Chapter 1
Introduction to sugarcane ethanol contributions to climate change mitigation and the environment

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1. Introduction

Life is energy. Humankind depends on energy and produces and consumes large volumes of energy. The total final energy consumption in industry, households, services and transport in 2005 was 285 EJ (OECD/IEA, 2008). And the consumption is growing fast. The growth of global final energy between 1990 and 2005 was 23%. Globally, energy consumption grew most quickly in the transport and service sectors. Between 1990 and 2005, global final energy use in transport increased by 37% to 75 EJ and according to the IEA study, road transport contributes the most to the increase in overall transport energy consumption. Between 1990 and 2005, road transport energy use increased by 41%. And with this growth, CO_2 emissions increased as well. These emissions grew during that same period with 25% (IEA, 2008). The associated CO_2 emissions increased to 5.3 Gt CO_2. There is a widely shared opinion that these emissions contribute to global warming and climate change. Reason enough for making a change.

Another reason for making a change, are the fossil oil prices. Fact is that the price increased from \$20 in 2002 to a record high of more than \$140 a barrel in July 2008. The price volatility creates a lot of uncertainty in global markets. So, it is not surprising that the world is looking for substitutes for petroleum-derived products. Securing a reliable, constant and sustainable supply of energy demands a diversification of energy sources and an efficient use of available energy.

One of the alternatives for fossil fuels is biofuels. And here we enter in to the heat of the debate. Do biofuels help to reduce greenhouse gas emissions and offering new sources of income to farmers, by producing biomass? Are biofuels competing with food, animal feed and contributing to higher food prices? And are biofuels directly or indirectly threatening the environment, biodiversity, causing irreversible or undesirable changes in land use and landscape?

In this publication we aim to set the stage for the discussion about both challenges and concerns of sugarcane ethanol by providing the scientific context, the basic concepts and the approach for understanding the debate on biofuel-related issues. This book largely limits itself to sugarcane ethanol and its contribution to climate change mitigation and the environment.

2. Biofuels

Biofuels encompass a variety of feedstock, conversion technologies, and end uses. They are used mostly for transport and producing electricity. Biofuels for transportation, like ethanol and biodiesel, are one of the fastest-growing sources of alternative energy in the world today. Global production of biofuels amounted to 62 billion litres or 36 million tonnes of oil equivalent (Mt) in 2007 - equal to about 2 % of total global transport fuel consumption in energy terms (OESO, 2008).

3. Bioethanol

Global bioethanol production tripled from its 2000 level and reached 52 billion litres (28.6 Mt) in 2007 (OESO, 2008). Based on the origin of supply, Brazilian ethanol from sugarcane and American ethanol from maize are by far leading the ethanol production. In 2007 Brazil and the United States together accounted for almost 90% of the world ethanol production.

In Brazil production of ethanol, entirely based on sugarcane (*Saccharum* spp.), started in the seventies and peaked in the 1980s, then declined as international fossil oil prices fell back, but increased rapidly again since the beginning of the 21st century. Falling production costs, higher oil prices and the introduction of vehicles that allow switching between ethanol and conventional gasoline have led to this renewed surge in output.

In the crop season 2007/08 Brazil produced 22.24 billion litres of ethanol. Conab/AgraFNP expects another jump for the crop season 2008/09 with an expected production of 26.7 billion litres (AgraFNP, 2008). This increase is mainly due to expansion of the sugarcane area. In 2007/08 the area for sugarcane was 6.96 million hectare, and is estimated to grow to 7.67 million hectare in 2008/09. The total sugarcane production will also increase from 549.902 Mt to 598.224 Mt.

A typical plant in Brazil crushes 2 million tonnes of sugarcane per year and produces 200 million litres of ethanol per year (1 million litres per day during 6 months – April to November in the south-eastern region). The size of the planted area required to supply the processing plant is on average 30,000 hectares. Due to process of degradation of the quality of harvested cane the distance to the mill is up to 70 kilometres at the most.

United States (US) output of ethanol, mainly from maize (*Zea mays* ssp. *mays* L.), has increased in recent years as a result of public policies and measures such as tax incentives and mandates and a demand for ethanol as a replacement for methyl-tertiary-butyl-ether (MTBE) a gasoline-blending component. Between 2001 and 2007, US fuel ethanol production capacity grew 220 from 7.19 billion to 26.50 billion litres (OECD, 2008). The new Energy Bill expands the mandate for biofuels, such as ethanol, to 56.8 billion litres in 2015.

Although the installed ethanol fuel capacity in the European Union (EU) amounts to 4.04 billion litres at the moment (OESO, 2008), Europe's operational capacity is significantly lower at 2.9-3.2 billion litres as some plants have suspended production. The bulk of EU production, however, is biodiesel, which, in turn, accounts for almost two-thirds of world biodiesel output.

