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BIOFUEL SUSTAINABILITY

Case Studies and Practical Lessons for South-South Experience Sharing

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BIOFUEL SUSTAINABILITY

Case Studies and Practical Lessons for South-South Experience Sharing

Editor

Emmanuel Kofi Ackom (PhD)

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Abbreviations

AEDP	Alternative Energy Development Plan
AEZ	Agro-ecological zoning
AFREPREN/FWD	Energy, Environment and Development Network for Africa
API	American Petroleum Institute
APU	Agricultural Production Unit
ANCAR	The National Rural and Agricultural Advisory Agency
ANCS	National Rural Councillors Association in Senegal
ASTM	American Standard Test Method
BD	Biodiesel
BDT	Bone dry tonnes
BEFS	Bioenergy and Food Security
BOD	Biological Oxygen Demand
BP	British Petroleum Company
Cap	Chapter
CBO	Community-Based Organisations
CDM	Clean Development Mechanism
CENBIO	The Brazilian Reference Center on Biomass but now GBIO, Research Group on Bioenergy (GBIO) of the Institute of Energy and Environment of University of São Paulo
CEPAL	Comisión Económica para América Latina y el Caribe
CETESB	São Paulo State Environmental Agency
CH4	Methane
CL	Cropland
Co	Company
CO	Carbon monoxide
CO2eq	Carbon dioxide equivalent
COMESA	Common Market for East and Southern Africa
CONAMA	National Council for the Environment
CONICET	Consejo Nacional de Investigaciones Científicas y Técnicas

CPO	Crude Palm Oil
CSS	The Sugar Company of Senegal
DANIDA	Danish International Development Agency
DEDE	Department of Alternative Energy Development and Efficiency
DST	Decision Support Tool
E	Bioethanol
EC	European Commission
EN	European Standard
ENDA	Environment and Development Action in the Third World (ENDA-TM)
ERC	The Energy Regulatory Commission
ESDA	Energy for Sustainable Development Africa
EU	European Union
E10	Blend composed of 10% ethanol and 90% gasoline
E85	Gasoline blended with anhydrous ethanol (85% in volume)
FACT	Fuels from Agriculture in Communal Technology
FAO	Food and Agriculture Organization of the United Nations
FAOStat	Food and Agricultural Organization Statistics
FFB	Fresh Fruit Bunch
FL	Forest land
FWD	Foundation for Woodstove Dissemination
GBEP	Global Bioenergy Partnership
GDP	Gross Domestic Product
GEB	Global Environmental Benefits
GEF	Global Environmental Facility
GENREN	Renewable Energies Electricity Generation Program
GHG	Greenhouse Gases
GIS	Geographical Information System
GIZ	Gesellschaft für Internationale Zusammenarbeit (German Technical Cooperation (presently GIZ)
GL	Grassland
GM	Genetically Modified
GNESD	Global Network on Energy for Sustainable Development
GWh	Gigawatt hours
Ha	Hectares

IA	Implementing Agencies
ICCR	Interdisciplinary Centre for Comparative Research in the Social Sciences
ICRAF	International Center for Research in Agroforestry
IEA	International Energy Agency
ILUC	Indirect land use change
INP	National Institute of Pedology
INTA	National Institute of Agricultural Technology
ISRA	Senegalese Institute for Agricultural Research
KBDA	Kenya Bio-Diesel Association
KEFRI	Kenya Forestry Research Institute
KGOE	Kilograms of Oil Equivalent
KNBS	Kenya National Bureau of Statistics
KPC	Kenya Pipeline Company
KPRL	Kenya Petroleum Refineries Ltd
KS	Kenya Standards
KSB	Kenya Sugar Board
Kshs	Kenya Shilling
LCA	Life Cycle Assessment
LEAP	Long-range Energy Alternatives Planning System
LPDSE	Policy Paper for Energy Sector Development
LPG	Liquefied Petroleum Gas
LPSERN	Policy Paper for the Environment
Ltd	Limited
LUC	Land Use Change
LULUCF	Land Use, Land Use Change, and Forestry
M	Million
MFA	Ministry of Foreign Affairs
MoE	Ministry of Energy
MSC	Mumias Sugar Company
MTBE	Methyl tert-butyl ether
MW	Megawatt
M3	Cubic metres
NEMA	National Environmental Management Authority
NGO	Non-Governmental Organisation

NJP	National Jatropha Programme
NMOC	Non-Methane Organic Compounds
No	Number
OECD	The Organisation for Economic Co-operation and Development
OLADE	Organización Latinoamericana de Energía
PAN	Peroxyacetyl nitrate
PIEA	Petroleum Institute of East Africa
PIF	Project Identification Forms
PM	Particulate matter
PROALCOOL	Brazilian Alcohol Program
REVA	A plan designed to establish populations on agricultural land
RFS	Renewable Fuel Standard
RPR	Residue to Product Ratio
RR	Roundup Ready
RSB	Roundtable on Sustainable Biofuels
RSPO	Roundtable on Sustainable Palm Oil
SCPC	Sugar Cane Pricing Committee
SMA	Secretariat for Environment of the State of Sao Paulo
SMEs	Small and Medium Enterprises
SOCOCIM	Cement company
SODEFITEX	Society for the Development of Textile Fibres (local cotton company)
TARDA	Tana/Athi River Authority
TCD	Tonnes of Sugarcane per Day
TOE	Tonne Oil Equivalent
UK	United Kingdom
UN	United Nation
UNCTAD	United Nations Conference on Trade and Development.
UNEP	United Nation Environment Programme
UNICA	Brazilian Sugarcane Industry Association
UDP	UNEP DTU Partnership
US	United States
USA	United States of America
USD	US Dollar
VOCs	Volatile organic compounds

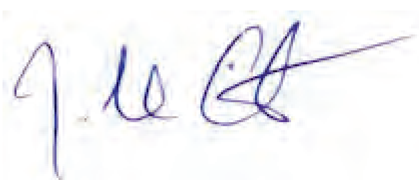
Foreword

Many global energy studies project increased use of liquid biofuels, but for this to be realistic a number of sustainability concerns will need to be addressed and either remedied or avoided. Major concerns include questions on land use competition and food security, realistic net carbon effects, possible water constraints, energy and water balance, etc.

A number of these sustainability concerns related to increased production of liquid biofuels have been analysed by a group of research institutions based in Africa, Asia and Latin America, and the results are compiled in this book. The biofuel policy papers prepared by members of the Global Network on Energy for Sustainable Development (GNESD) constitute the analytical chapters in this book providing specific case examples and approaches ranging from addressing agro-ecological zoning and sustainability indicator issues to policy design (i.e., targets and measures) on end-products.

The book is targeted at decision makers and researchers especially those working on development issues in the energy, food and related areas.

The GNESD objective is to contribute policy relevant research on key energy and sustainable development issues, and we hope that this book makes a valuable contribution to the sustainability discussion around increased biofuel operations. Finding workable solutions to the key sustainability concerns will offer opportunities for properly undertaking expansion of biofuel activities, securing the durability of the sub-sector.



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Preface

Liquid biofuels, the focus of this study are of great interest to many developing countries. Primary drivers for biofuels in developing countries include: national energy security; reduction in crude oil import bills (via substitution with biofuels); benefits to rural economies through diversification of agricultural, energy and allied sectors; and greenhouse gas mitigation benefits. Socially and environmentally benign biofuels are an enabler to sustainable development with the potential to help countries in their effort to achieve a number of sustainable development goals (SDGs).

Biofuels have a unique position among other clean energy options because they can be utilized directly in existing transport fuel infrastructure. This opportunity and convenience presented by the use of biofuels in existing structures, present added cost saving advantage by offsetting the construction of new infrastructure.

Realizing the actual benefits from biofuels will require addressing several environmental and social sustainability issues related to the sub-sector. The discussions on the sustainability concerns of biofuels are far from conclusive at the moment due to the complex nature of the subject matter. It has been argued by some that trade-offs are inevitable especially with large scale biofuel activities. On the contrary however, equitability is of essence and the benefits from biofuels should not be mutually exclusive. Indeed, it is possible for biofuels to result in benefits for governments, investors, rural communities, the environment, and climate in mutually inclusive multiple wins for everyone.

Realizing the importance of the topic, GNESD engaged in policy research to contribute to ongoing discussions and analytical efforts to find pragmatic solutions regarding the environmental sustainability of biofuels. The chapters in this book focus on diverse but key aspects of environmental sustainability, illustrating the unique national circumstances and experience in biofuel implementation in the five selected countries i.e., Brazil, Kenya, Senegal, Argentina and Thailand. In the Brazilian and Senegalese examples, studies included agro-ecological zonings which provide clear information to policymakers and stakeholders on where to grow or not to grow biofuels after taking into consideration the biological ecosystem, and in some cases the social aspects also. The Argentine paper brought new perspectives to sustainability indicators for biofuels. Cross-cutting sustainability issues that encompass first and second generation biofuels were extensively investigated in the Thai and Kenyan examples.

The specific topics covered are:

- *Biofuels Environmental Zoning in Brazil* (by *GBIO,* Research Group on Bioenergy (GBIO) of the Institute of Energy and Environment, University of São Paulo. Previously known as CENBIO-IEE-USP/CENTROCLIMA-COPPE-UFRJ, Brazil).
- *Analysis of national Jatropha biodiesel programme in Senegal* (by ENDA, Senegal)
- *Biofuels Sustainability Indicators for Argentina (by FB, Argentina)*
- *Potential of Liquid Biofuel in Kenya (by AFREPREN/FWD, Kenya)*
- *Policies and Future Potential of Biofuel in Thailand (by AIT, Thailand)*

(However, the opinions expressed in this book are those of the authors and they do not necessarily represent the views of GNESD, UNEP nor UNEP DTU Partnership)

The five (5) chapters in the book showcase the immense opportunities as well as challenges in undertaking biofuels in the countries. It is hoped that this policy relevant book would be a useful information and reference for South-South experiential sharing and lessons on biofuel sustainability.

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Sugarcane harvesting. Photo credit: Flickr

1. Sustainability considerations of liquid biofuels: possible way forward

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Introduction

Many developing countries spend substantial amounts of national revenue on importation of crude oil for transportation fuel and/or electricity generation. Liquid biofuels from locally derived sources are a good substitute from an energy security perspective. Additionally, agricultural sectors in these countries are economically challenged and liquid biofuels are a good option for diversification of rural agricultural economies and in reducing their dependence on crude-oil based transportation fuels.

Several studies have investigated liquid biofuels at global scales indicating the growing importance and projected growth of the fuel. It is, however, important to examine a number of sustainability concerns, especially within local contexts, in order to understand the reality of liquid biofuel potential. This book focuses on aspects of environmental sustainability of liquid biofuels in the studied countries and interlinks with social and economic perspectives, such as jobs, production, consumption, trade, blending targets, etc.

Sustainability issues surrounding biofuels have been studied by a number of authors [1] including greenhouse gas (GHG) emissions (direct and indirect) [2-8], energy requirements [9-10], water [11-12], impact on natural ecosystems [13], competition with humans for food resources, labour concerns, land grabbing, and displacement of communities, among others. The use of labour should comply with the requirements stipulated by the International Labour Organization (ILO).

Looking forward

Liquid biofuels overall, are cleaner energy sources compared to petroleum (the dominant transportation fuel), however, that in itself does not exempt liquid biofuels from considerable scrutiny regarding sustainability performance. For example, there are expectations to improve aspects of liquid biofuels, especially their environmental and social sustainability performance, in order to ensure greater acceptability, durability and long term success. Looking forward, the editor has elaborated a number of factors that can help improve the durability and environmental sustainability of the liquid biofuels sub-sector including (but not limited) to: the use of biomass residues

1. the use of biomass residues
2. agro-ecological zoning
3. certification
4. social inclusion

1. Liquid biofuels from residues perform better on environmental sustainability

Second generation biofuels typically derived from residues have better sustainability performance as compared to their first generation counterparts that are mostly obtained from food (i.e., corn, sugarcane, and palm fruits etc.) and non-food crops such as Jatropha. Therefore, enabling frameworks and targeted policies that support the increased production of biofuel types that have high GHG emission savings and energy savings (relative to fossil fuels) should be strongly promoted and encouraged. For example, reported GHG emission savings (relative to fossil fuels) of second generation liquid bioethanol derived from agricultural residues range from 93% (switchgrass), 87% (wheat straw) to 77% (wood) with first generation bioethanol achieving lower GHG emission reductions of 48% (beet), 48% (wheat) and 27% (corn) with the exception of sugarcane which has a high GHG emission reduction of 92% [14, 15]. First generation biodiesel performs relatively better than its first generation bioethanol counterpart with reported values of 67% (sunflower), 44% (soybean), 44% (palm oil) and 38% (rapeseed) [14, 15]. To improve the GHG emission reduction in bioethanol would require the substitution of petrol chemical synthetic fertilizers with biomass sources such as manure and residues. This is due to the fact that nitrous oxide (N_2O) found in petrol chemical synthetic fertilizers is a very potent GHG source with a global warming impact that is approximately 300 tonnes of carbon dioxide (CO_2). Additionally, the use of biomass residues in liquid biofuel plant to offset fossil fuel utilization helps to improve GHG emission reduction.

