose primary goal is emission saving, reduces even more emission and adds up to the net emission saving. Consequently, the benefits in the form of carbon tax income has also been increased as shown in figure 45.b, and ultimately, causes even more saving on the balance of payment (can be clearly seen on the summary table 9), a reduction of 17billion ETB in 2050.

5.3.5. Subsidy Scenario

In the previous scenario options, the main focus was improving the production and consumption of ethanol in the transport sector. However, as production of ethanol is increasing, the cost of feedstock production will also increase and at some point in time the production cost may exceed the market price of its substitute fossil fuel. In this case, although a policy of increasing production and consumption is in place, the increase in production cost discourages the consumption level and results in a lower consumption than what was targeted in the policy scenario.

5.3.5.1. Base run with Subsidy Scenario

As an alternative scenario, subsidy is tested first as a standalone option and later, combined with the other policy scenarios; subsidy of different amounts are tested to see which subsidy amount is appropriate.

Figure 46: Runs to test the individual subsidies compared to the Base Run. "No Subsidies", "Subsidy 2000": 2000 ETB per ton of ethanol is paid, "Subsidy 3500": 3500 ETB per ton of ethanol is paid

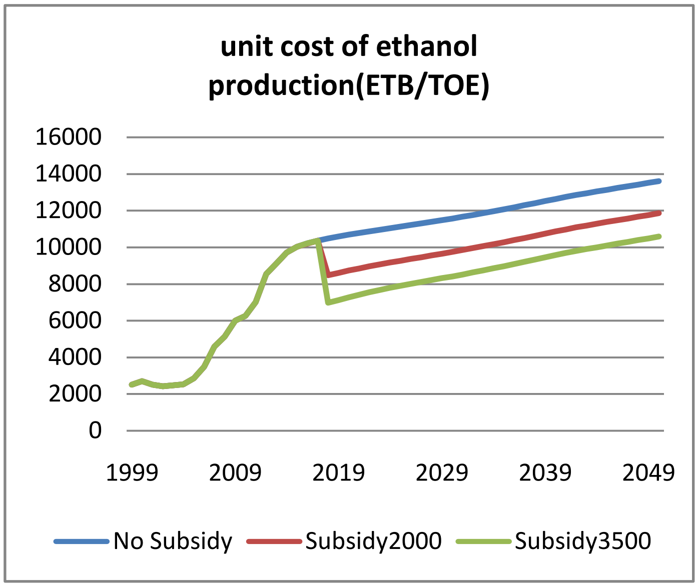


Figure 46.a. ethanol production cost with subsidy

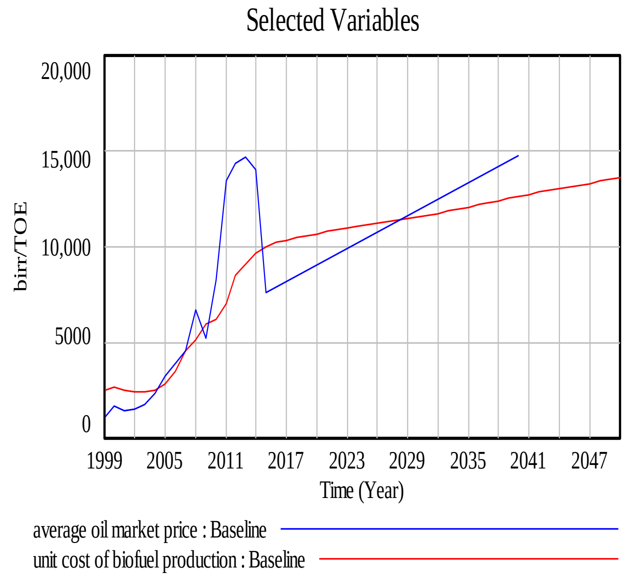


Figure 46.b. oil market price &cost of ethanol in the base run

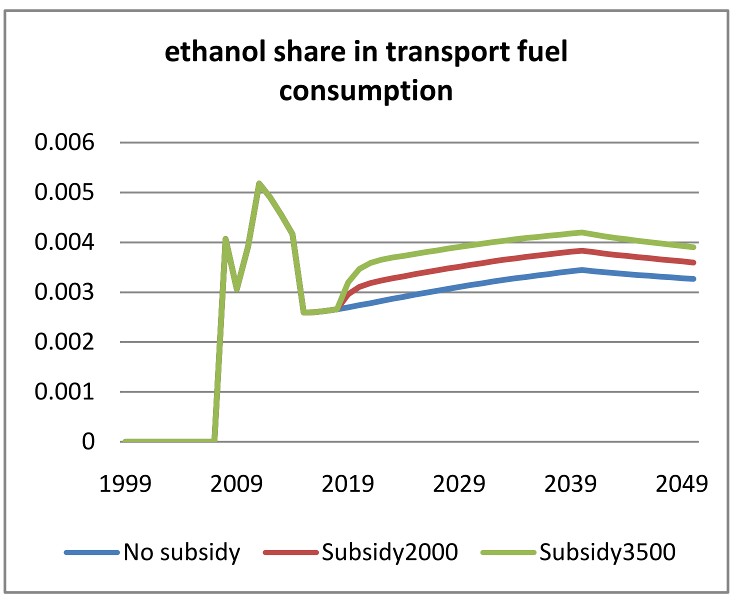


Figure 46.c. ethanol share with subsidy in the base run

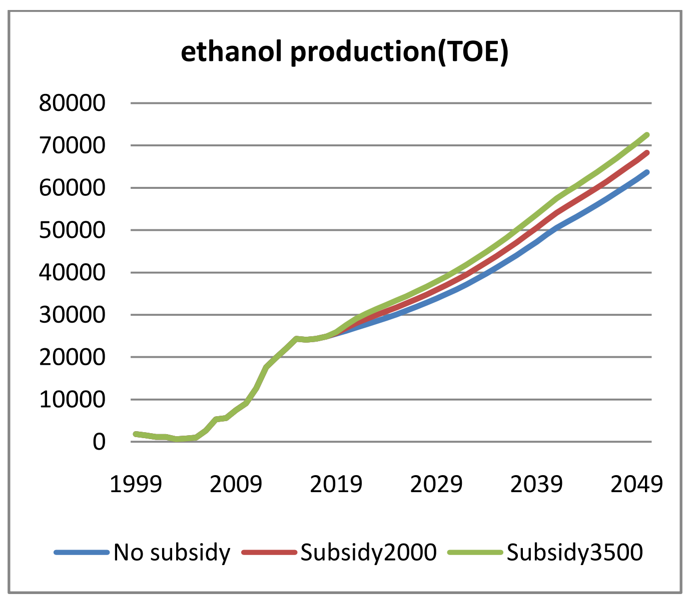


Figure 46.d. ethanol production with subsidy

Subsidy scenario summary table				
Scenario	ethanol unit production cost			
	2020	2030	2040	2050
No subsidy	10,688	11,573	12,636	13,608
Subsidy2000	8,728	9,748	10,865	11,864
Subsidy3500	7,266	8,412	9,569	10,586
	share of ethanol in transport			
	2020	2030	2040	2050
No subsidy	0.00274	0.00314	0.00344	0.00326
Subsidy2000	0.00310	0.00355	0.00383	0.00359
Subsidy3500	0.00346	0.00394	0.00419	0.00390