Elsewhere, China with 1.8 billion litres of ethanol (Latner *et al.*, 2007), Canada with 0.8 billion litres are relatively smaller producers.

4. Production and use of bioethanol

Ethanol is manufactured by microbial conversion ofbiomass materials through fermentation. The production process consists of three main stages:

- conversion of biomass to fermentable sugars;
- fermentation of sugars to ethanol; and
- separation and purification of the ethanol (Figure 1).

Fermentation initially produces ethanol containing a substantial amount of water. Distillation removes the major part of the water to yield about 95 percent pure ethanol. This mixture of 95% ethanol and water is called hydrous ethanol. If the remaining water is removed, the ethanol is called anhydrous ethanol and is suitable for blending with gasoline. Ethanol is 'denatured' prior to leaving the distillery to make it unfit for human consumption.

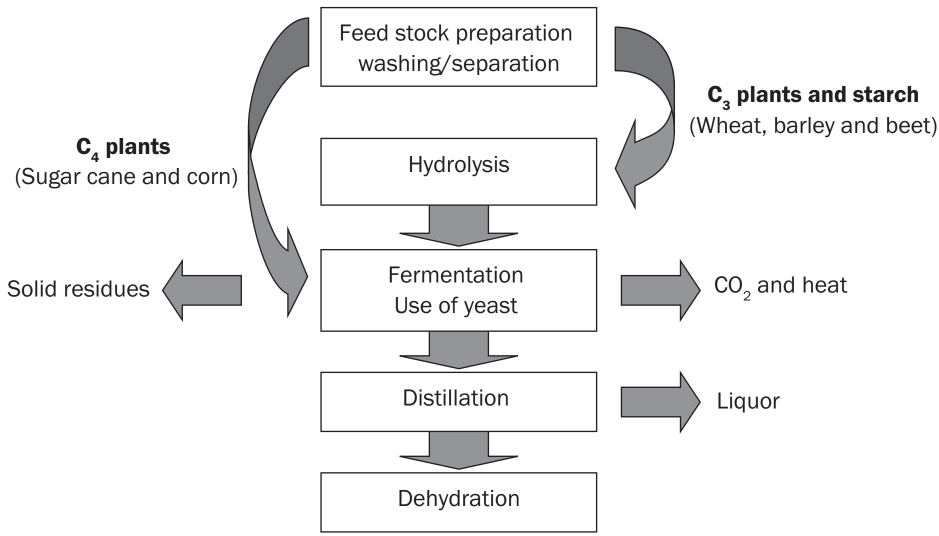

Figure 1. Production process of ethanol (Barriga, 2003).

Traditional fermentation processes rely on yeasts that convert six-carbon sugars, such as glucose, into ethanol. Ethanol is used primarily in spark-ignition engine vehicles. The amount of ethanol in the fuel ranges from 100 percent to 5 percent or lower, blended with gasoline. In Brazil the Flex-Fuel-Vehicles (FFV) are fit to use the whole range of blends of ethanol, up to 100%. The attractiveness of FFV is shown by the fact that in 2008 of the new cars sold 87.6% are FFV's (Anfavea: www.anfavea.com.br/tabelas.html). In other countries, such as Sweden, a maximum of 85% (E85) is used.

Anhydrous ethanol is used in a gasoline-ethanol blend. For example, of the total Brazilian ethanol production in the crop-season 2007/08, 8.38 billion litres are anhydrous and the rest, 13.86 billion litres hydrous ethanol (AgraFNP, 2008). Aside from FFV's manufactured to run on hydrous ethanol, non-FFV's in Brazil run on a 25 % mixture of a gasoline-ethanol blend and hydrous ethanol.

Another application of ethanol is as a feedstock to make ethers, most commonly ethyl tertiary-butyl ether (ETBE), an oxygenate with high blending octane used in gasoline. ETBE contains 44 percent ethanol. A last application, that we mention here, is the use of ethanol in diesel engines. Take for example Scania: Scania's compression-ignition (CI) ethanol engine is a modified 9-liter diesel with a few modifications. Scania raised the compression ratio from 18:1 to 28:1, added larger fuel injection nozzles, and altered the injection timing. The fuel system also needs different gaskets and filters, and a larger fuel tank since the engine burns 65% to 70% more ethanol than diesel. The thermal efficiency of the engine is comparable to a diesel, 43% compared to 44% (http://gas2.org/2008/04/15).

5. Where does it come from: the feedstock for ethanol

The term feedstock refers to the raw material used in the conversion process. The main types of feedstock for ethanol are described below.