A similar trend was observed in energy savings with second generation liquid bioethanol performing better with reported energy savings (relative to fossil fuel) of 88% (wheat straw), 85% (switch grass) and 82% (wood), with the exception of sugarcane which actually has the highest energy savings among all bioethanol types equating to 89%. Generally, first generation biodiesels are better on energy savings when compared to first generation bioethanol. For example energy savings (relative to fossil fuel) of 72% (sunflower), 63 % (rapeseed) and 45% (soybean) have been reported for first generation biodiesel compared to 48% (beet), corn (43%) and wheat (42%) in first generation bioethanol [14, 15].

Admittedly, competition for biomass feedstock exists in both first and second generation biofuels activities [16]. Competing uses as animal fodders, fertilizers and for maintaining soil organic matter persist in farming communities [16-20]. However, the competition is more profound in first generation biofuels as compared to second generation. Utilizing agricultural residues in developing countries have the potential benefits of preventing land use changes, GHG emissions mitigation, net positive energy balance, reduced water consumption and avoidance of food security issues. Indeed growing more food crops could actually support the food-fuel dualism with agricultural residues being utilized for energy applications. Careful consideration based on edaphic and climatic investigation might help in determining the optimal amount of residues to be extracted in specific locations [21]. A conservative environmentally benign extraction amount of 20% was applied in Table 1 as a reasonable amount which takes into consideration the other competing applications of the residues. However, the local specificity should be based on scientific evidence that strongly takes into consideration the soil type and conditions, topography of land as well as climatic conditions [22].

Second generation biofuels such as those derived from agricultural and forestry residues have better environmental sustainability over food based sources [1, 17, 23-25]. These residues however, have competing utilizations in some cases for energy, animal beddings, folder and to replenish soil nutrients [16, 26, 27].

Table 1: Bioethanol and Fischer-Tropsch diesel potential from sustainably extracted agricultural crop residues

Country	Agricultural crop residues (20%) sustainable extraction bone dry tonnes (bdt) /year	Biochemical conversion to ethanol (litres/year)		Percentage of national (year 2011) gasoline consumption it could potentially displace	Biomass to Liquid (BtL) -Fischer-Tropsch diesel (litres/year)		Percentage of national (year 2011) diesel consumption it could potentially displace
		Low	High		Low	High	
Brazil	*21.1×10^6	2.32×10^9	6.32×10^9	8 - 21 %	1.58×10^9	4.21×10^9	4 - 12 %
Senegal	0.7×10^6	0.08×10^9	0.21×10^9	33 - 89 %	0.05×10^9	0.14×10^9	8 - 22 %
Argentina	11.9×10^6	1.31×10^9	3.56×10^9	14 - 39 %	0.89×10^9	2.37×10^9	13 - 34%
Kenya	*1.16×10^6	0.12×10^9	0.32×10^9	13 - 35 %	0.08×10^9	0.22×10^9	8 - 21 %
Thailand	10.4×10^6	1.14×10^9	3.12×10^9	25 - 69 %	0.80×10^9	2.1×10^9	6 - 15 %

* This amount excludes sugar cane bagasse which is already in high demand for co-generation for heat and power.
Source: Author

The author's analysis regarding second generation liquid biofuel potential from 20% agricultural crop residues extraction in Brazil, Senegal, Argentina, Kenya and Thailand and how these could offset current petroleum demand showed some interesting findings (Table 1). The conservative extraction of residues based on 20% of the total residues was applied to enable other competing utilization including animal fodder, soil nutrient and integrity and cooking fuel. Using the conversion factors [28] and method [17], the analysis shows that Brazil (especially in the best scenario in Table 1) has second generation bioethanol potential of 6.3 billion litres/year and 4.2 billion litres/year of Fischer-Tropsch diesel respectively. However these can offset up to 21% of national gasoline consumption and up to 12% for petroleum diesel demand.

Argentina can produce approximately 3.6 billion litres/year and 2.4 billion litres/year of second generation bioethanol and Fischer-Tropsch diesel respectively. In the best case this would be enough to offset 39% of gasoline demand and 34% for petroleum diesel.

In the case of Thailand, there is second generation bioethanol potential of 3.1 billion litres/year and Fischer-Tropsch diesel potential of 0.8 billion litres/year in the best case from sustainably harvested agricultural residues. This could offset up to 69% of Thailand's gasoline demand and 15% for petroleum diesel.

In Kenya up to 35% of national gasoline consumption can be achieved from the 0.3 billion litres/year of bioethanol derived from agricultural residues. With regards to petroleum diesel, 21% of the country's demand can be achieved from the 0.2 billion litres/year of Fischer-Tropsch diesel.

A significant 89% of Senegal's gasoline consumption can be achieved from 0.21 billion litres/year derived from agricultural residues and 22% of their diesel demand could be offset by approximately 0.2 billion litres/year Fischer-Tropsch diesel.

2. Agro-ecological zoning

Agro-ecological zoning is very useful especially where biomass feedstock for liquid biofuel application has to be cultivated.

Agro-ecological zoning is not new but it has been used in the agricultural sector for several years for natural resource analysis and land-use planning. It however hold good potential for applications in biofuel operations as it is a potentially useful tool that could help define the *what, where* and *how* to undertake biofuel activities in a proper manner. For example, agro-ecological zoning could help provide information on the:

- *where* (land suitability assessments taking into consideration competing uses);
- *what* (biomass options); and
- *how* (the implementation. For example the use of direct precipitation or irrigation, soil nutrient enrichment through the application of organic manure instead of synthetic fertilizers etc).

In areas where agro-ecological zoning techniques are currently implemented they appear to be based on static models which do not take into consideration the temporal dynamisms of pressures on land as influenced, for example by population growth over time and projected impact on land use and economic activities. Additionally, current agro-ecological zoning is limited in the extent to which socio-economic and cultural perspectives are included in the assessment. Incorporating socio-economic and cultural perspectives into existing agro-ecological models would for example help prevent the displacement of communities or the use of historically and culturally sensitive lands for biofuel cultivation.

3. Certification (biomass)

Certification provides a system for verification and assessment by an independent third party along the lines of agreed criteria, requirements and standards. In the biomass area, the forest sector has the most experience in certification. The certification as practiced in the forest sector for example, works towards ensuring adherence to sustainable forest-management practices. Since certification alone is not enough to get sustainably sourced certified products to the market place, a chain of custody (CoC) scheme which works in tandem with forest certification is often implemented in the forest sector to help track and audit the biomass material from forest floor, through several processing steps up to the market place [29]. Admittedly, existing forest certification and accompanying chain of custody are not without shortcomings; however, a culture that promotes continuous improvement could hold good promise to mitigate current challenges or to eliminate them. Certification and chain of custody based on ambitious indicators (i.e. national, international, association, voluntary) that embodies good sustainability practices should be tested for biofuels. Continued improvements in certification and chain of custody and support for the forestry as well as agricultural sectors would help strengthen the similar activities for the allied biofuel sector. At the market place, biofuels would be utilized in the existing infrastructure, therefore certification and chain and custody throughout the value chain of the transportation fuel sector would go a long way to support that for biofuel. A number of studies have analysed sustainability certification of bioenergy (including biofuels) examining both *top-down* and *bottom-up* approaches in addition to global initiatives and associations [30-34].

Admittedly, key challenges to implementing certification standards and chain of custody for biofuels include (among others):

- heterogeneity of the feedstock;

- multi-faceted aspect of the biofuel sub-sector and its several interconnectedness with other areas such as agriculture, forestry, energy, trade, transport, industry, scientific/academic, government, indigenous and rural communities etc;
- establishing clear criteria that are easy to measure and operationalize;
- effective monitoring and/ or enforcement, capacity building, information dissemination and further research.

In spite of the challenges, it is possible to implement sustainability certification and chain of custody practices for biofuels through a continuous improvement process. A strong culture on due diligence with regards to environmental and social performance and continuous improvements would be key to ensure the success and longevity of the biofuel sub-sector. Certification and chain of custody of biofuels, if properly managed and enforced, would help to differentiate environmental benign and ethically sourced biofuels from the others.

There are a number of relatively robust certification initiatives in the forestry sector that have been in existence for decades now. However bioenergy is nascent and such certification initiatives are few. Existing bioenergy initiatives includes the Global Bioenergy Partnership (GBEP) which comprise of diverse stakeholders including public, private and civil society actors. GBEP provides support to standardization of biofuel activities for example by developing empirical-based sustainability indicators for use by decision makers, investors and all stakeholders [1]. Other initiatives include the International Standards Organization (ISO 13065 standards), Roundtable for Sustainable Biomaterials, Council for Sustainable Biomass Production, Roundtable for Sustainable Biofuels (which is affiliated with the International Social and Environmental Labeling Alliance). There are also some government-led initiatives of some countries and regions such as Germany (International Sustainability and Carbon Certification), UK (Renewable Transport Fuel Obligation), The Netherlands ('Cramer Criteria'), Belgium, Switzerland, USA (the Environmental Protection Agency Renewable Fuels Standard, EPA RFS2) and the European Union [1].

4. Social inclusion

Investing in farm workers and host communities should be a key focus of any biofuel activity. Therefore, a key goal of any biofuel operation should be to make continuous efforts that significantly improve the livelihoods of farmers and communities so there could be poverty alleviation in out-growers' communities. These could include carefully planned initiatives that invest in the people and communities such as provision of electrification, roads, schools, and health facilities. This can help ensure the longevity of biofuel operations in communities. Public-private partnerships (PPPs) provide a possible option for biofuel operators and investors to invest in communities and people working together with governments. Some biofuel operators have reported social inclusion efforts to include provision of shower facilities, lunch breaks and transportation of farm workers to and from the sites. Though these are positive measures, they are however insufficient towards eradicating poverty in such communities. What is really needed to improve livelihood and move communities away from poverty cycle would be investments in infrastructure as access to modern energy, roads, schools and health care facilities. Additionally, the provision of benefits such as health and life insurance for workers especially for those on farm lands would be essential. An example of social inclusion in bioenergy that could be further studied for possible replication can be found in Mauritius, where the revenue from bioenergy operations is set aside by the operators to establish health posts, educational facilities, and provision of clean drinking water. Another example is found in Kenya where bioenergy operators helped to improve road networks in the host rural communities [35].

In summary, the use of biomass, especially residues from existing agricultural activities holds good promise for liquid biofuel production. In the case the biomass feedstock need to be cultivated then it will

be appropriate to undertake this in a designated agro-ecological zone and apply certification and chain and custody principles. These would go a long way to boost confidence in biofuels thereby ensuring its longevity.

The following chapters in this book focus on diverse aspects of liquid biofuels sustainability. They illustrate unique national circumstances and experience in biofuel implementation in the five selected countries Brazil, Kenya, Senegal, Argentina and Thailand.

This book is structured in three parts. *Part I: Agro-ecological zoning: a promising first step tool for informing policy decisions on biofuel cultivation* comprises of two case examples that have applied agro-ecological zoning and suggests its utilization based on empirical in-country studies. This part showcases the experience of Brazil and Senegal. The second section that is *Part II: Sustainability indicators* highlight perspectives to biofuel sustainability indicators peculiar to Argentina which could be useful for other developing countries having similar conditions. The third and final part, *Part III: Cross-cutting sustainability issues for first and second generation biofuels* examines multi-faceted issues on biofuel sustainability in Thailand and Kenya.

The first part (Part I) sets the scene by showing case examples of agro-ecological zonings and how they have been (and could be) utilized in developing countries to help inform decision makers, investors and national policy guidance.