	ethanol production			
	2020	2030	2040	2050
No subsidy	26,973	35,933	50,628	65,318
Subsidy2000	28,085	38,175	54,247	70,070
Subsidy3500	29,192	40,337	57,611	74,386

Table 10: Summary table of subsidy scenario compared to the base run

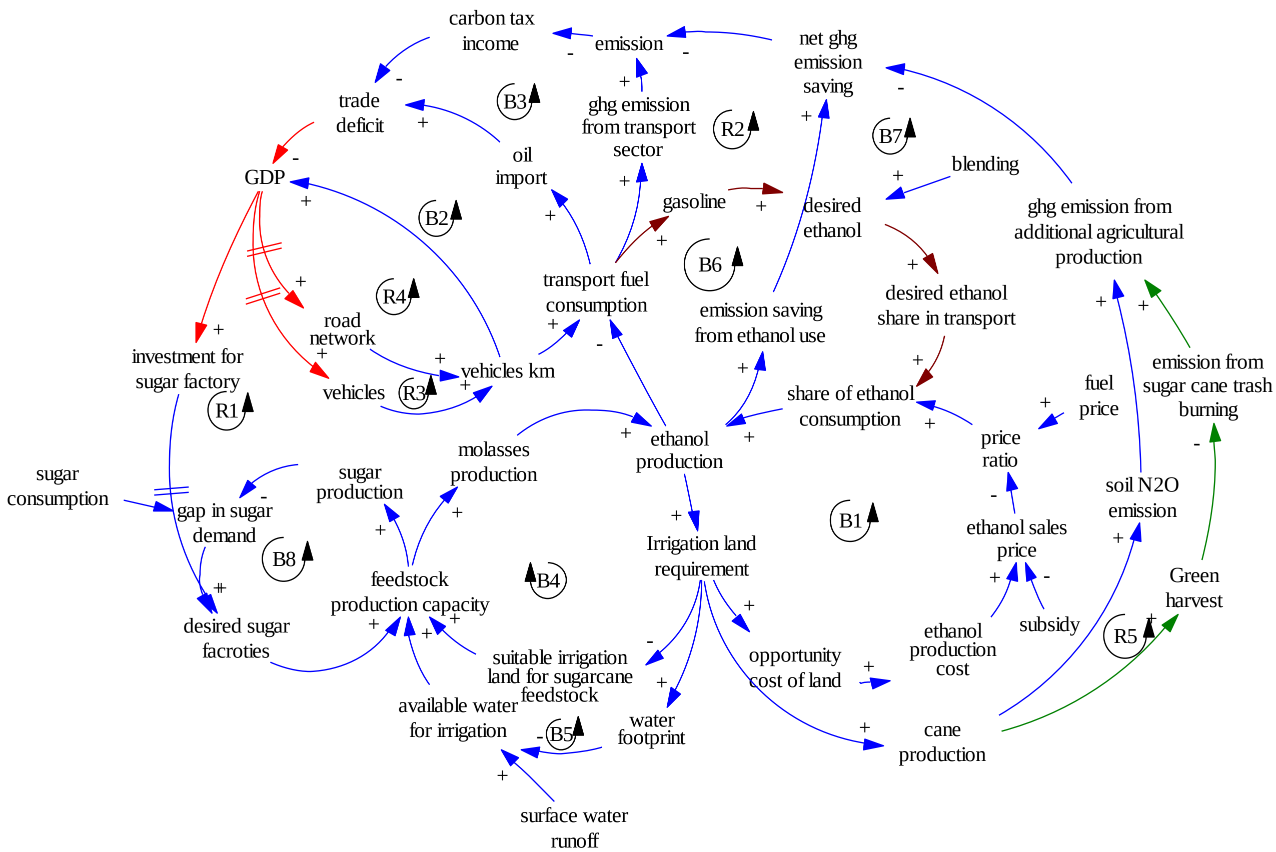


Figure 47: Main causal loop structure of the explanatory model (in blue and red) capturing the base run with the subsidy scenario

In case of no subsidy, the unit production cost is greater than the value of fossil fuel market price from the year 2016 until the year 2028 figure46(b), and resulted in a steady increase in ethanol production and consumption. However, this price difference can't be a major cause for the lower level of ethanol share in transport sector fuel consumption; this is because of a very small initial share of ethanol in transport sector fuel consumption that can be tested by applying a different level of subsidy assumptions and assessing if the real cause is price difference. A subsidy of 2000ETB per ton of ethanol results in an 18%, 16%, 14% and 13% cost reduction compared to the business as usual (no subsidy) scenario during 2020, 2030, 2040 and 2050 respectively, however, it brings about an 13%, 13%, 11% and 10% increase on share of ethanol as well as an 4%, 6%, 7% and 7.3% increase on ethanol production which is not a significant amount of increment as clearly be seen from table 10. Finally, subsidy of 3500ETB per ton of ethanol results in an 32%, 27%, 24% and 22% cost reduction compared to the business as usual (no subsidy) scenario during 2020, 2030, 2040, and 2050 respectively, however, it brings about 26.5%, 25.4%, 21.8% and 19.4% increase on share of ethanol as well as 8%, 12%, 13.8% and 13.8% increase on ethanol production.

In general, subsidizing ethanol compared to the business as usual case has no significant impact on improving both the production and share of ethanol. A consistent subsidy of 3500ETB per ton of ethanol until the end of the simulation period (2050) pushed the share of ethanol in transport sector from 0.00274 in 2020 to 0.003895 in 2050, a19.4% increment, which is a very small improvement compared to the cost incurred for the subsidy.