1. *Sugar and starch-based crops*: As mentioned earlier bioethanol is mainly produced of sugarcane and maize. Other major crops being used are wheat, sugar beet, sorghum and cassava. Starch consists of long chains of glucose molecules. Hydrolysis, a reaction of starch with water, breaks down the starch into fermentable sugars (see Figure 1).
   The co-products include bagasse (the residual woody fibre of the cane obtained after crushing cane), which can be used for heat and power generation in the case of sugarcane; distiller's dried grains sold as an animal feed supplement from maize in dry mill processing plants; and high-fructose maize syrup, dextrose, glucose syrup, vitamins, food and feed additives, maize gluten meal, maize gluten feed, maize germ meal and maize oil in wet mill processing plants. In all cases, commercial carbon dioxide (CO_2) can be captured for sale.
2. *Wastes, residues and cellulosic material*: according to Kim and Dale (2005), there are about 73.9 million tonnes of dry wasted crops and about 1.5 billion tonnes of dry lignocellulosic biomass.

Cellulose is the substance that makes up the cell walls of plant matter along with hemicellulose and lignin. Cellulose conversion technologies will allow the utilization of nongrain parts of crops like maize stover, rice husk, straws, sorghum stalk, bagasse from sugarcane and wood and wood residues. Among the cellulosic crops perennial grasses like switchgrass (*Panicum virgatum* L.) and Miscanthus are two crops considered to hold enormous potential for ethanol production. Perennial crops offer other advantages like lower rates of soil erosion and higher soil carbon sequestration (Khanna *et al.*, 2007; Schuman et al, 2002) However, technologies for conversion of cellulose to ethanol are just emerging and not yet technically or commercially mature.

Furthermore, lignin-rich fermentation residue, which is the co-product of ethanol made from crop residues and sugarcane bagasse, can potentially generate electricity and steam.

6. Brazil as main exporter

Brazil has been by far the largest exporter of ethanol in recent years. In the crop season 2007/08, its hydrated ethanol exports amounted to 3.7 billion litres, of the 5 billion litres of ethanol traded globally (excl. intra-EU trade) (AgraFNP, 2008). The US imported more than half the ethanol traded in 2006. Of the 2.7 billion litres imported by the US in 2006, about 1.7 billion litres were imported directly from Brazil, while much of the remainder was imported from countries which are members of the Caribbean Basin Initiative (CBI) which enjoy preferential access to the US market and import (hydrated) ethanol from Brazil, dehydrate it and re-export to the US.

China, too, has been a net exporter of ethanol over the last several years, though at significantly lower levels than Brazil. Despite some exports to the US as well as to CBI countries, most of the larger destinations for Chinese ethanol are within the Asian region, in particular South Korea and Japan (OESO, 2008). The EU is also a net importer.

7. What makes the ethanol attractive?

One may observe a variety of reasons for the recent bioethanol interest. From the market point of view, there is an increasing consensus about the end of cheap oil and the volatility in world oil prices. Nowhere is the need for alternative to fossil oil felt more than in the transport sector. Transport consumes 30% of the global energy, 98 % of which is supplied by fossil oils (IEA, 2007).

From a policy point of view, other factors are mentioned, such as assuring energy security, reducing greenhouse gas emissions, increase and diversification of incomes of farmers and rural communities and rural development. And next there are arguments that ethanol is replenishable, that the ethanol industry can create new jobs, and that feedstock for ethanol can be made easily available considering already existing technologies.

However the debate on biofuels in general and bioethanol in particular shows a lot of counterarguments. They include that production of feedstock for ethanol might have negative environmental impacts on GHG, land use change, water consumption, biodiversity and air quality; also indirect negative environmental impacts are mentioned as a result of the interactions between different land uses. The development of biofuels, it is said, may also have both direct and indirect negative social and socio-economic impacts.

A third point of view comes from developing countries being motivated to diversify energy sources. Specifically net importing countries, may consider enhancing their energy security by domestically produced ethanol. Quality of air might be another argument for countries where the vehicle fleet is old, causing huge polluting emissions. However, also for these countries the counterarguments are widely discussed. Will the bioethanol production contribute to small farmers? And what will be the impact of production for bioethanol on the food production in those countries. Next to possible environmental impacts, developing countries might decide to take irreversible decisions that might, according to this point of view, create more instead off less poverty (Oxfam, 2008).

8. The core of the debate

The debate on sugarcane ethanol contains several major issues. The first one is impact of sugarcane production on land use change and climate. Here the assumption is made that land use for sugarcane implies serious impacts on the carbon stock, GHG emissions, and water and soil conditions. (Macedo *et al.*, 2004). Also, the reallocation of land or land cleared for ethanol may have unforeseen impacts on biodiversity. The main question here is, can production of sugarcane ethanol be sustainable?