Chapter 2 describes environmental sustainability improvements on biofuel production in Brazil with a focus on agro-ecological zoning as a decision making tool. Brazil is widely known for its large-scale ethanol production predominately from sugarcane which commenced about 35 years ago. Achievements in Brazil's ethanol programmes include the decrease of its production costs thus enabling ethanol to be economically competitive with gasoline. At the federal and state levels of government, environmental and social legislation and regulations have been implemented including the use of agro-ecological zoning with the ultimate goal of improving biofuel sustainability. For example, the governments of Minas Gerais and São Paulo have launched agro-ecological zoning that also includes social and economic aspects in addition to soil, climate, topography, water availability, air quality, protected and biodiversity conservation components. Through agro-ecologically zoning, the Brazilian federal government on its part bans the cultivation of sugarcane within 92.5% of national territory. Areas forbidden by the federal government for biofuel activity includes the Amazon Forest, Pantanal wetlands, native and fragile biomes. Informed by agro-ecologically zoning 64 million hectares that comply with the criteria have been earmarked that could potentially be used for biofuel crops that avoids competition between food and fuel productions and the deforestation of native fragile biomes. This chapter shows how agro-ecological zoning for bioenergy cultivation that takes into consideration key sustainability requirements could be an important first step in undertaking bioenergy activities, possibly learning from the Brazilian experience.

Chapter 3 assessed the ambitious National Jatropha Programme (NPJ) in Senegal, and gaps identified and demonstrate how evidence from agro-ecological zoning could be used to make informed decisions. A key driver for the interest in Jatropha biodiesel by Senegal is the fact that 45% of the nation's import bill is spent on petroleum. It has therefore put in place measures to reverse this especially through the use of locally cultivated Jatropha biodiesel. The challenge however is that the government Programme was introduced without having first assessed the feasibility for Jatropha production based on edaphic-climatic, socio-economic and environmental sustainability factors. The NJP also plans to establish Jatropha plantations in each rural community. The result shows that without a prior agro-ecological zoning, NJP could lead to community displacement, competition with land for food, water, biodiversity

and areas of cultural heritage importance and communities. It proposes a well-balanced decision that is based on scientific evidence provided by agro-ecological zoning to inform the implementation of the NJP. This chapter has been published in *AIMS Energy*, an open access peer reviewed journal.

Chapter 4 assesses Argentina's biofuel activities against selected sustainability indicators such as GHG emissions, land use, sector concentration, glyphosate use, soil quality and rural employment in Argentina, which is a major global exporter of biodiesel. The study raises some concerns on reported GHG emissions reduction and employment attributed to the Argentine biodiesel activities. The chapter argues that the increased dependence on agrochemicals for biofuels for example glyphosates has led to increased health and environmental issues.

Chapter 5 describes Kenya's growing dependence on imported petroleum to meet its national energy demand. The country spends a substantial amount of its gross domestic product (GDP) on petroleum importation. It has been estimated that biofuels could lead to US $21 million in savings in the country's oil imports. There are, however challenges in the implementation of the biofuel programme in Kenya. The chapter recommends an effective and integrated approach that focuses on opportunities found in the synergies involving the environmental, economic and social aspects of biofuels in Kenya. For example, lack of favourable pricing does not motivate farmers to go into sugarcane cultivation. An option would be a revenue-sharing mechanism that ensures that out grower farmers are adequately compensated for their effort, also from a social inclusion perspective. Indeed, Kenya has an Act in place that is the Sugar Act (2001) which provides a revenue-sharing mechanism however, the Act needs to be implemented and enforced.

Chapter 6 provides an assessment of biofuels from first generation sources. It also estimates the potential for second generation biofuels from agricultural crop residues. It provides an analysis of planned targets and policies, notably the Alternative Energy Development Plan (AEDP). In the AEDP, Thailand's target is to meet 44% of its national petroleum demand from biofuels by 2021. In terms of environmentally sustainability considerations second generation biofuels, such as those obtained from agricultural residues are preferred over first generation sources. Agricultural residues nevertheless also have competing utilization including animal bedding, fodder, energy and soil nutrient recycling. Findings indicate that by utilizing environmentally benign agricultural residues that are sustainably extracted, 1.14–3.12 billion litres of ethanol per year could be produced to replace 25%–69% of Thailand's demand for transportation. With regards to biodiesel, an estimated 0.8–2.1 billion litres of biomass to Fischer-Tropsch diesel could be derived per year from the same residues to replace 6% –15% of the country's diesel demand for transportation. This chapter has been published in *Sustainability*, an open access peer reviewed journal.

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Part I

Agro-ecological mapping: a promising first step tool for informing policy decisions on biofuel cultivation

Sugarcane harvesting in Brazil. Photo credit: Flickr

2. Environmental zoning as a policy tool to improve the sustainability of sugarcane ethanol production in Brazil

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1. Introduction

Brazil began a large-scale sugarcane ethanol programme (PROALCOOL) in 1975, as a result of the world oil crisis which led to rising prices of fossil fuel. Since then, a number factors including, concerns for the environment have necessitated a move towards more sustainable production (economic, environmental and social).

Investments in research and technology resulted in constantly increasing yields in both – agricultural and industrial segments [1]. As a consequence, production costs decreased rapidly making ethanol economically competitive with petroleum. Concomitantly, social and environmental legislation were introduced both at the Federal and State level regarding sustainable use of natural resources, and social welfare. This is pertinent, since biofuels are the subject of much controversy today not only because of environmental and social concerns, but also due to the economic leverage that they can wield.

While biofuels provide the possibility of reducing global greenhouse gas emissions by replacing fossil fuels and providing local environmental and social benefits, many studies point to negative impacts such as the promotion of deforestation and competition with food. Some studies [2-4], amongst others, claim that biofuels can be responsible for more greenhouse gases than fossil fuels when they are produced in native forests areas that are deforested for bioenergy crops. Other studies, however, indicate that not all biofuels are responsible for such impacts, particularly in the case of sugarcane ethanol [5-6]. Nevertheless, several controversies remain.

Some Brazilian policies have been implemented to guarantee sustainable production of sugarcane ethanol. Environmental zoning of sugarcane has also been introduced at the Federal and State level, such as in São Paulo and Minas Gerais. Recently, Mato Grosso do Sul also announced the development of an economic-environmental zone to protect the Pantanal Wetlands and other fragile biomes within the state. São Paulo is the most industrialised state in Brazil and possibly due to this, it has the strictest air emission legislation in the country. It is also an important producer of agricultural products besides being the largest sugar/ethanol producer in the country. For these reasons, in many cases only data from the State of São Paulo has been used.

This paper begins by presenting a general overview of liquid biofuels in Brazil (ethanol and biodiesel from sugarcane) and electricity from bioenergy (sugarcane bagasse cogeneration). It continues with a discussion on the environmental and social issues which affect sustainability and discusses the economic-environmental policies on sugarcane.

Other developing countries, mainly in Africa and Asia, could benefit from the lessons learned from the implementation of these policies in Brazil.

2. Current bioenergy situation in Brazil

Bioenergy has contributed to the Brazilian energy matrix since many years. Ethanol production was initiated in 1975 through a subsidised programme. Over time, however, improvements in technology and economies of scale have driven down production costs. Since 2004, ethanol has become economically competitive without subsidies as compared to petroleum [7-8].

Brazil is the largest producer of sugarcane ethanol and the second largest producer of ethanol in the world after the United States which produces ethanol from corn. In the 2009–10 harvesting season 427 sugar mills produced ethanol and sugar, with a planted area of 8.6 million hectares of sugarcane. The national average yield in 2010 was almost 78 tonnes of sugarcane per hectare, with some regions reaching 100 tonnes [9].

Initially ethanol was available for ethanol-dedicated engines (hydrated ethanol, 96% ethanol) or as an octane enhancer (anhydrous ethanol, 99.5%), replacing lead and the additive methyl tert-butyl ether (MTBE). The Federal Government currently mandates the blending of 20–25% of anhydrous ethanol with petroleum. Presently, instead of ethanol-dedicated vehicles, hydrated ethanol is used in flex-fuel vehicles. These now represent more than 90% of all new cars sold in Brazil. They can run on any blend of petroleum or ethanol, allowing drivers to make price-driven fuel choices [10]. In the domestic market, ethanol makes up 41.5% of the light duty transportation fuel used in the country [11]. Projections anticipate an increase in ethanol production to almost 57 billion litres over the next 10 years, which will provide 51.7% of the total light duty transportation fuel consumed in the country [12].

Bagasse, the residue from sugarcane crushing, is used for combined heat and power generation (cogeneration) in sugar mills. The surplus electricity generated by them is sold to the grid. The installed capacity from bagasse was almost 6,000 MW (megawatts) in 2010 [12]. In the 2009–10 harvesting season, the total electricity produced from sugarcane bagasse was 20,031 GWh (gigawatt hours) and 28.2% of the mills sold their surplus power to the grid [12]. Cogeneration of electricity can be increased further by using the best available technology. To provide an idea of the potential, an indicative scenario considered the use of high-pressure boilers (99 bars) in all mills and an overall sugarcane production of 1.04 billion tonnes per harvesting season. In this case, electricity production from sugarcane bagasse would increase to 68,730 GWh over the next 10 years [12]. This corresponds to 13.5% of all Brazilian electricity produced in 2010 [13].

A possible trade-off for the use of bagasse as feedstock for cellulosic ethanol production could exist once this technology is commercially available. In fact it is possible that bagasse could be used for ethanol production through second generation. However, there is only about 10% bagasse surplus in Brazil according to GBIO (formerly CENBIO's) assessment for cogeneration [14]. In addition, if the bagasse currently used for cogeneration was to be diverted to second generation, there is still the possibility of using the tops and leaves of the sugar cane in boilers. Existing boiler technology is not capable of burning tops and leaves completely unless combined with bagasse, and R&D is required in this area. The use of

natural gas for co-firing boilers has been proposed as an option [15], however, this is not feasible since natural gas being a fossil fuel would significantly reduce the energy balance of ethanol in Brazil which is currently 8-10:1 [5] and would increase carbon emissions.

Bagasse for the use of animal feed does not seen to be economically viable in Brazil as all the sugar mills use it for production of energy.

There have been no studies conducted on biodiesel. However, as it plays an important role in the Brazilian bioenergy market, the role of biodiesel must be mentioned. Brazil is the second largest producer of biodiesel in the world. By the end of 2010, production was 2.3 billion litres and there were 68 registered plants, with an installed capacity of 6.2 billion litres [16]. The domestic biodiesel market is guided by the government mandate to blend 5% biodiesel (B5) in all diesel sold in the country. Soy is the main feedstock used for biodiesel production, (accounting for 80%), followed by animal fat (almost 13%) and others vegetable oils.

3. Environmental issues

PROALCOOL was created with the goal of partially replacing petroleum as a result of the high cost of imported oil in 1975 and the revitalisation of the sugarcane industry [17]. But there were some environmental issues which have diffused this programme. An analysis of the sustainability of biofuels has been discussed in this chapter from the perspective of the following environmental issues: water, land use, soil and biodiversity.

3.1 Air quality

3.1.1 Emission from ethanol use

An important factor in atmospheric pollution is the lead emission from fuels. Brazil was one of the first countries in the world to ban the use of lead as an octane enhancer. Lead additives were reduced while the amount of alcohol in petroleum was increased and eventually, lead was completely eliminated by 1991.

The use of E10 blends to reduce carbon monoxide (CO) emissions has proved to be very effective in the US. Tests at the National Center for Vehicle Emissions Control and Safety at Colorado State University document a 25% to 30% reduction in CO when automobiles use E10. It is important to note that CO, in addition to being a significant air pollutant in itself, also contributes to the formation of photochemical smog. [1;18].

Aromatic hydrocarbons (such as benzene), which are particularly harmful, were also banned and sulphur content in fossil fuels reduced. Since ethanol has no sulphur content, vehicles using E100 have a salutary effect on the total sulphur emissions from the transport sector. The substitution of ethanol in commercial gasoline has significantly reduced transport emissions, considering the lower levels of CO, hydrocarbons, sulphur, and lead concentration in large cities.

One of the drawbacks of pure ethanol combustion is an increase in aldehyde emissions compared to gasoline or gasohol (gasoline and ethanol blend). Total aldehyde emissions from ethanol engines are higher than those from gasoline but it must be observed that these are predominantly acetaldehydes in the case of ethanol and for gasoline they are mainly formaldehydes than are more noxious to human health. Besides the increase of acetaldehyde, there is also concern about the increase in peroxyacetyl

nitrate (PAN) concentrations as compared to gasoline. PAN is a by-product of the combustion of ethanol that is an eye irritant and noxious to plants. Several studies [19-20] were performed to determine the impact of ethanol blends on air quality. One of the conclusions of a study conducted in Canada was that the risks of increased aldehyde pollutants are insignificant and the impacts in levels of pollution are similar for high (E85) and low proportion blends [21].