5.3.5.2. Progressive Mandatory Blending with Subsidy Scenario

Figure 48: Runs to test the individual subsidies added to progressive blending scenario compared to the progressive blending scenario. "No Subsidies", "Subsidy 2000": 2000 ETB per ton of ethanol is paid, "Subsidy 3500": 3500 ETB per ton of ethanol is paid

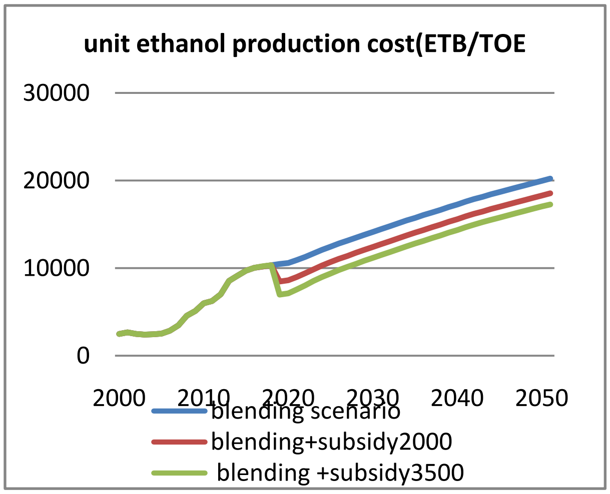


Figure 48.a. unit production cost with subsidy

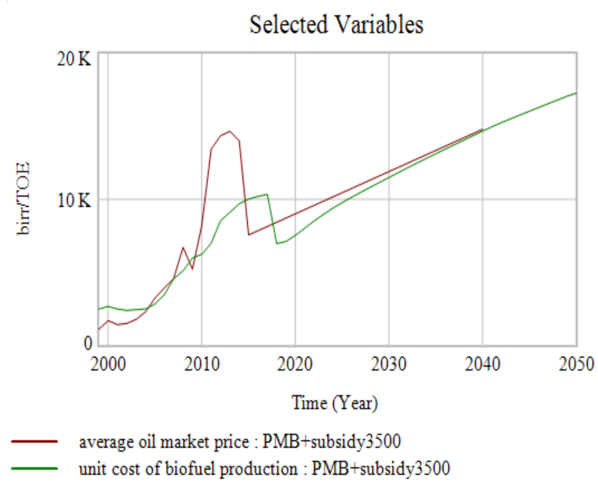


Figure 48.b. oil market price & cost of ethanol with subsidy of 3500

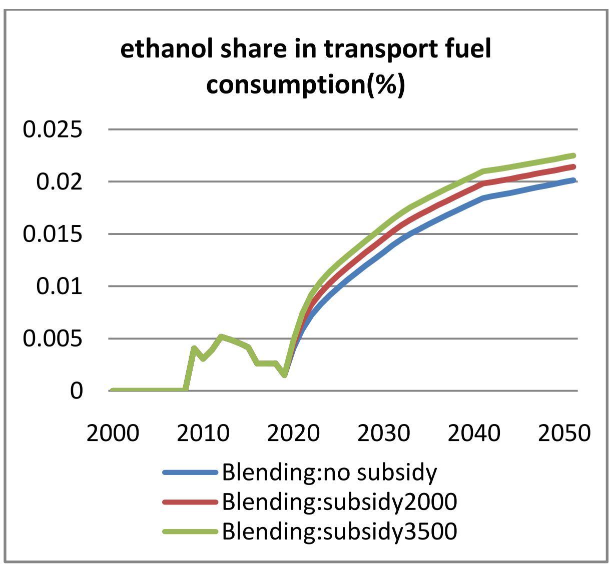


Figure 48.c. share of ethanol with subsidy

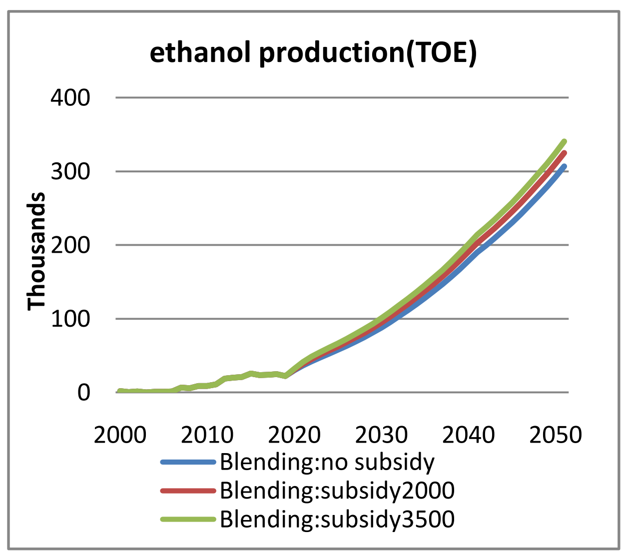


Figure 48.d. ethanol production with subsidy

Subsidy plus progressive blending scenario summary table				
	ethanol unit production cost			
Scenario	**2020**	**2030**	**2040**	**2050**
No subsidy	10,920	14,468	17,598	20,240
Subsidy2000	8,985	12,758	15,916	18,563
Subsidy3500	7,546	11,508	14,679	17,278
	share of ethanol in transport			
	2020	**2030**	**2040**	**2050**
No subsidy	0.005885	0.013921	0.018444	0.020144
Subsidy2000	0.006656	0.015240	0.019816	0.021419
Subsidy3500	0.007419	0.016418	0.020996	0.022511
	ethanol production			
	2020	**2030**	**2040**	**2050**
No subsidy	36,601	95,424	190,253	307,064
Subsidy2000	38,958	102,707	203,018	325,320
Subsidy3500	41,291	109,205	213,996	340,949

Table 11: Summary table of results of subsidy and progressive blending policy scenario