Second, the demand side of the sugarcane ethanol may have impacts on the automotive industry, as happened in Brazil by the introduction of FFV's. Here the assumption is that demand will not so much be geared by balanced growth of the supply, but by the price and attractiveness of new automotive solutions. And this may have unintended consequences for sustainable production of sugarcane ethanol (Von Braun, 2006).

Third issue is the impact of new technologies on the efficiency of biomass for biofuels and the conversion of biomass for ethanol. Here the assumption is that new technologies may provide not only higher efficiency, but also the need for larger scale of operations, asking more land to be cleared for ethanol with possible negative environmental effects (Faaij, 2006).

Fourth, the public policies may have positive effects on balanced growth of the ethanol industry. However, these policies may also contribute to numerous distortions in trade, consumption, supply and technology development and on the environment as well (Hertel *et al.*, 2008).

Fifth, the debate also addresses the impacts of biofuels on developing countries. These societies may benefit greatly by diversifying the energy matrix. However, unbalanced growth may have unintended consequences for the food security domestically and land use (Teixeira Coelho, 2005; Kojima and Johnson, 2005; Dufey *et al.*, 2007).

Sixth, the last issue deals with the food prices hike. How do biofuels rank as factor for explaining the food prices in 2007-2008 and, possibly, the coming years (Banse, 2008; Maros and Martin, 2008)? And how does ethanol fit into this explanation and projection?

The impact studies are conducted from a multidisciplinary point of view. Also, the impacts are observed on different scale levels: global, regional and on value chain level. Hence, the analysis focuses on land use dynamics, market demand, technology development and public policies. These four main factors are assumed to contribute to the understanding of impacts of sugarcane ethanol on climate change mitigation and the environment. The debate asks understanding based on the latest science based insights (The Royal Society, 2008). This book aims to contribute to present these insights.

9. Structure of the book

In Chapter 2 the debate on sugarcane ethanol focuses on land use from a global point of view. There are many competing demands for land: to grow crops for food, feed, fibre and fuel, for nature conservation, urban development and other functions. The objective of the chapter is to analyze current and potential sugarcane production in the world and to provide an assessment of land suitable for sugarcane production.

Considering the particular situation in Brazil, Chapter 3 discusses the prospects of the sugarcane production, considering land use allocation and the land use dynamics. It shows on an empirical basis the expected sugarcane land expansion. This expansion is supposed to convert annual crops, permanent crops, pasture areas, natural vegetation and degraded areas. The chapter presents substitution patterns based on a reference scenario for sugarcane and ethanol production.

What are the impacts of sugarcane ethanol for the mitigation of GHG emissions? Chapter 4 goes into this debate. The chapter compares the ethanol production in 2006 with a scenario for 2020. Next energy flows and a life cycle analysis is presented. Then the effects on land use change on GHG emissions on global scale are discussed. Finally the chapter discusses the indirect effects of land use change in the Brazil.

Chapter 5 addresses the question on environmental sustainability of the sugarcane ethanol production in Brazil. Sustainable production is discussed worldwide. For bioethanol sustainability criteria vary among countries and institutions. Criteria that are pertinent in the debate are use of agricultural inputs, air quality and burning of sugarcane vs. mechanization, use of water, soil, farm inputs such as fertilizer and the energy and carbon balance. The chapter ends with the discussion on certification and compliance

Chapter 6 starts with the assessment of studies on the market potential of ethanol. The demand predictions will be considered, taking into consideration technological development and innovation. The study provides an overview of the main issues and challenges related to the current and potential use of ethanol in the transport sector.

In Chapter 7 the technology developments for bioenergy will be analyzed. It gives a state of the art overview of technologies for bioenergy production from biomass. Next the chapter highlights some challenges in developing technologies from biomass. Further it sheds light on some scenarios for technologies to be developed in the 10-15 years to come.

As described earlier, public policies play a major role in the biofuel industry. What are the policies, what measures are implemented and what are the impacts? This Chapter 8 will deal specifically with the policies originating from the United States of America and the European Union. The chapter starts with an overview of policies and policy instruments of both. Next, these policies will be evaluated from an economic point of view. Based on this analysis, the impacts on the global biofuel industry will be considered.

There is much debate on the impacts of biofuels on developing countries. Just positive, only negative? In Chapter 9 the impact will be discussed within the framework of theMillennium Development Goals (MDG). The chapter will deal with the question: How can global biofuels industry support sustainable development and poverty reduction?

The book ends with the probably most heated debate: the impacts of bio fuels production on food prices. Chapter 10 covers the following questions: what is the state of the art: what are the relations between production of food and food prices and bio-fuels? Then the main drivers for the hike in food prices are discussed. Based on quantitative model studies some core findings will be presented. Finally, the chapter ends with the impacts of bioethanol on food production and prices.

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