Nitrous oxides (NO_x) and volatile organic compounds (VOCs) emission from ethanol engines are negligible or zero. Since modern vehicle technology allows the efficient control of NO_x, reducing ground-level ozone. Depending on engine characteristics, reduction of VOCs from exhaust emissions, which are a potent precursor of photochemical smog and noxious substances, were achieved [1].

3.1.2 Atmospheric emissions from ethanol production

Atmospheric emissions during ethanol production are discussed separately for each sector – industrial and agricultural.

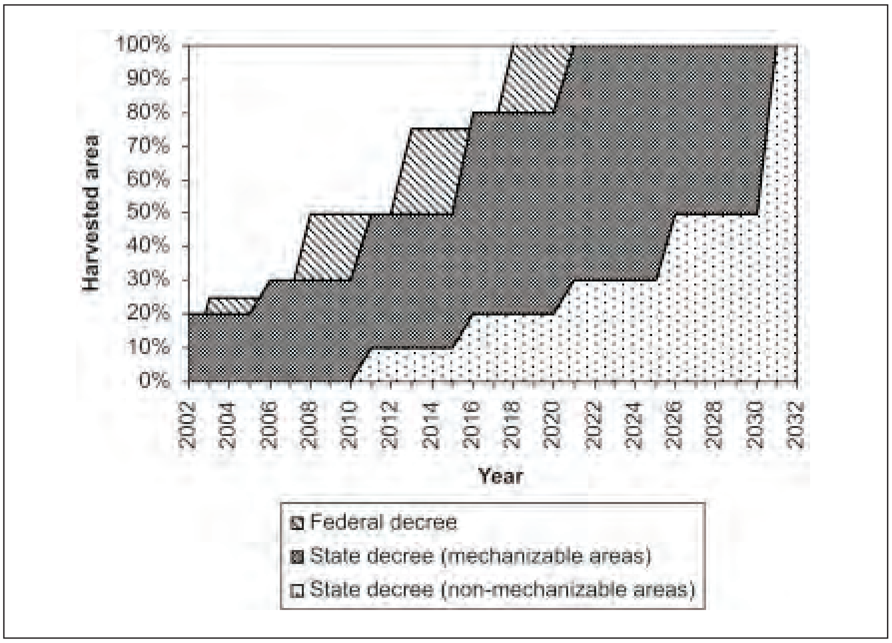
In the industrial sector, the process that contributes most to atmospheric emission is the burning of bagasse in boilers. As already mentioned, all the energy needs for the sugar-ethanol process are supplied by sugarcane bagasse (bagasse represents 30% of the weight of sugarcane). In the past, bagasse was burned inefficiently in low pressure boilers (21 bar) which are now being replaced by more efficient ones (up to 80 bar and in some cases 99 bar) which have lower emissions.

Emissions from bagasse boilers are mainly PM and NO_x which are monitored through a Resolution by the National Council for the Environment (CONAMA number 382/2006) which has established limits for such pollutants. State government bodies, such as the São Paulo State Environmental Agency (CETESB) are in charge of law enforcement.

In the agricultural sector, the burning of sugarcane fields before harvesting contributes the most to atmospheric emission. This is practiced to facilitate manual harvesting of stalks and also to repel poisonous creatures such as spiders and snakes. On the other hand, this practice can damage the cell tissue of the cane stalk and increase the risk of diseases in sugarcane, decrease sucrose content, and damage soil structure due to increased drying and soil erosion. This also poses risks to electrical systems, railways, highways and forest reserves. Besides these impacts the process emits harmful atmospheric emissions such as CO, CH_4 (methane), non-methane organic compounds (NMOC) and PM. The burning of sugarcane is also responsible for the increase of ground-level ozone concentrations in sugarcane producing areas.

The practice of harvesting-burning is being phased out [5]. Essentially, this is being carried out according to a schedule by a Government initiative (Federal and State levels) specifically for the gradual reduction of cane trash pre-burning (Figure 1). In the last season (2011–12) 1.67 Mha were burned in São Paulo, which represents 34.5% of total area harvested. In São Paulo harvesting-burning practices are controlled by the São Paulo State Secretary for the Environment and are authorised depending on atmospheric conditions (State Law 11,241/2002).

Figure 1. Phase out schedules for trash burning practices [5]



In 2007, the São Paulo Secretariat for the Environment and the Sugarcane Agro-industry Association (UNICA) signed a voluntary environmental agreement called the São Paulo Agro-environmental Protocol, which rewards good practices in the sugarcane sector [48]. As of February 2011, 149 out of the 196 ethanol plants had adhered to this agreement to establish a timetable to phase out the use of fire. The new timetable represents more than 90% of total sugar cane crushing in the state which has accelerated the timelines for phasing out burning.

Following the timetable, 65.5% of the sugarcane was mechanically harvested in São Paulo in 2010. In May 2013, 72.6% of the area harvested without burning, corresponded to 3.38 million hectares[1] and revised in 2012, against 34.2% in 2006. In areas where mechanisation is not feasible, the legal deadline of 2031 will be anticipated as from 2017.

Besides reducing local emissions, mechanical harvesting of green cane has other benefits. When sugarcane is not burnt before harvesting, 0.48 Mt C/yr is sequestered in soil and 0.05 Mt C/yr of methane emission equivalent avoided [22]. Mechanisation also results in increased potential for energy production. An increased availability of biomass from sugarcane by-products can generate higher surpluses of electricity because tops and leaves correspond to 30% of sugarcane in weight. This means that one tonne of sugarcane produces 300 kg of bagasse (50% wet) and with green harvesting, 300 kg more of tops and leaves (15% wet). Even considering that part (40-60%) of it must be left to protect the soil [23] we have 120-180 kg of added biomass.

1 http://www.ambiente.sp.gov.br/acontece/colheita-mecanizada-da-cana-cresce-em-sao-paulo/

Despite the high investment costs – each harvesting machine costs about US$ 600,000 – these machines reduce operational costs and result in increased productivity. Despite this, most producers did not consider this option until the State Law in 2002. Impacts on employment were also an important factor as discussed later.

3.2 Water

Water is necessary for agriculture and for industrial operations. Water consumption in Brazil decreased rapidly as a result of environmental legislation and the imminent introduction of payment for water usage.

3.2.1 Agricultural demand for water

The use of crop irrigation for sugarcane is significantly low in Brazil and implemented mainly in the dry North-eastern Region. In the rest of Brazil crops are mainly rain fed.

The evapotranspiration of sugarcane is estimated at 8-12 millimeters per tonne of cane. The total rainfall required by sugarcane is estimated to be 1,500-2,500 millimeters per year, which should be uniformly spread across the growing cycle [24].

Irrigation is rarely used for São Paulo sugarcane production [25]. Thus, sugarcane irrigation is indeed a minor problem in Brazil [26].

3.2.2 Industrial demand for water

Conversion of cane to ethanol requires large amounts of water. The total gross water used is 22 m^3 per tonne of cane. Most of it is used in processes that have closed-loop circuits, leading to low net withdrawal from water bodies [27].

However at the industrial processing level, water use has substantially decreased in the last years, from around 5.6 m^3/ tonne of sugarcane collected in 1990 and 1997 to 1.0 m^3/ tonne in 2008 [27], as per figures from a sampling in São Paulo. The rate of water re-use is very high.

The São Paulo Agro-environmental Protocol has established goals for reducing water withdrawal to 1.0 m^3/ tonne of sugarcane in non-stressed areas, while in areas where water is scarce, policy limits consumption to 0.7 m^3/ tonne of sugarcane. The use of 1.0 m^3 water/tonne of sugarcane is achievable with basic engineering, but to achieve lower levels it is necessary to implement new technologies such as the dry cane cleaning process. The standard wet cane washing process is also being replaced with the dry cane washing process that recycles most of the water and results in lower net water usage (98%) [24].

3.2.3 Water pollution

Regarding wastewater issues, there is the problem of organic and inorganic pollutants. Environmental problems related to water quality as a result of irrigation (from nutrients and pesticides in water run-off or erosion) or industrial usage, have not been reported in São Paulo.

The main liquid effluents of ethanol production are vinasse and the wastewaters from cleaning sugarcane stalks. Modern agricultural practices include recycling of the washing water and ashes via “fertirrigation” with the vinasse (a pollutant by-product from ethanol distillation not allowed to be disposed into rivers).

Vinasse disposal represents the most important potential impact due to the large amounts produced (0.011 to 0.014 m^3 per cubic metre of ethanol), and the high organic loads and pH (4 to 5) [28]. If disposed in water, the high organic load can reduce the amount of oxygen available, leading to the death of fish, whereas, disposal of large quantities in the soil impair nutrient balance and can promote soil salinisation.

A number of studies on leaching and the possibilities of underground water contamination from vinasse indicate that there are in general no damaging impacts for applications of less than 30,000 m^3 of vinasse per square kilometer. A technical standard by CETESB [29] regulates all relevant aspects: risk areas (prohibition), permitted areas, and adequate technologies.

Ways to reduce the amount of organic pollutants in wastewater include mechanical removal of suspended particles, aerobic treatment, anaerobic treatment and recycling [30].

Agrochemicals such as herbicides, insecticides, mitecides, fungicides, maturators and defoliants are inorganic pollutants applied in ethanol crop production. Federal legislation is adequate and includes rules and regulations on aspects from production to the use and disposal of materials. Moreover, pesticide consumption per square kilometer in sugarcane crops is lower than in citrus, corn, coffee and soybean crops, along with a low use of insecticides and fungicides.

Genetic research has produced plant varieties resistant against diseases, herbicides, fungus and the sugarcane beetle [24]. There are more than 500 commercial varieties of sugarcane.

The most important practice is nutrient recycling through application of industrial waste (vinasse and filter cake), considering the limiting topography, soil and environmental control (legal) conditions. Thus, substantial increases in productivity and potassium content of the soil have been observed. Nutrient recycling is being optimised but tops and leaves utilisation is yet to be implemented.

3.3 Land Use

3.3.1 Expansion of sugarcane

The main concerns related to expanding the amount of land under cultivation for ethanol is the irreversible conversion of virgin ecosystems and competition with food crops. These impacts have not been observed in the case of new sugarcane plantations since these have been planted mostly on degraded land where there is little competition for food.

In the year 2008, increased prices and speculation affected the price of all commodities [31], and the increase in oil prices was an incentive to biofuel production [32].

It is important, however, to keep the discussion in the corrective perspective. From 2004 to 2007, despite 70% of additional corn production being diverted to the production of ethanol, and 40% of the additional production of rapeseed used for biodiesel production, the increase in demand was supplied by the increase in production, reducing the trade-off. If ethanol production in the United States were responsible for the increase in corn prices, then it should have increased more sharply than wheat prices, which did not happen. The crop area dedicated to biofuel production is still low: 5% in the United States and less than 4% in the other four countries that are the largest bioenergy producers [33].

These issues are also discussed by Sen [34], who stresses that most of the dramatic events of famine around the world were not due to a physical shortage of food but a problem of affordability. Poorly

designed policies and bad governance generate unemployment and more poverty in already impoverished areas, aggravating the difficulties in paying for food. The impact on food prices appear to be mostly due to the price of oil [35].

Sugarcane growth in Brazil does not seem to have had any impact on food production, the areas used for food crops have not decreased. New sugarcane crops were planted in lands that had previously been used for pasture but which had become degraded. The main problem regarding food in Brazil is the inadequate logistics for distribution.

In Brazil, the expansion of sugarcane is limited by the soil quality, precipitation and logistics. The Environmental Zoning previously mentioned forbids production in the Amazon Forest, Pantanal Wetlands, Alto Paraguai Basin, areas with native forest, environmental protection areas (such as national parks, and other notified areas), indigenous lands and mangroves.

The zoning study considers climate and suitability of soil to the production of sugarcane, environmental restrictions, topography, and current land use. The results indicate that there are an additional 64.7 million hectares suitable for the production of sugarcane without irrigation and slope lower than 12% (meaning they can be harvested mechanically). Of this total, 37.2 million hectares are currently pasturelands.

It is of utmost importance to stress here that zoning is an indication of areas suitable to sugarcane production and areas where its cultivation will not be allowed.

Besides the existing zoning at national and state levels, the cultivation of cane and installation of sugar/ethanol facility is still subject to processes where environmental authorities will consider various aspects, such as water scarcity.

Sugarcane is not a particularly demanding crop in terms of soil quality, adapting reasonably well to soils of average fertility and high porosity/permeability, i.e., sandy soils. It is true that more fertile soils result in higher productivity levels, and/or lower requirement of costly fertilisers and corrective products. Nevertheless, high grade soils are more expensive due to the many other competing agricultural demands for land and are thus not usually cost effective.