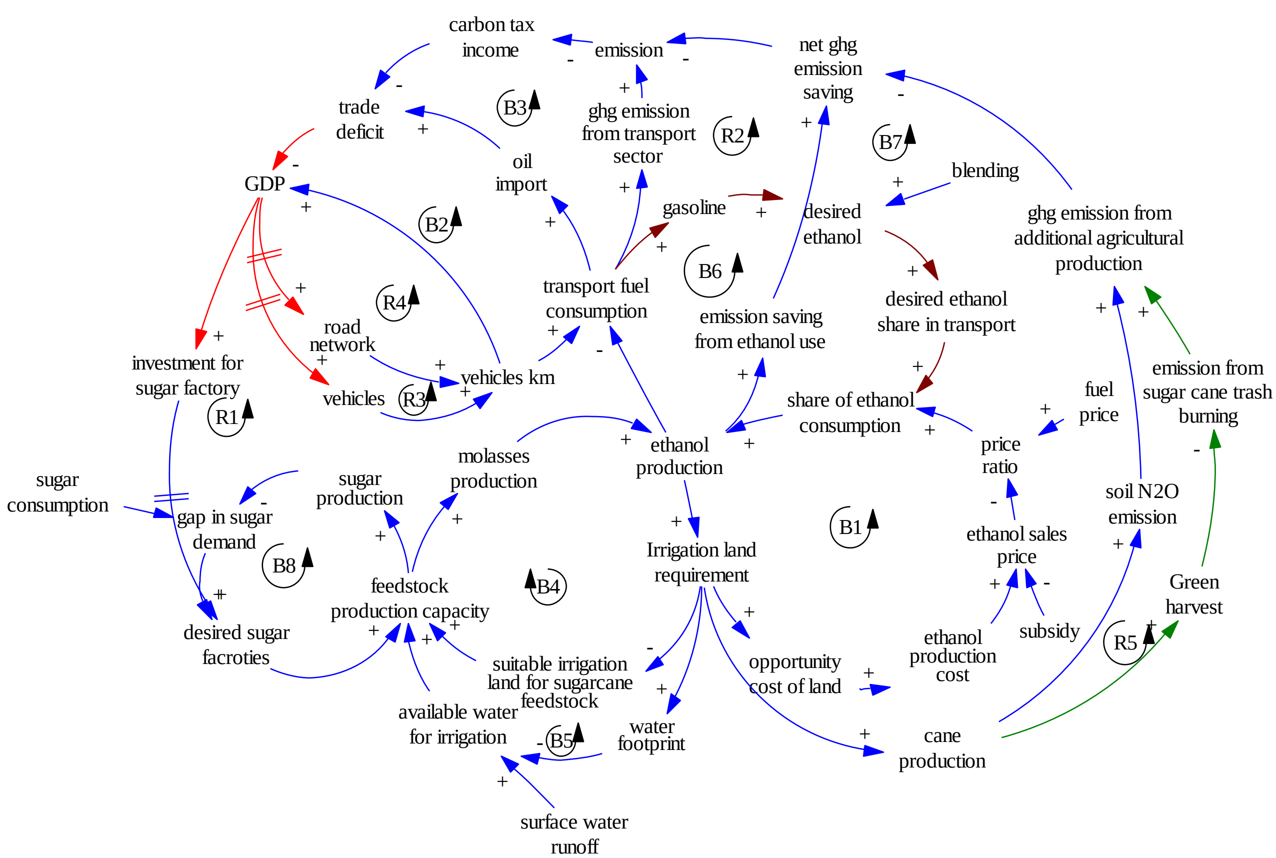


Figure 49: Main causal loop structure of the explanatory model (in blue and red) capturing subsidy with progressive mandatory blending scenario

We recall that the introduction of Progressive blending scenario in section 5.3.2, balancing loop (B6), has resulted in a rise to an increase in share of ethanol in transport sector, consumption and production level and reduces the level of transport oil consumption. However, this increase in a no subsidy scenario has caused ethanol unit production cost to grow to a higher level, 10,920 ETB in 2020 to 20,240ETB in 2050, by strengthening the balancing loop (B1) whereas the market value of fossil fuel is much lower than the stated amount and contributes for a lower share of ethanol consumption and ethanol production than it would otherwise have been. Therefore, subsidy is introduced in a way to reduce the production cost by reducing the impact of the balancing loop B1, as a result, the price ratio compared to market fuel price increases. Consequently, share of ethanol in transport sector fuel consumption increases. In this context, a subsidy of 2000ETB per ton of ethanol produced on top of progressive blending scenario results in 17.7%, 11.8%, 9.6% and 8% cost reduction in 2020, 2030, 2040 and 2050 respectively compared to progressive blending alone. This level of cost reduction results in 13%, 9.5%, 7% and 6% increase in ethanol consumption and 6%, 7.6%, 6.7% and 5.9% increase in ethanol production.

Subsidy of 3500ETB per ton of ethanol on top of progressive blending scenario results in 31%, 20%, 17% and 15% reduction in cost of ethanol production during 2020, 2030, 2040 and 2050 respectively, which in turn results in 26%, 18%, 14% and 12% increase in ethanol consumption and 13%, 14%, 12% and 11% increase in ethanol production compared to progressive blending scenario.

Subsidy of 3500 equalizes the cost of ethanol to the projected market fuel price figure 48.b. which tells us the effect of the balancing loop B1 remains insignificant in the process of ethanol production and consumption and enable the balancing loop B6 gain more power in increasing ethanol consumption and finally reduces the transport sector fossil fuel consumption due to ethanol substitution; capacity loop B4 and B5 will be the only factors limiting the production and consumption of ethanol. The performance of the policy scenario is also summarized in the following table 12 to enable comparison among the scenarios.

Performance indicators for different scenarios for the year 2050									
Scenario	Total Ethanol production cost	Ethanol share	ethanol production	transport oil consumption	oil import	net emission saving	Carbon tax income	Trade balance in trillions	resources released compared to base run
Base run	888,828,288	0.0033	65,318	14,254,350	29,290,000	6,945	22,919,376	-2.2662	NI
Progressive blending	6,214,839,808	0.0201	307,064	14012604	29,048,256	76,690	253,075,344	-2.2501	15,985,278,976
Green harvest	NA**	0.0033	65,318	14,354,350	29,290,000	101,910	336,303,520	-2.2658	313,524,224
Green harvest plus Blending	NA	NI*	NI	NI	NI	497,688	1,642,370,944	-2.2488	17,374,642,176
Subsidy2000 with Base run	971,415,616	0.0036	70070	14249598	29,285,248	7,514	24,796,768	-2.2658	311,689,216
Subsidy3500 with Base run	1,047,825,792	0.0039	74386	14245282	29,280,932	7,969	26,298,318	-2.2656	594,542,592
subsidy2000 with Blending	6,689,548,288	0.0214	325,320	13994348	29,030,000	79,920	263,736,624	-2.2489	17,185,636,352
subsidy3500 with Blending	7,084,120,576	0.0225	340,949	13978719	29,014,370	90,194	297,639,584	-2.2479	18,238,144,512
units	ETB	-	TOE	TOE	TOE	TCO_2e	ETB	ETB	ETB