Most expansion of existing sugarcane crops is located on degraded and pasturelands [36]. Through intensification of cattle rearing, the cattle population of São Paulo has increased in density from 1.28 animals per hectare (2004) to 1.46 animals per hectare (2010) [37] while at the same time providing 0.88 million hectares of pasturelands for other crops, especially sugarcane.

Brazilian environmental legislation is based on the National Forestry Code and the Environmental Crimes Law. The Forest Code was first passed in 1965 and revised in 2012[2]. In general, forestry practices are directed by the (New) Forest Code (Law 12727/2012). Deforestation is connected to the "National Environmental Policy" as a whole. The Forest Code sets general rules for the protection of natural vegetation, Permanent Preservation Areas, the Legal Reserve (LR) and important biomes.

The revised Forest Code mandates rural property owners inside the Legal Amazon to set aside 50% for their LR if the state has granted more than 65% of its total area "protected status" and if a state has approved a law specifically authorising the reduction of the LR. In a permanent preservation area (APP)

2 Law 12.651, 25 May 2012. Available at http://sbcpd.org/portal/images/stories/Novo-Codigo-Floresta-Lei-12651-2012.PDF

for rivers up to 10 metres wide, the set aside area should be at least 15 metres from the riverbank to protect the so-called riparian forests. Rules have also been set for larger rivers.

As a result, sugarcane plantations as well as other crops in São Paulo must guarantee the preservation (or re-forestation) of at least a 20% forest cover of native trees. São Paulo also has special requirements in the case of environmental licensing to maintain riparian forests. The main problem is the lack of adequate enforcement mainly in other states.

3.3.2 Land competition: ethanol versus food crops

In the 1970s and 1980s ethanol caused a change in land use patterns from food crops to sugarcane. In São Paulo from 1974 to 1979 this expansion replaced food crops. Maize and rice had the biggest decline, of which the planted area reduced by 35% [38]. However, since then, the growth of sugarcane cultivation does not seem to have had any adverse impact on the area covered by food crops. The expansion in the state is confined to pasturelands [36].

Sparovek et al. [39] concluded that sugarcane expansion during the period 1996–2006, within the region that encompasses the states of São Paulo, Minas Gerais, Paraná, Goiás and Mato Grosso do Sul, resulted in the reduction of pasturelands and the number of animals, thus not promoting deforestation. Such expansion promoted greater economic growth in these areas than in those where sugarcane production areas did not increase.

Also it must be noted that half the sugarcane plantation is used to produce sugar, not energy. This means that nowadays ethanol crops utilise less than 5 million hectares (compared to 22 million hectares for soybeans and 120 million hectares for inefficient pasturelands as discussed ahead).

Besides an expansion of the sugarcane area, the increase in ethanol production in states like São Paulo, that is already a large producer, was also due to growth in overall productivity in the country – both agricultural and industrial.

Brazil has achieved a sugarcane agricultural productivity average of around 65 tonnes/hectare. In São Paulo the productivity can be as high as 100 tonnes/hectare. There has been an improvement of 33% in São Paulo since PROALCOOL started in 1975. This increase in production can be related to the development of new species and the improvement of agricultural practices. In addition, cultivation of new varieties promote more resistant, productive crops which are better adapted to diverse conditions. Such improvements have allowed the growth of sugarcane production without unnecessary land expansion.

3.4 Soil

Improvement in land management increased erosion protection, compacting and moisture losses, and appropriate fertilisation. In Brazil there are soils that have been producing sugarcane for more than 200 years with ever-increasing yields. Sugarcane cultivation in Brazil is in fact well-known for its relatively small levels of soil erosion, especially when compared to the case of soybean and corn [24].

3.5 Biodiversity

Direct impacts of sugarcane production on biodiversity are limited because new crops are established mainly in pasturelands which are degraded lands. As mentioned, these areas are far from important biomes like the Amazon Rain Forest, Cerrado, Atlantic Forest and Pantanal [30].

According to the State Secretariat for the Environment there are one million hectares of degraded riparian areas in São Paulo, of which 235,000 hectares should be returned to productive use by the sugar/ethanol sector. This example shows the interesting perspective of impacts from riparian recuperation areas on biodiversity. Considering existing legislation to protect such areas and local projects aiming to recuperate them, as are seen in São Paulo, it is expected that positive impacts on biodiversity can be achieved.

4. Social sustainability issues

Regarding the socioeconomic impacts of agribusiness, the most important analysis is related to job and income creation across a wide range of capacity building of the workforce, with the flexibility to support local characteristics using different agricultural technologies.

Brazil has labour legislation that follows International Labour Organization (ILO) rules for protection of workers. The labour unions are developed and play a key role in securing adequate employment conditions even in rural regions, such as: severance-pay (funded by employers), a 13th annual salary (equal to a month's salary), annual vacations (30 days, plus a cash bonus equal to one-third of salary), among other things.

For sugarcane, certain aspects of employment conditions are better than other rural sectors, for example, there is guarantee of employees' rights under labour laws, mainly in São Paulo for employed (formal) workers in sugarcane harvesting. There are also other issues such as labour health and safety; transparency in measurement of production; working contracts; accommodation; transport; migration; schooling, qualifications and relocation; remuneration; working hours; child labour and forced labour; organisation of unions and collective negotiations; and unemployment protection [40]. Compared to an average rate of 40% for formal jobs in Brazil, the sugarcane industry's agricultural activities now have an average rate of 72.9% (up from 53.6% in 1992), reaching 93.8% in São Paulo (in 2005), with 60.8% in the North/Northeast Region.

The formal direct jobs in the industry are now increasing in number (up by 18% from 2000 to 2002), reaching 764,000 in 2002, while jobs in other agricultural sectors decreased. Considering the workers profiles, people having studied for less than four years represent 37.6% of the workers, with 15.3% being illiterate (4% are illiterate in the Centre-South), which means that the workers in sugarcane industry are becoming more skilled and are receiving higher wages [41].

According to Neves, Trombin and Consoli [42], in 2008 the sugarcane sector accounted for 1,283,258 formal jobs, amounting to 37.5% of all agricultural activities. However, owing to the seasonality of sugarcane crops, 54% of these jobs were temporary. Nevertheless, there was a positive balance of 588,000 full-time jobs. Taking informal jobs into account, 1.43 million jobs have been generated in all. Considering that each direct job is responsible for another two indirectly, 4.29 million jobs can be associated with the sugarcane production chain.

In São Paulo, Law 11.241/2002 that established mandatory mechanised harvesting of green cane includes a programme of professional re-qualification for those rural sugarcane harvesters (temporary) who were replaced by mechanisation. Despite reduction of jobs due to phasing out of sugarcane burning, the expansion of sugarcane over the same period allowed the creation of new positions which maintained a consistent numbers of employees [41]. Workers previously employed temporarily in sugarcane harvesting were trained in other activities (permanent in some cases) such as construction, industry and drivers of mechanised harvesting machines.

In fact, the cane-ethanol sector conducts one of the world's largest training programmes for manual sugarcane cutters, their families, and members of the surrounding communities who have been replaced by mechanised harvesting through the *Renovação project* (Retraining Program for Sugar Cane Rural Workers, introduced in 2009)[3].

In Brazil, almost 75% of sugarcane land is owned by large producers. Nevertheless, there are also around 60,000 small producers in the Midwest-Southern Regions who are organised in cooperatives due to which they have substantial negotiating power. A payment system based upon the sucrose content in sugarcane has been used for a long time which has promoted significant growth in agricultural productivity.

Unlike the situation in São Paulo, where most sugarcane plantations belong to large producers, in the State of Paraná (situated in the southern region and one of the largest sugarcane producers in the country) most sugarcane producers are small and are members of cooperatives.

In the Centre-South, the income of people working in sugarcane crops is higher than those working in coffee, citrus and corn crops but lower than those working in soybean crops (which is highly mechanised and thus has more specialised jobs). In the North-Northeast, incomes of workers in sugarcane crops are higher than in coffee, rice, banana, manioc (cassava) and corn crops, equivalent to the income in citrus crops and lower than soybean crops. Payment is always based, however, on the amount of sugarcane harvested.

Sugarcane crop workers in São Paulo receive, on average, wages that are 80% higher than workers holding other agricultural jobs. Their incomes are also higher than 50% of workers in the service sector and 40% of those in industry [24].

According to Smeets [30], the Gini coefficient for the sugarcane and ethanol production sector is low as compared to the national average and to other sectors.

The Brazilian Government has signed ILO recommendations which forbid hazardous work from child labour and limit physically demanding jobs to those who are at least 18 years of age. Furthermore, Brazil has intensified inspections of working conditions in the sugarcane sector [28]. Nevertheless, inspections remain insufficient and worker rights violations have been reported in the Northeast Region and elsewhere.

A mechanism to ensure access to education for children of sugarcane workers is in place. Parents are given a stipend for school-going children who attend school. This compensation is calculated to increase ethanol costs by 4% [30]. However, even with these incentives 3% of workers in sugarcane and ethanol production sector are younger than 17 years of age.

Despite the improvements in working conditions achieved over the last decade, more progress is needed.

3 The *Renovação* project is a partnership between Unica, the Federation of Rural Workers in São Paulo State (Feraesp), the Solidaridad Foundation and supply-chain companies, with support from the Inter-American Development Bank (IADB). In the 2012/2013 season 4,350 workers have been qualified. Available at http://www.unica.com.br/noticia/1671572892036406485/projeto-renovacao-por-cento3A-mais-de-quatro-mil-trabalhadores-requalificados-em-dois-anos/ (accessed on July 5, 2013).

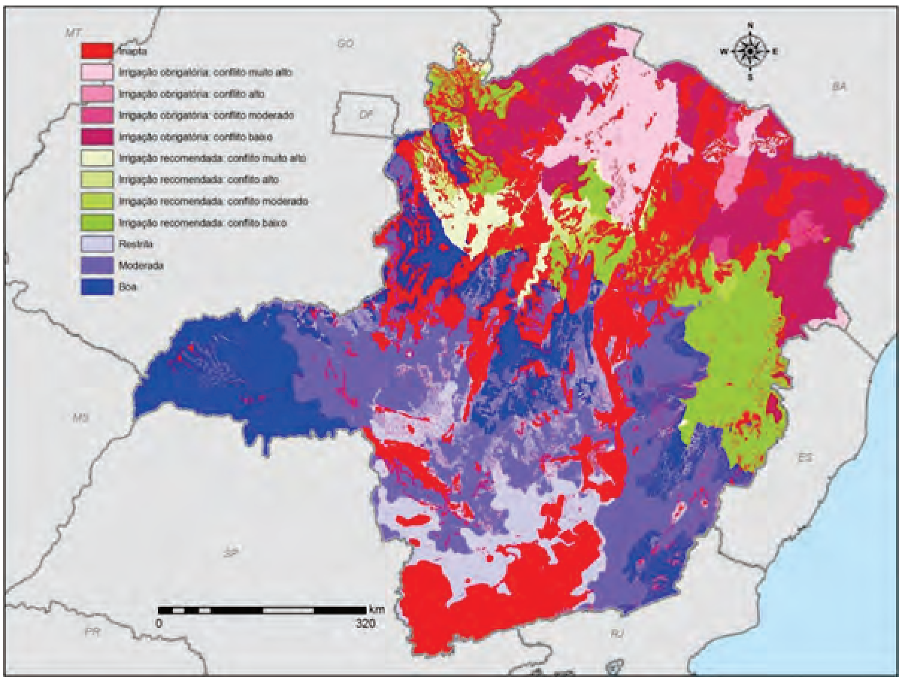
5. New policies – environmental zoning of sugarcane

As environmental zoning is a recent and important policy related to land use it is being discussed separately.

Due to the expansion of sugarcane production in recent years, concerns about the direct impacts of land use change led Federal and State Governments to adopt policies to determine which areas are suitable for cultivating sugarcane, with adequate protection for existing biomes.

The State of Minas Gerais was the pioneer in this process and launched its economic-environmental zoning in 2007 [43] (Figure 2). This is based on social, economic and environmental data that shows regional characteristics, potential and vulnerabilities. It is an orientating tool that can support policy makers and entrepreneurs from different sectors.

Figure 2. Ecological and Economic Zoning of the State of Minas Gerais



* Index of agroecological potential from blue to red
Blue area: greater possibility of agroecological development and lower natural vulnerability
Red area: low potential and high vulnerability
Source: [43]

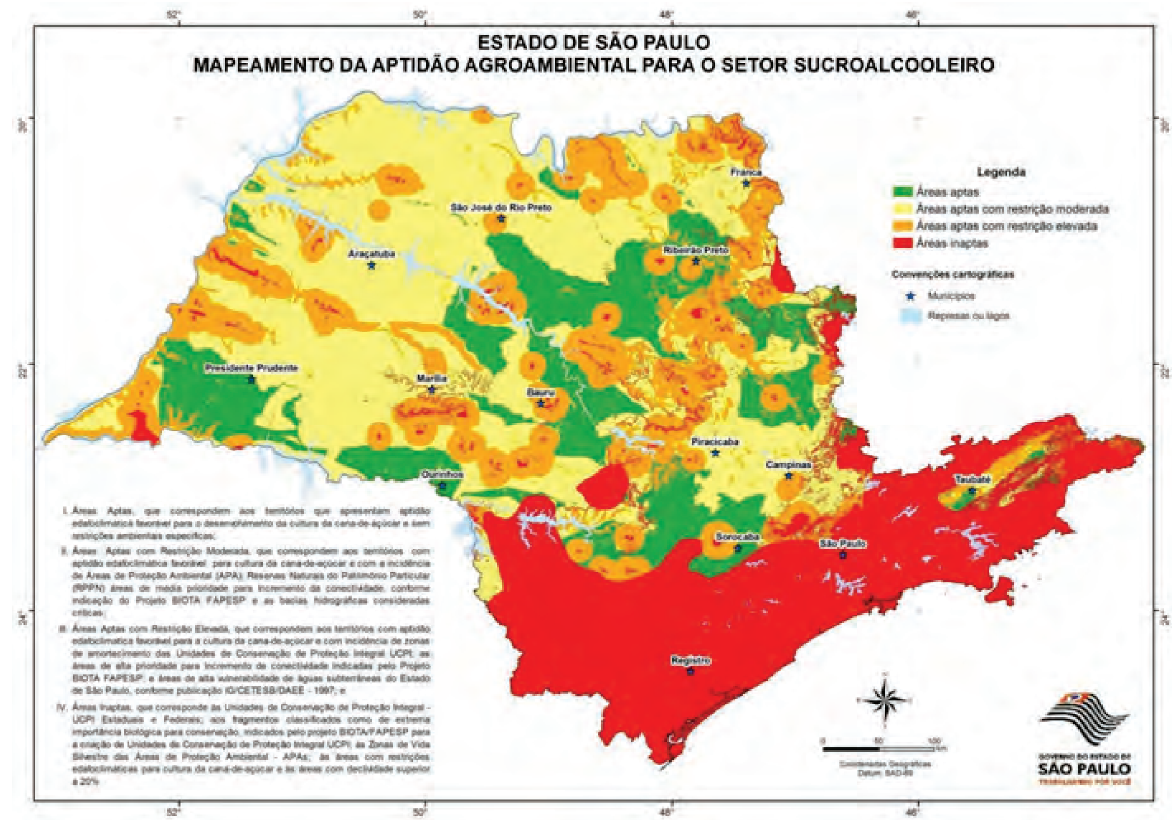
In São Paulo, agro-environmental zoning was launched in September 2008. It was conducted by the State Secretariat for the Environment in partnership with the state Secretariat for Agriculture and Food Supply, aiming to control and coordinate the agricultural extensification by the sugarcane industry, [44].

This zoning comprises information about soil and climate potential, surface water availability, underground water vulnerability, restrictions to mechanised harvesting, biodiversity protection areas, biodiversity connectivity, importance of biodiversity protection, and integral protection units. All the information has

been consolidated in thematic maps that determine the suitability of areas for sugarcane cultivation within the state.

Resolution SMA 88/ 2008 that defines parameters and guidelines for environmental licensing of sugarcane facilities has been based on the agro-environmental zoning information. For example, applications for permits in the red zone of the map (Figure 3) are not even accepted. Each area (colours) of the map has specific requirements to be accomplished by the entrepreneurs. The parameters established in the Resolution must be accomplished by existing mills and new ones.

Figure 3. Final sugarcane agro-environmental zoning in São Paulo



* Green: authorised areas
Yellow and orange: authorised areas with restrictions
Red: restricted areas
Source: [44]

The text stipulates a set of measures to be followed regarding the environment and also anticipates legal deadlines for the elimination of sugarcane harvest burning and stopping of burning practices immediately in sugarcane fields located in expansion areas as already mentioned. In addition, the Protocol targets the protection and recovery of riparian forests and water springs located within sugarcane farms; controls erosion and the content of water runoff; implements water conservation plans; stipulates the proper management of agrochemicals; and encourages reductions in air pollution and solid wastes from industrial processes.

The Federal Government launched two national agro-ecological zonings: for sugarcane in September 2009 [45] and for oil palm in 2010 [46]. The federal zoning was led by Embrapa Solos, involving dozens of institutions and researchers of agricultural and environmental issues. In this process maps were produced showing soils, climate and rainfall, and topography.

Agro-ecological zoning is an important policy tool and has innovated by taking into account environmental, economic and social aspects while providing solutions for challenges in sustainable expansion, mainly that of sugarcane production and investments in sugar and ethanol sectors. This regulation also gives guidance to credit policies and is used by public banks for financing production.

The land was classified, on a scale (1:250,000). It shows areas of highest yield potential, based on minimum resource input. It takes into account environmental regulations and others areas which should be preserved and it seeks to reduce competition with areas devoted to food production.

Areas where sugarcane crop expansion could take place were identified as shown in Figure 4. Figure 4 indicates such areas in green color). It forbids sugarcane cultivation in 92.5% of national territory. It also identified 64 million hectares [45] that comply with environmental and productivity requirements, mainly from intensification of cattle raising, which is currently very inefficient (less than one head/ha).

Figure 4. Agro-ecological sugarcane zoning (ZAE)

*Green: authorised areas

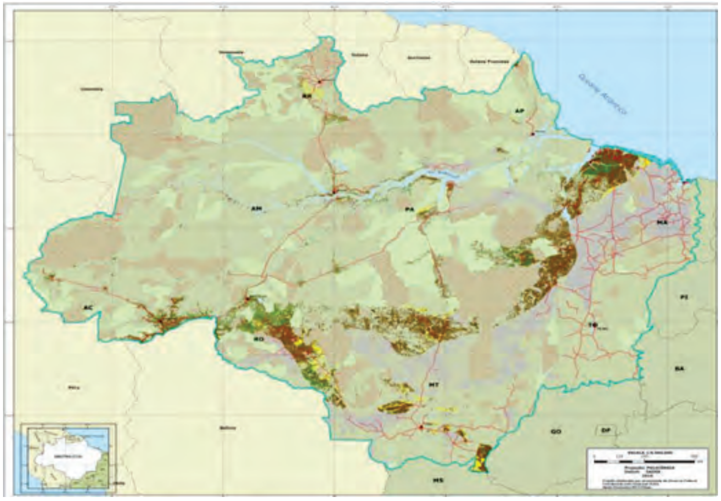
Source: [45]

The agro-ecological zoning of sugarcane was an important and innovative initiative because it not only considered environmental aspects but technological criteria and productivity as well. The guidelines set were: exclusion of areas with native vegetation and prohibiting the removal of native vegetation for expansion of sugarcane cultivation; exclusion of areas for cultivation in the Amazon and Pantanal biomes,

and in the Upper Paraguay River Basin; identification of areas with agricultural potential with minimal need of irrigation for sugarcane production; identification of areas with slope below 12%, which allows the use of machinery for harvesting; ensuring that expansion of sugarcane production does not cause any risk to food production or food security; and prioritisation to degraded areas or pastures suitable for sugarcane production [45].

Similar to sugarcane zoning, Embrapa also developed zoning for palm tree cultivation, which resulted in 300,000 km^2 becoming available for the same, free from undesirable impacts (Figure 5) [46].

Figure 5. Agro-ecological palm oil zoning [46]



*Green: high potential for palm trees production
Brown: medium potential
Yellow: low potential
Source: [46]

States like Mato Grosso do Sul have also launched their own environmental economic zoning, not only for sugarcane but also for eucalyptus plantations grown for pulp and charcoal production, which are mainly allowed in degraded areas, previously used for pastures.

6. Conclusion

Agro-ecological zoning is expected to be the licensing baseline for allowing future expansion of energy crops by environmental agencies in Brazil as is already happening in São Paulo.

The Brazilian experience with agro-ecological zoning provides valuable lessons to be shared with other developing countries, mainly in Africa (especially Sub-Saharan countries) and Asia. Competition between food and fuel production, and the deforestation of fragile native biomes can be avoided through the implementation and enforcement of policies based upon zoning tools, coupled with incentives (e.g., certification) to maintain overall sustainability of the aspects in biofuels production chain.

This experience appears to hold good promise for South-South experiential lessons and knowledge transfer. This is evident from Brazil's collaboration with the Dominican Republic, Haiti, El Salvador, Guatemala and Senegal[4,5].

To achieve the implementation of such policies, adequate capacity building at national, regional and local level is required (related to technical, environmental and economic dimensions) together with the dissemination of lessons learned.

The Brazilian experience also shows the value of complementing command and control-type policies (such as zoning laws) with the use of economic incentives. Access to soft loans from public development banks can also be made conditional upon meeting zoning criteria. Funding from international agencies can play a similar role, for example the experience of the Cogen for Africa Project funded by GEF (the Global Environmental Facility) through UNEP-Nairobi and by the AfDB (African Development Bank) [6].

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Jatropha farm in Senegal. Photo credit: Flickr

3. Analysis of national Jatropha biodiesel programme in Senegal

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Review

Analysis of national Jatropha biodiesel programme in Senegal

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1. Introduction

The seeming potential of *Jatropha curcas L* to help in energy security, agricultural product diversification and overall development of rural communities in Senegal, has been of interest to government and donor organizations. Additionally, interest has been shown by industrial investors who are primarily concerned with profits rather than development assistance. Research on the Jatropha plant, its potential benefits, risks as well as the hype linked with it is ongoing. The plant could be found in different parts of the world, including several locations in West Africa, where its utilizations had been limited to medicinal purposes, land and road fencing. A number of small-scale initiatives in West Africa are on-going particularly those in rural areas that have been motivated by issues of local development and women's empowerment, with the utilization of the plant for oil and soap production [1]. Jatropha is a tough, drought resistant plant, possessing toxic chemicals that are unpalatable to livestock [2-4]. It has a rather short gestation period and produce seeds of relatively high oil content ranging between 27–40% (w/w) [5-12]. Detailed physico-chemical properties of Jatropha has been studied and reported [8,13-14]. Jatropha similar to other vegetative biodiesel has been heralded as a suitable alternative to petroleum diesel but without sulphur and potential environmental damaging effect from the sulphuric acid that occurs during combustion of petroleum diesel [15-18]. Similar to most plants, Jatropha requires good moisture, temperature and soil nutrients in order to produce high fruit yields. However, the plant was heralded as an excellent high yielding oil crop even under marginal conditions and possessing considerable carbon dioxide mitigation potential, hence its hype in the early 2000s. During the hype, for example, India and China introduced mandatory biodiesel (primarily Jatropha) blending targets of 30% and 15% respectively by the year 2020 using marginal lands. Similarly, other countries in Asia, Africa and Latin America follow suit and did

cultivate Jatropha on large tracts of marginal land only to be disappointed with very low yields. In India, it is reported that 85% of Jatropha farmers have abandoned their operations as a result of the meagre yields [19]. Epigenetic characteristics, however, of Jatropha enables the plant to survive and bear fruits even in drought conditions but this has a consequent lowered seed production that is not desired by investors [20]. Most affected in the global hype were poor farmers who had shifted from food cultivation to the apparently lucrative Jatropha as well as those that were displaced from their farmlands by large Jatropha investment companies. It is important therefore that due diligence, informed by empirical scientific findings be exercised prior to any large scale Jatropha cultivation [20]. Additionally, extensive stakeholders' consultations with all relevant parties and sectors need to be done before any commercial scale Jatropha activities.