* No Impact,
**not available

Table 12: Performance indicators for different scenarios at the year 2050

Table 12 illustrates that the baseline scenario has the lowest aggregate production cost, whereas, progressive blending together with subsidy3500 scenario has the highest cost. The later scenario is also the highest source of resources released compared to other scenarios. On the other hand, green harvest scenario by itself is a source of 313million ETB in the year 2050 that comes from merely carbon tax income as this scenario has no effect on fuel consumption. However, the cost of green harvest scenario can't be estimated at this stage and hence difficult to judge if this scenario is worth to implement, but we believe that the startup cost could be reasonably fair compared to its benefits; as it is a fixed cost and once it is established, the running costs are expected to be well below the benefits to be gained.

Subsidizing ethanol in the base run at any amount has insignificant positive impact as it is clearly indicated in table 12; both subsidy of 2000 and subsidy of 3500 ETB has resulted in a cost of 946 million and 1 billion ETB respectively, whereas, the benefits are lower than the costs incurred, 311million and 594 million ETB respectively. This indicates that subsidy by itself can't be a policy mechanism to effect positive improvements in this context. However, subsidy has resulted in an improvement when applied with the progressive blending scenario. Subsidy scenarios, subsidy of 2000 and subsidy of 3500, generated a valuable amount of carbon tax income next to the green harvest and progressive blending scenario, however, progressive blending together with subsidy 3500ETB gives the highest reduction in trade deficit compared to other scenarios, and progressive blending with green harvest is the second highest.

Most importantly, subsidy of 3500 is a better option than subsidy of 2000 due to the fact that subsidy of 3500 has only an additional cost of 395million ETB on top of subsidy of 2000, however, it resulted in an additional 1billion ETB compared to subsidy of 2000 on the same year. Green harvest can be used together with progressive blending and subsidy of 3500 scenario to improve the benefits further if the implementation cost of green harvest scenario doesn't exceed the benefits, and overtime, it may substitute subsidy; as subsidy can't be a long term policy mechanism as it requires a large public expenditure.

In general, from the scenario analysis we can conclude that improving the amount of ethanol production and consumption in the transport sector is vital for assisting the nation in building climate resilient green economy. However, the decision on the best scenario lies on the tradeoff between cost, motive to use renewable energy source and reduce oil import dependency, release of resources in the form of trade deficit reduction and relocating the resources to other investment sectors. We believe that this scenario analysis could give a good insight for decision makers. Given this scenario shown above and their analysis, we recommend progressive blending scenario with subsidy of 3500 should be considered. In addition, progressive blending with green harvest scenario can be the second best option especially if we want to avoid subsidy in the long run.

Chapter 6: Conclusion and Recommendation

6.1. Conclusion

Driven by the country's economic growth, the consumption oil products are steadily growing making the reduction of dependency on oil products import a priority. Ethiopia is spending over 75% of its foreign currency earnings to import oil products every year. This trend has aggravated the country's balance of payment. On top of its effect on the country's trade balance, significant increase in the GHG emission released from fossil fuel combustion in the transport sector is also another area of concern. Various projects aiming at increasing hydro power, solar, geothermal and wind energy generation capacity are undertaken to satisfy the energy demand in the country enabling a shift towards renewable energy sources. Bio-fuel is considered as one potential source of renewable energy to assist this transition effort, but large scale bio-fuel production incorporates various actors involving multiple feedback process and non-linear relations that are complex to understand and interpret through human mental models. However, system dynamics tools can help stakeholders identify the causes of cost drivers with the application of feedback control systems. This research investigates the overall impacts of ethanol production and consumption, particularly in reducing the level of fossil fuel consumption in the transport sector, the major cause of oil products import.

Various theories across agriculture, economics, and energy and environment sectors were combined and applied to build a bio-fuel energy simulation model for representing ethanol production on a country level. The model was calibrated to the case of Ethiopia and its sugar factories in order to test a large scale sugarcane ethanol production and make substitutions in the transport sector fuel consumption. It was specified for the production of ethanol from molasses, a by-product for sugar factories that used to be thrown and dumped to rivers and caused pollution. Simulation results suggest that the current inputs in the sugar industry, land, water and capital, theoretically have the potential to increase the level of ethanol production over 300,000 ton per year. However, in practice a small amount of ethanol is being produced and used in the transport sector.

The model was applied to the investigation of policy scenarios for improved production and consumption performances. Model simulations indicate that ethanol production requires a critical assessment on the estimation of production cost and comparing it to the market price of possible substitutes, fossil fuel in this case. The desire for ethanol consumption arises from the existing price difference. However, the production quantity is subject to the available resources primarily, land and water. In addition, the delay in the construction of sugar factories, currently 6-7years determines ethanol production capacity. Thus, it is observed that outlining the appropriate blending strategy that considers the feedbacks mentioned is vital for the sustainable and consistent implementation of ethanol substitution in the transport sector, the performance could be further improved when ethanol production cost is subsidized for an amount of 3500 ETB per TOE ethanol.

6.2. Limitations of the Research

Providing a complete picture about the cost drivers of ethanol production, such as, labor, spare parts, maintenance costs and some others, a full understanding and representation of the entire costs incurred during the production phase would be necessary. However, due to time constraints and confidentiality of information in the finance sector, our research considers only the opportunity cost of land as a cost driving factor. In addition, the stock of land used to grow sugarcane feedstock doesn't consider degradation and rehabilitation dynamics, hence our estimate of cost might be inaccurate, and thus results would change according to the change in the land size; if the size of the land suitable to sugarcane plantation degrades faster than the rehabilitation work, land scarcity will be inevitable, and this has an impact on ethanol production cost. There is therefore room to improve the model by adding land dynamics and then create possible links to yield and opportunity cost of land in the model.

The GHG emission during additional agricultural production caused by ethanol processing considers only two major sources, the release of GHG emission during cane field burning and the release of N_2O from the soil due to fertilizer decomposition. Although there are various sources of GHG emission in the process of sugar and ethanol production, some of them can be ignored as their level of emission is very low.