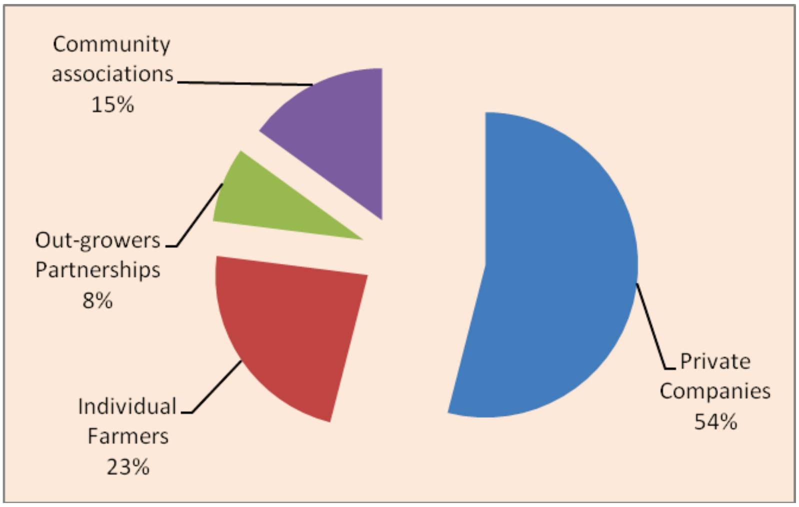
Senegal is a country in West Africa with a total land mass of 19.7 million ha, of which 3.8 million are arable (19% of the total area of the country), 9.6 million are not arable (49%), and 6.3 million (32%) are protected areas. Despite the availability of sufficient arable land, Senegal imports food crops including staple cereals therefore it is important that land for biodiesel production be carefully selected so as not to compete with food production. It is imperative, that large scale Jatropha activities be carefully considered on a holistic perspective (as will be explained later in this study) otherwise it could present significant socio-economic challenges (including food security) and environment threats.

Due primarily to high import bills on petroleum diesel by Senegal, there has been urgent need by the government to identify alternative options to offset petroleum diesel demand from year 2012. Biodiesel from Jatropha is considered by the government as the suitable alternative to offset import bills from petroleum diesel without due consideration to other potential biodiesel crop options (which will be explained later). The government thereby established the National Jatropha Programme (NJP) to offset Senegal's reliance of crude petroleum. The decision on the choice of selected biofuel crop could have benefitted from empirical scientific analysis, examining a number of competing alternatives; however, this was not the case for the NJP. Senegal therefore launched the NJP in 2006 with the ultimate goal of achieving biodiesel production from Jatropha to provide 100% of the country's diesel needs starting in 2012. The NJP sought to convert 321,000 ha for Jatropha cultivation, with an average of 1000 ha planted in every rural locality in Senegal. Overall, it is expected that the 321,000 ha would be available and utilized resulting in estimated production of approximately 1 billion litres of Jatropha biodiesel to completely offset petroleum diesel starting in year 2012. This development regarding the NJP has led to significant increase in Jatropha activities with several plantations primarily by private companies being established in the country over a short period of time (Figures 1&2) without much due diligence to potential risks. Majority of these Jatropha activities (approximately 88% of all Jatropha cultivations) are large scale plantations typically 50ha or more (Figure 2). However, as earlier indicated, it is needful to carefully investigate the realistic potential benefits as well as associated threats prior to any large scale Jatropha activity, hence the rationale for this study.

The objectives of this paper were to address the following research questions:

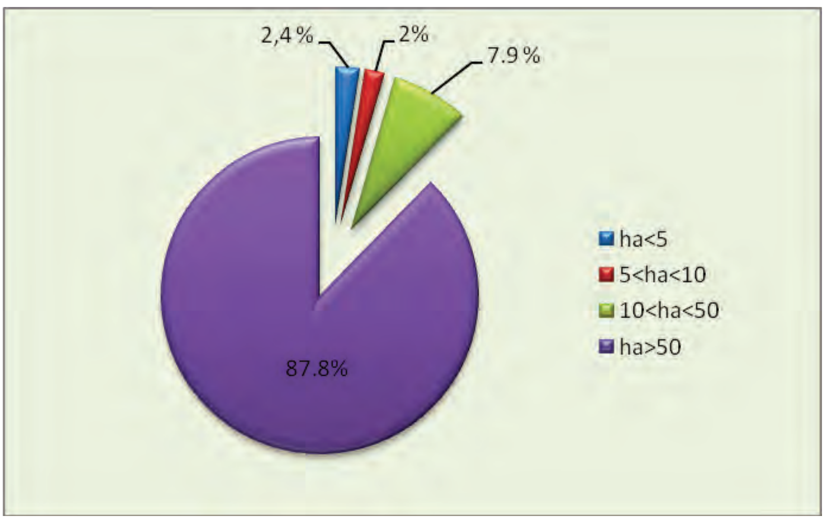
- how the National Jatropha Programme evolved?
- what are gaps in the National Jatropha Programme?
- how much of the biodiesel production should rely on Jatropha and other crops using agro-environmental mapping?

The paper then proffers policy options for sustained, environmentally benign biodiesel production.



Source: [21].

Figure 1. Distribution of key players in Jatropha cultivation in Senegal.



Source: [21].

Figure 2. Distribution of Jatropha curcas cultivated areas.

2. Methodology and structure

In terms of method, this paper utilized a combination of desktop study and geographical information system (GIS). The geographical information system Arc-GIS 9.3 was used for information and data processing regarding the agro-environmental mapping. This software provided maps based on satellite images and topographical background.

The rest of the paper is structured in the following sequence along the lines of the study's objectives. It first explores the evolution of the NJP by reviewing previous policies in relation to relevant sectors mainly the agricultural and energy sectors. It subsequently investigates gaps in the NJP and provide recommendations on how to redress loopholes in the NJP. This is followed by estimations on the biodiesel potential from *Jatropha curcas* and other energy crops (such as Pongamia, sunflower, cotton) that could be sustainably produced based on information from agro-environmental

mapping. Findings from the agro-environmental mapping were then compared with the government's estimates (which were primarily based on national petroleum diesel demand) for policy options recommendation and finally, conclusions.

3. Evolution of the National Jatropha Programme: review of relevant related policies (past and existing)

Several economic sectors such as agriculture, energy, land, water are linked to Jatropha as well as rural development issues including healthcare, education, food security and environment. This section focuses on policy issues of two key sectors that is agricultural and energy and how they have contributed to the establishment of the National Jatropha Programme. (Institutional arrangements on the NJP and the potential for effective streamlining such institutional issues can be found in the supplementary material).

3.1. Agricultural policy

Agriculture has an important place in the economic and social life of Senegal. This sector contributes significantly to the country's gross domestic product GDP amounting to approximately 15.2% in 2012 and involves a large proportion (>60%) of the workforce. In addition, agriculture is the primary basis for agro-industrial and craft development. Population growth and increasing urbanisation is a concern for agricultural production and food security in the country. Achieving food securing and reducing poverty are key to the Government's agricultural policies.

Policy in Senegal's agricultural sector is based on the Guidance Law on Agriculture[i] adopted by the National Assembly on May 25, 2004. This law defines the nation's agricultural and rural developmental policies for the next 20 years. Excerpts of specific goals in this law with relevance to biodiesel include:

- the formal recognition of professions and professional organisations in agriculture;
- the social protection and the definition of legal statuses for farm and land use;
- the assessment of food security and water control;
- the diversification of production, including energy crops, market regulation, and the development of infrastructure and public services in rural areas;
- the promotion of social equity in rural areas and protection against the natural calamities and hazards related to agricultural, forestry, and livestock activities;
- the development of agricultural information and education, training, and capacity-building for rural organisations; and
- the development and provision of sustainable financing for agricultural services.

To implement this national policy, the government initiated development programmes such as "Return to Agriculture" (REVA 2006; please refer to Box 1, in the supplementary material), which helped established the country's Biofuels Programme, and the Great Agricultural Offensive for Food and Abundance Programme (GOANA; see Box 2 in the supplementary material).

Relevant to Jatropha, the existing agricultural policies (i.e. REVA and GOANA—supplementary materials) seem on the one hand to have provisions to protect farmers and their lands, prioritizing food production and avoiding other competing activities with food production while on the other hand encouraging agricultural products diversification with specific mention of energy crops.

[i] Loi d'Orientation Agro-sylvo-pastorale

Implementation and enforcement however, of the provisions in the policies seem weak but there exist good opportunities for strengthening the NJP.

3.2. Energy policy

The Government of Senegal allocates almost half of the country's export-derived revenue to import petroleum products. Energy imports increased from 184 billion CFA Franc[ii] in 2000 to 600 billion CFA Franc in 2008 [2].

3.2.1. Policy paper for energy sector development

To increase energy independence, reduce reliance on thermal energy sources, and address the shortfall in energy services, the government has adopted a new energy policy that includes increased development and use of renewable energies including biodiesel. The target of the energy policy is to increase the share of renewable energy and biofuel (including biodiesel) by up to 15% by 2020. This was established in the Policy Paper for Energy Sector Development (LPDSE), the most recent version was submitted in September 2012. Objectives of the LPDSE that pertains to biodiesel includes: i) to develop and mobilise local energy resources such as renewable energy and biofuels ; ii) to diversify the energy mix through the use of mineral coal and renewable energy, especially hydropower; iii) to increase access to modern energy services; iii) to improve energy efficiency and demand-side management; and iv) to promote good governance through the participation of the private sector and the restructuring of the power sector. The LPDSE provides modalities for operationalization of the Renewable Energy Agency and the development of incentives for renewable energy.

3.2.2. Renewable energy and biofuel laws

Rudimentary analysis suggests a strong political support for biodiesel in Senegal. For example, the Renewable Energy Directorate, established the Renewable Energy Guidance Law (Law 2010-21) that was enacted in December 2010. Subsequently, two implementing decrees i.e. by-laws 2011-13 and 2011-14, were passed in December 2011. Furthermore, the government enacted the Law for Biofuels (2010) and initiated its implementation by decree (2011). This guidance law is designed to create the conditions required for biodiesel and other biofuel production for the local market. The law include incentives to promote biofuels (including biodiesel) via the following support systems that: i) all tools, seeds, and seedlings used for biofuel production are exempt from the value added tax and customs duties; ii) revenues from biofuel farming are tax exempt for up to 5 years; iii) entrepreneurs interested in biofuel crop production benefit from the state's support in accessing seeds, seedlings, fertilisers, equipment aimed at improving biofuel productivity; and iv) specific by-laws are set to provide attractive biofuels prices. The next sub-section provides more information on the biofuel programme that embodies the NJP.

3.2.3. Overview of the National Jatropha Programme: its design

The Biofuels Programme includes the NJP biodiesel and ethanol production using the molasses generated from the sugarcane industry) [5]. However, the focus of this paper was on biodiesel

[ii] 1 Euro = 655.9 CFA Franc, which is the currency of eight states in West Africa, the Financial Community of Africa (Communauté Financière d'Afrique)

components and the NJP. Senegal's NJP has several objectives involving agriculture, energy, rural development as well as aspects of economy and trade, such as:

- the reduction of household energy expenditures;
- energy source diversification;
- the reduction of the country's oil expenditures for energy provision;
- the promotion of energy independence and diesel self-sufficiency beginning in 2012;
- the production of ethanol from crops such as sugarcane;
- the production of electricity from power plants that operate using Jatropha crude oil;
- the creation of (approximately 100,000) jobs in the agricultural sector;
- crop diversification;
- agriculture modernisation;
- the creation of an attractive rural environment;
- improving the trade balance; and
- the reduction of poverty and the minimisation of the disparity between rural and urban areas.

Biodiesel aspect of Senegal's Biofuel Programme was designed to be implemented in three phases as follows:

- Phase 1. Production of Jatropha seeds (2007–2012);
- Phase 2. Processing Jatropha seeds into oil; and
- Phase 3. Biodiesel distribution.

In the NJP seeds, seedlings, and technical support would be provided to local communities. Additionally, it provides support for investors regarding administrative, informative, and counselling functions on industrial scale biodiesel production. The NJP recommends the use of oil presses or light expeller units for processing on-farm or community biodiesel production. Biodiesel production from the NJP is planned to be sold either to the state or to private market organisations at a price fixed by state-partners agreement.

According to the NJP, the Ministry of Agriculture is responsible for implementing seed production at a national level. This ministry also leads a national technical committee that consists of representatives from the ministry, farmers' organisations, rural organisations, professional agricultural organisations, elected officials, deputy governors for development, non-governmental organizations (NGOs), representatives of youth and women's village associations. Regarding the NJP implementation, Senegal's Institute for Agricultural Research (ISRA) is in charge of the technical coordination. Additionally, a national programme supervisor represented by the president of the National Rural Councillors Association in Senegal (ANCS) is responsible for awareness-raising activities, liaising with rural authorities and rural producers, and returning with the rural communities' requirements to the programme's national coordinators.

In addition to the NJP's objectives, important conditions and safeguards have been set as the basis for implementation, including

- at least 51% of the capital for any biodiesel industry establishment should be Senegalese;
- guaranteed prices for farmer production to ensure massive refunds and secure farmer interest;
- state-partner sales agreements that include secured prices for biodiesel sales to the state or appropriate institutions;
- assistance to farmers through the provision of agricultural inputs and technical expertise by promoters of the programme;

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- land tenure based on the protection of national patrimony (i.e., the land remains the property of the state or local community owners and is not subject for sale or lease); and
- oil production and processing to be conducted in the country.