Formulations of investment costs, production capacity and the land size assigned to each sugar factories are aggregated to average values as the requirements for different sugar factory projects vary according to the size and capacity of the projects and therefore there is no single way of representing the variables in this research context. However, we believe that the variables could be well represented if there is detailed information in the sector, which unfortunately is not the case.

Lastly, the growth in GDP in this thesis is reflected in the form of the growth in number of vehicles and road networks. The assumption we make is that, the continuous growth in GDP caused the resulted changes in the overall development activities in the country, and the change is manifested in the form of vehicles and road network growth. If GDP is endogenously represented, it is possible to identify the real impact of the reduction in oil products import and the effect of the change in GDP itself on investments assigned to development programs, specifically, road infrastructure and the number of vehicles. However, the general formulation of GDP includes various sectors performances:

$$\text{GDP} = \text{Household consumption} + \text{Investments} + \text{Government spending} + \underbrace{(\text{Export-Import})}_{\text{Net Export}}$$

And modeling GDP endogenously requires adding various sectors to the model apart from net export as it indicated in the formula. Therefore, we preferred to indicate the impact of GDP in the form that we mentioned.

6.3. Recommendations for Future Research

The findings and limitations of this work point to potentially valuable extensions. They include:

- The investigation of the impact of extending the feedstock production process to out growers and incorporating them as suppliers.
- Add model structure to internalize currently exogenous inputs to the model such as vehicles growth rate and the growth in road network in order to get the real impact of GDP.
- The model can constitute a point of departure for examining other sources of feedstock types to produce other forms of renewable energy, such as, biodiesel.
- The model can also be used as a stepping stone to assess the impact of implementing private investments to the sector.

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The World Bank. https://data.worldbank.org/indicator

Appendix

Appendix A: Model Equation

additional sugar cane production=

sugar cane land for biofuel*sugar cane yield

Units: tonne

available water for irrigation=

MIN(surface water run off*surface water usage ratio,maximum water storage capacity

)

Units: m3/Year

Average Cereal Price:INTERPOLATE:

Units: birr/tonne

average current irrigation land development per year=

35000

Units: Ha/Year

average irrigation land requirement per sugar mill=

30000

Units: Ha/sugar mill

average life time of sugar mill=

25

Units: Year

average oil market price:INTERPOLATE:

Units: birr/TOE

average sugar production capacity of sugar mill=

260000

Units: tonne/Year/sugar mill

average vehicle fuel consumption:INTERPOLATE:

Units: TOE/km

"bio-fuel"=

ethanol production

Units: TOE/Year

biofuel consumption by other sectors:INTERPOLATE:

Units: TOE/Year

biofuel consumption by transport sector=

MIN(maximum possible blending percentage of biofuel with fossil fuel*transport oil consumption

,transport oil consumption*share of transport fuel consumption from biofuel

)

Units: TOE/Year

biofuel yield per hectare=

0.672

Units: TOE/Ha/Year

burned and cropped sugar cane=

desired sugar cane production*percentage of burned and cropped sugar cane from sugar cane production

Units: tonne/Year

capacity utilization=

ethanol production/maximum ethanol production rate

Units: 1

capital= INTEG (

real investment,

2.2e+010)

Units: birr2000

carbon tax income=

carbon tax per tonne of co2*net emission saving

Units: birr/Year

carbon tax per tonne of co2=

3300

Units: birr/ton co2e

cereal yield:INTERPOLATE:

Units: tonne/Ha

change in irrigated land=

maximum irrigable land potential*fraction of irrigated land requirment

Units: Ha/Year

change in land for biofuel crop=

gap in land for biofuel crop

Units: Ha/Year

change in sales price=

(inidicated producer price-sales price)/price adjutment time

Units: birr/(Year*TOE)

change in share of transport fuel consumption from biofuel=

(desired share of transport fuel consumption from biofuel-New share of transport fuel consumption from biofuel

)/time to adjust the share of biofuel from transport sector furl consumption

Units: 1/Year

completed sugar mill= INTEG (

completion rate-degredation rate,

initial number of sugar mill)

Units: sugar mill

completion rate=

Under construction sugar mill/construction delay

Units: sugar mill/Year

constraction start time=

3

Units: Year

construction delay=

4

Units: Year

construction start rate=

degredation rate+sugar mill adjustment

Units: sugar mill/Year

conversion rate=

0.009

Units: 1/Year

crushed sugar cane= INTEG (

crushing-molasses production-steam burning loss-sugar production,

0)

Units: tonne

crushing=

(crushing efficiency*burned and cropped sugar cane)

Units: tonne/Year

crushing efficiency=

0.85

Units: Dmnl

cummulative GHG emission= INTEG (

emission,

930000)

Units: ton co2e

degredation rate=

completed sugar mill/average life time of sugar mill

Units: sugar mill/Year

desired ethanol=

gasoline*progressive blending(Time)

Units: TOE/Year

desired number of sugar mill=

sugar consumption/average sugar production capacity of sugar mill

Units: sugar mill

desired share of transport fuel consumption from biofuel=

desired ethanol/transport oil consumption

Units: 1

desired sugar cane land for biofuel=

MIN(total biofuel consumption/biofuel yield per hectare,total sugar cane irrigation land requirement

)

Units: Ha

desired sugar cane production=

(MAX(sugar cane land for biofuel,total sugar cane irrigation land requirement

)*sugar cane yield)/harvesting time

Units: tonne/Year

effect of fuel price on total average vehicle kilometer=

relative fuel price^elasticity of vehicle kilometer to fuel price

Units: 1

effect of price ratio on biofuel consumption=

relative price ratio^elasticity of biofuel consumption to price ratio

Units: 1

effect of relative land cost on cost of biofuel production=

relative land cost^elasticity of biofuel production cost to relative land cost

Units: 1

effect of relative road network on total average vehicle kilometer=

relative road network^elasticity of total average vehicle kilometer to relative road network

Units: 1

effect of relative vehicle on total average vehicle kilometer=

relative vehicles^elasticity of total average vehicle kilometer to relative vehicle

Units: 1

elasticity of biofuel consumption to price ratio=

0.7

Units: 1

elasticity of biofuel production cost to relative land cost=

0.2666

Units: Dmnl

elasticity of total average vehicle kilometer to relative road network=

0.6

Units: Dmnl

elasticity of total average vehicle kilometer to relative vehicle=

0.6

Units: Dmnl

elasticity of vehicle kilometer to fuel price=

-0.02

Units: 1

emission=

ghg emission from transport-net emission saving

Units: ton co2e/Year

emission from additional agricultural production=

(emission per tonne of sugar cane production*additional sugar cane production

)/production year

Units: ton co2e/Year

emission from sugar cane trash burning=

0.009

Units: ton co2e/tonne

emission per tonne of sugar cane production=

IF THEN ELSE(Time<2018, emission from sugar cane trash burning+soil N2O emission

, Green harvest emission from trush burning+soil N2O emission)

Units: ton co2e/tonne

emission saving from ethanol use=

ethanol production*ghg emission saving

Units: ton co2e/Year

energy efficiency=

1

Units: 1

estimated investment cost of sugar mill=

2e+010

Units: birr/sugar mill

ethanol production=

MIN(maximum ethanol production rate, total biofuel consumption)

Units: TOE/Year

ethanol yield of molasses=

0.24

Units: TOE/tonne

Exports of goods and services:INTERPOLATE:

Units: birr

extraction=

MIN(Water in aquifer*maximum affordable extraction rate,water gap)

Units: m3/Year

FINAL TIME = 2050

Units: Year

The final time for the simulation.

fraction of irrigated land requirment=

average current irrigation land development per year/total irrigable land potential

Units: 1/Year

gap in land for biofuel crop=

(desired sugar cane land for biofuel-sugar cane land for biofuel)/time from preparation to harvesting

Units: Ha/Year

gasoline=

transport oil consumption*proporiton of gasoline in transport fuel

Units: TOE/Year

gdp deflator:INTERPOLATE:

Units: birr/birr2000

ghg emission from transport=

transport oil consumption*ghg emission per tonne of oil co2 equivalent

Units: ton co2e/Year

ghg emission per tonne of oil co2 equivalent=

2.9148

Units: ton co2e/TOE

ghg emission saving=

ghg emission per tonne of oil co2 equivalent*ghg emission saving percentage from ethanol substitution

Units: ton co2e/TOE

ghg emission saving percentage from ethanol substitution=

0.9

Units: Dmnl

green harvest desired emission=

0

Units: ton co2e/tonne

Green harvest emission from trush burning= INTEG (

improvement,

emission from sugar cane trash burning)

Units: ton co2e/tonne

harvesting time=

1

Units: Year

improvement=

IF THEN ELSE(Time<2018, 0 , (green harvest desired emission-Green harvest emission from trush burning

)/time to make complete improvement)

Units: ton co2e/(tonne*Year)

inidicated producer price=

unit cost of biofuel production

Units: birr/TOE

initial average fuel price= INITIAL(

average oil market price)

Units: birr/TOE

initial export of goods and services= INITIAL(

Exports of goods and services)

Units: birr

initial land cost= INITIAL(

land cost)

Units: birr

initial non fuel import= INITIAL(

non fuel imports)

Units: birr

initial number of sugar mill=

2

Units: sugar mill

initial oil import value= INITIAL(

oil import value)

Units: birr/Year

initial price ratio= INITIAL(

price ratio)

Units: 1

initial road network= INITIAL(

road network)

Units: km

initial share of transport fuel consumption from biofuel=

IF THEN ELSE(Time<2008 , 0 , 0.0025)

Units: 1

initial surplus or deficit= INITIAL(

-5e+009)

Units: birr/Year

INITIAL TIME = 1999

Units: Year

The initial time for the simulation.

initial total average vehicle kilometer=

2.1e+009

Units: km/Year

initial unit cost of biofuel production= INITIAL(

2500)

Units: birr/TOE

initial vehicles= INITIAL(

80000)

Units: car

investment=

investment cost per sugar mill*construction start rate

Units: birr/Year

investment cost per sugar mill=

investment cost per ton of sugar production capacity*average sugar production capacity of sugar mill

Units: birr/sugar mill

investment cost per ton of sugar production capacity=

estimated investment cost of sugar mill/sugar production capacity

Units: birr*Year/tonne

"irrigation water demand, non sugar cane"=

Non sugar cane irrigated land*"water demand per hectar, non sugar cane"

Units: m3/Year

jet fuel consumption:INTERPOLATE:

Units: TOE/Year

land cost=

opportunity cost of production

Units: birr

land for sugar cane crop=

500000

Units: Ha

maximum affordable extraction rate=

0.18

Units: 1/Year

maximum available sugar cane land=

600000

Units: Ha

maximum ethanol production rate=

molasses fermentation rate*ethanol yield of molasses

Units: TOE/Year

maximum irrigable land potential=

total irrigable land potential-Non sugar cane irrigated land-sugar cane irrigated land

Units: Ha

maximum possible blending percentage of biofuel with fossil fuel=

0.8

Units: 1

maximum water storage capacity=

(per capita irrigation water storage capacity*"Population - Est. & Proj.")

Units: m3/Year

molasses fermentation rate=

DELAY1(molasses production , production time)

Units: tonne/Year

molasses percentage of crushed sugarcane=

0.04

Units: Dmnl

molasses production=

DELAY1(crushing*molasses percentage of crushed sugarcane, production time)

Units: tonne/Year

net emission saving=

emission saving from ethanol use-emission from additional agricultural production

Units: ton co2e/Year

net growth fraction=

IF THEN ELSE(Time<2015, 0.125 , 0.06)

Units: 1/Year

net growth rate=

vehicles*net growth fraction

Units: car/Year

net recharge=

normal net recharge*Water in aquifer

Units: m3/Year

New share of transport fuel consumption from biofuel= INTEG (

change in share of transport fuel consumption from biofuel,

0)

Units: 1

non fuel imports:INTERPOLATE:

Units: birr

Non sugar cane irrigated land= INTEG (

change in irrigated land,

640000)

Units: Ha

normal net recharge=

0.001

Units: 1/Year

number of vehicles per 1000 people=

vehicles/"Population - Est. & Proj."*1000

Units: car/person

official exchange rate:INTERPOLATE:

Units: birr/usd

oil import value=

oil products import*average oil market price

Units: birr/Year

oil products import=

(other sectors fuel consumption+transport fuel demand)

Units: TOE/Year

opportunity cost of production=

cereal yield*Average Cereal Price*sugar cane land for biofuel

Units: birr

other sectors fuel consumption=

proportion of other sectors fuel consumption with transport sector*transport oil consumption

Units: TOE/Year

pc sugar consumption(

[(0,0)-(2050,10)],(1999,0.005),(2010,0.01),(2015,0.017),(2030,0.025),(2050

,0.03))

Units: tonne/(Year*person)

per capita ghg emission from transport fuel consumption=

ghg emission from transport/"Population - Est. & Proj."

Units: ton co2e/(Year*person)

per capita irrigation water storage capacity=

160

Units: m3/person/Year

percentage of burned and cropped sugar cane from sugar cane production=

0.77

Units: Dmnl

"Population - Est. & Proj.":INTERPOLATE:

Units: person

price adjutment time=

1

Units: Year

price ratio=

average oil market price/retail price biofuel

Units: 1

production time=

1

Units: Year

production year=

1

Units: Year

progressive blending(

[(0,0)-(3000,10)],(1999,0),(2000,0),(2001,0),(2002,0),(2003,0),(2004,0),(2005,0),(2005,0),(2006,0),(2007,0),(2008,0),(2009,0),(2010,0),(2011,0),(2012,0),(2013,0),(2014,0),(2015,0),(2016,0),(2017,0),(2018,0.05),(2030,0.1),(2050,0.15))

Units: 1

proporiton of gasoline in transport fuel=

0.14

Units: 1

proportion of other sectors fuel consumption with transport sector=

1.05

Units: 1

real investment=

(investment/gdp deflator)

Units: birr2000/Year

relative export of goods and services=

Exports of goods and services/initial export of goods and services

Units: 1

relative fuel price=

average oil market price/initial average fuel price

Units: 1

relative land cost=

land cost/initial land cost

Units: 1

relative non fuel import=

non fuel imports/initial non fuel import

Units: 1

relative oil import value=

oil import value/initial oil import value

Units: 1

relative price ratio=

price ratio/initial price ratio

Units: 1

relative road network=

road network/initial road network

Units: 1

relative vehicles=

(vehicles/initial vehicles)

Units: 1

retail price biofuel=

sales price

Units: birr/TOE

road network:INTERPOLATE:

Units: km

sales price= INTEG (

change in sales price,

1500)

Units: birr/TOE

SAVEPER = 1

Units: Year [0,?]

The frequency with which output is stored.

share of transport fuel consumption from biofuel=

IF THEN ELSE(Time<2018 , initial share of transport fuel consumption from biofuel

*effect of price ratio on biofuel consumption

, New share of transport fuel consumption from biofuel*effect of price ratio on biofuel consumption

)

Units: 1

soil N2O emission=

0.0063

Units: ton co2e/tonne

steam burning loss=

DELAY1(crushing*steam burning loss and other dry matter percentage , production time

)

Units: tonne/Year

steam burning loss and other dry matter percentage=

1-(sugar percentage+molasses percentage of crushed sugarcane)

Units: 1

subsidy=

IF THEN ELSE(Time<2018, 0,0)

Units: birr/TOE

sugar cane crop water demand=

sugar cane irrigated land*sugar cane water foot print

Units: m3/Year

sugar cane irrigated land=

MIN(total sugar cane irrigation land requirement,maximum available sugar cane land

)

Units: Ha

sugar cane land for biofuel= INTEG (

change in land for biofuel crop,

1830)

Units: Ha

sugar cane water foot print=

12000

Units: m3/Ha/Year

sugar cane yield:INTERPOLATE:

Units: tonne/Ha

sugar consumption=

pc sugar consumption(Time)*"Population - Est. & Proj."

Units: tonne/Year

sugar mill adjustment=

DELAY N(sugar mill gap/constraction start time , constraction start time

, sugar mill gap/constraction start time , 1)

Units: sugar mill/Year

sugar mill gap=

desired number of sugar mill-(completed sugar mill+Under construction sugar mill

)

Units: sugar mill

sugar percentage=

0.1

Units: Dmnl

sugar production=

DELAY1(crushing*sugar percentage, production time)

Units: tonne/Year

sugar production capacity=

486000

Units: tonne/Year/sugar mill

surface water irrigation potential=

3.73122e+006

Units: Ha

surface water run off=

1.25e+011

Units: m3

surface water usage ratio=

(surface water irrigation potential*"water demand per hectar, non sugar cane"

)/surface water run off

Units: 1/Year

surplus or deficit=

-initial surplus or deficit*(relative export of goods and services-(relative non fuel import

+relative oil import value

)

)+carbon tax income

Units: birr/Year

time from preparation to harvesting=

3

Units: Year

TIME STEP = 0.0625

Units: Year [0,?]

The time step for the simulation.

time to adjust the share of biofuel from transport sector furl consumption=

2

Units: Year

time to make complete improvement=

8

Units: Year

total average vehicle kilometer=

initial total average vehicle kilometer*effect of relative road network on total average vehicle kilometer

*effect of relative vehicle on total average vehicle kilometer

*effect of fuel price on total average vehicle kilometer

Units: km/Year

total biofuel consumption=

biofuel consumption by transport sector+biofuel consumption by other sectors

Units: TOE/Year

total ethanol produced= INTEG (

ethanol production,

0)

Units: TOE

total irrigable land potential=

5.3e+006

Units: Ha

total production cost=

ethanol production*(subsidy+unit cost of biofuel production)

Units: birr/Year

total sugar cane irrigation land requirement=

completed sugar mill*average irrigation land requirement per sugar mill

Units: Ha

total water demand=

sugar cane crop water demand+"irrigation water demand, non sugar cane"

Units: m3/Year

transformable molasses= INTEG (

molasses production-molasses fermentation rate,

0)

Units: tonne

transport fuel consumption after biofuel=

transport oil consumption-"bio-fuel"

Units: TOE/Year

transport fuel demand=

transport fuel consumption after biofuel/energy efficiency

Units: TOE/Year

transport oil consumption=

((total average vehicle kilometer*average vehicle fuel consumption)+jet fuel consumption

)

Units: TOE/Year

Under construction sugar mill= INTEG (

construction start rate-completion rate,

0)

Units: sugar mill

unit cost of biofuel production=

(initial unit cost of biofuel production*effect of relative land cost on cost of biofuel production

)-subsidy

Units: birr/TOE

vehicles= INTEG (

net growth rate,

initial vehicles)

Units: car

"water demand per hectar, non sugar cane"=

6000*2

Units: m3/Ha/Year

water gap=

MAX(0,total water demand-available water for irrigation)

Units: m3/Year

Water in aquifer= INTEG (

net recharge-extraction,

6.5e+009)

Units: m3