The following sections summarises the potential for Jatropha plantations in terms of land and water resources; moreover, it considers the critical issue of Jatropha competition with food security, which affects biodiversity and conservation.

4. Gaps in the National Jatropha programme

Senegal launched the National Jatropha Programme (NJP) in 2006 with the ultimate goal of achieving diesel production from Jatropha that would serve 100% of the country's diesel needs starting in 2012. The NJP sought to convert 321,000 ha for Jatropha cultivation, with an average of 1000 ha planted in each rural locality. The estimated 321,000 ha area according to Senegalese government would correspond to the production of approximately 1 billion litres of biodiesel thereby ensuring independence from diesel imports. This was to be utilized as an alternative to petroleum diesel starting from year 2012. It is worth noting that the implementation of the National Jatropha Project (NJP) only commenced in 2007–2008 and the achievement within the first years were very limited. The reasons for the limited achievements on the ground (against the planned targets in NJP) predominantly include institutional and regulatory challenges, gaps in the strategy and the absence of clearer action plans.

Under the NJP, 5293 ha of Jatropha were planted during 2007–2008; with the total cultivated area reaching only 10,000 ha by end of 2011. This represents significant delays in the progress of meeting the NJP targets and the reasons being primarily due to apparent lack of ownership by rural communities but also the other factors already mentioned including institutional, strategy and the absence of clearer action plans. In spite of the delayed progress, the NJP did not completely stop in 2011 but it is ongoing.

The government enacted the Biofuels Law in 2010, but the process of endorsing the related by-laws has not yet been finalised. The Biofuel Law provides appropriate guidelines for the promotion and development of biofuels in Senegal. However, the implementation of the Biofuels Law (which includes Jatropha biodiesel) has lagged behind the demands of private investors for land upon which to grow Jatropha. There was no commencement of liquid biofuel bioconversion from Jatropha seeds in contrast to what was stipulated in the NJP.

Additionally (as earlier noted), the Directorate of Biofuels has been under the supervision of several ministries since the launch of the Biofuel Programme in 2007. From June 2010 to April 2012, the Ministry of Renewable Energy conducted and supervised activities pertaining to regulatory aspects of Jatropha biodiesel. The institutional framework in Senegal for coordinating biofuel activities has been rather unstable with several ministries having taken on the responsibility of policy development and regulating the biodiesel activity, which has caused delays in the implementation of the NJP. Detailed analysis on market and value chain analysis are yet to be undertaken. Notably absent from the NJP are allocations of the produced Jatropha biofuel to the various sectors of the domestic economy as well as the portion for export.

Notwithstanding these institutional, regulatory and implementation challenges, several Jatropha cultivation by private initiatives have been launched including small- to large-scale Jatropha plantations. However, further Jatropha development in Senegal under the NJP would require additional scientific information and experience with its cultivation as well as knowledge of redressing practical barriers and helping to shape existing policies and regulations. These aspects are prerequisites for the successful large-scale deployment of Jatropha biodiesel production in Senegal.

5. Land suitability regarding which biodiesel crop type to cultivate?

The Environnement et Développement du Tiers Monde (ENDA-TM) with the support of United National Environment Programme (UNEP) conducted an agro-environmental mapping of the potential for biofuel (including biodiesel) production in Senegal. This mapping exercise was done in collaboration with the Senegalese Institute for Agricultural Research (ISRA) and the National Institute of Pedology (INP) [22]. A key objective of the mapping was to provide a comprehensive zoning of potential lands and assess the areas suitable for which type of biodiesel crop. This mapping took into account major selection criteria including the appropriateness of the crop vis-à-vis eco-geographical conditions in the country; the biochemical quality of extracted oils; socioeconomic advantages including intercropping with suitable food crops, the avoidance of competition with food production, water, biodiversity conservation, increased contributions to local economies based on generated by-products, and social acceptability; and political interests.

This mapping process considered the following major crops: Jatropha, Pongamia, sunflower, and cotton. These crops were selected for their capacity to adapt to the ecological and geographical conditions in Senegal, for being socially acceptable to the communities, and for not generating competition for land and water with staple crops. Other crops (e.g. castor, palm, soy, maize, and cashews) were excluded for various reasons including the lack of significant commercial exploration of their potential for large-scale plantations or verified experimentations. Peanut, which is a cash crop in Senegal, was excluded from the mapping process because its use for biodiesel source is likely to conflict with current utilization for food.

The four broad criteria utilized for biodiesel crop selection include:

i) The crop should have agronomic features that match the eco-geographic conditions of the country’s land (e.g., required temperature, rain, and soil quality).
ii) The characteristics and quality of the extracted oil should be of good standards for local use without additional treatment.
iii) Crop selection should help provide socioeconomic advantages including intercropping with suitable food crops, the avoidance of competition with food production, water, biodiversity conservation, increased contributions to local economies based on generated by-products, and social acceptability.
iv) Prioritization of crop development should not be in conflict with government priorities. (As indicated earlier it is important to realise that the government highly prioritizes Jatropha).

The primary agro-environmental data considered in the mapping process based on some of the above listed key criteria are presented in Table 1.

Table 1. Jatropha’s agro-environmental data.

Parameters	Jatropha
Ecological requirements	
Water/rain required	300 to 1200 mm
Temperature	20 °C to 42 °C
Altitude	0 to 1500 m
Type of land	Sandy, degraded, saline soils (NB. compacted lands hinder the plant growth).
Land pH	5 to 8
Density of plantation	1500 to 2500 plants/ha (in monoculture)
Fertiliser	Manure or plantation compost

Toxicity	Average
Crop yield	1.75 to 9.75 tonnes/ha/year (Can reach 12 tonnes/ha/year with irrigation)
Biodiesel Characteristics	27% to 40%
Oil content	600 to 1800 litres/ha
Oil yield	Low viscosity
Oil quality	
By-products	Jatropha cake
Other uses of the by-products	Soap, fertiliser, pesticides
Competition with food crops	Monoculture/intercropping
Intercropping with food crops	Associated with grain or vegetable crops (large planting distance)
Type of plant	Shrub with long life expectancy

Source: [22] based on information provided by ISRA.

The mapping process has preliminarily zoned the potential land to be used for cultivating the selected biodiesel crops based on the exclusion of certain areas (e.g., natural parks, classified forests, fauna reserves, shooting sites, grazing land, biodiversity zones, and marine protected areas (refer to Map 2 and 3 in the supplementary material).

With regard to land tenure, clarification is required to assess the extent to which the NJP could be implemented across all rural communities of Senegal as the NJP suggests that every rural locality should be able to dedicate 1000 ha to Jatropha plantation.

Findings from the agro-environmental mapping revealed that land suitability for Jatropha plantations is not found in all rural localities but only in some areas. Therefore, the implementation of the NJP according to its planned objectives of total 321,000 ha (distributed throughout 1000 rural communities in the country) is experiencing challenges in terms of availability of 1000 ha of suitable land in each rural locality in Senegal. Furthermore, the NJP is focused on the production/agriculture aspects; however, a gap remains in terms of the processing, distribution, and end use of biofuels. The mapping process also revealed that Jatropha initiatives in the NJP have been planned to spread out across a wide variety of zones in Senegal even in pristine and protected ecosystems (which should not be if agro-environmental mapping had been undertaken in the NJP).

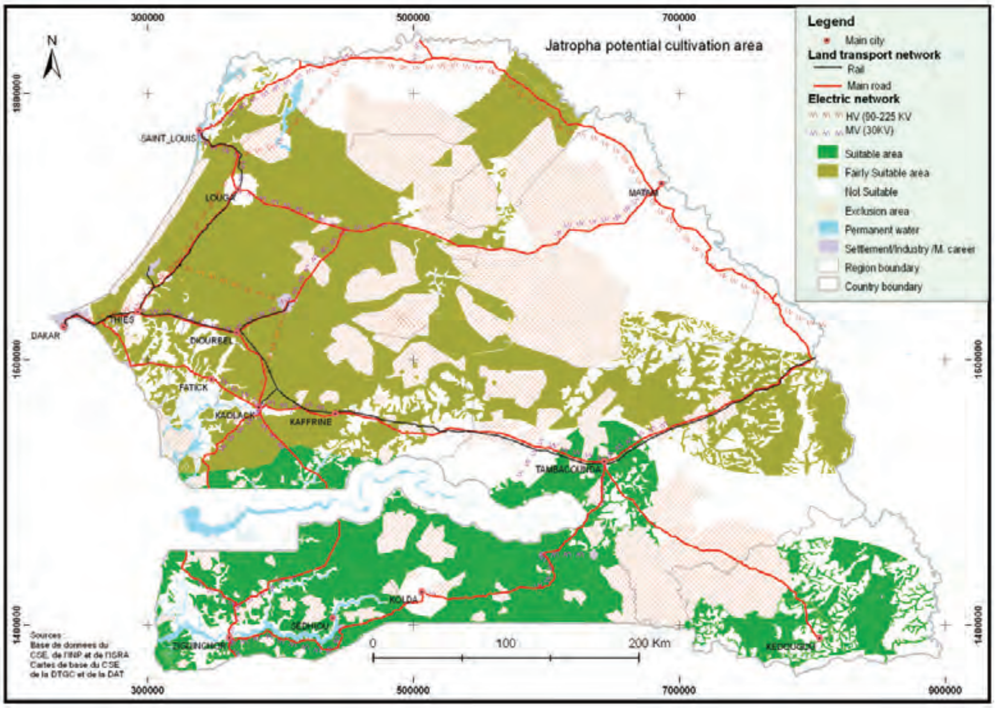
The agro-environmental mapping process undertaken in this study did reveal interesting findings with regards to land tenure, food security and water requirements. Findings show that the proposed distribution of 1000 ha of Jatropha in each of the 321 rural administrative zones leads to some land-tenure problems. For example, the mapping revealed that several rural localities in the north, northeast, and central-east are not suitable and cannot host the 1000 ha needed for an additional energy crop without land expropriation or conversion from food crops, especially in cases of large-scale production systems. Conversely, food security might be compromised by attractive biodiesel prices, thereby driving farmers to switch from traditional food crops to Jatropha. Therefore, it could be a recommended option that the NJP approach and its position concerning land tenure possibly be carefully re-examined. With regard to water requirements, young Jatropha shrubs must be watered during the initial years after planting if they are to survive in areas where the rainfall is less than 700 mm per year. Therefore, water difficulties might occur among rural communities located within these isohyets. In these agricultural and grazing areas, conflicts over water distribution should be expected if Jatropha is planted at large commercial scale as stipulated in NJP where irrigation is inevitable.

The strategic decision to deploy Jatropha on a large scale for energy proposes (as contained in the NJP) was made without assessing the potential for Jatropha production in terms of farming and climate

suitability or socioeconomic sustainability. The issues that could have been appraised prior to rolling out the NJP could have included the use of appropriate scientific tools and criteria that analyzes for example, the availability and capacity of land to produce Jatropha, the social acceptability of land use for Jatropha, crop specifications in terms of water and land requirements, temperature, yield, the quality of the crop for generating fuel, competition with food crops, and knowledge of planting practices.

The agro-environmental mapping process undertaken in this study determined the areas suitable for Jatropha cultivation and categorizes the land into the following:

- *Highly Suitable*. This category refers to areas with biophysical features (i.e., land types), environmental (e.g., temperature and rainfall), and socioeconomic variables (such as avoidance of competition with food, biodiversity conservation, water requirement etc) that allow for sustainable crop production. Highly suitable land is located in the south and southeast regions of Senegal and (to a limited extent) in the west and central regions (Map 1). Highly suitable zones coincidentally are located in the regions of the country that have the most significant rainfall (700 to 1200 mm).
- *Fairly Suitable*. This category refers to areas that partially meet the biophysical features and socioeconomic elements (such as possible competition with food, biodiversity conservation, water requirement) that allow for sustainable crop production. Fairly suitable land is located in the central, west, and northwest regions, with scattered locations in the northwest region of the country (Map 1). Fairly suitable land (400 to 600 mm of rainfall) is more extensive than highly suitable land.
- *Not Suitable*. This category refers to areas that are not recommended for biofuel plantations because they do not comply with the identified criteria related to the land type, environment, or socioeconomic variables (such as competition with food, biodiversity conservation, water requirement. Not suitable areas are located in the north and east regions, with scattered locations along the southeast and central regions as well as along the coast. Not suitable land generally has high salinity (Map 1).



Source: [22].

Map 1. Land suitability for Jatropha plantations in Senegal (year 2010).

The potential and suitability of other biodiesel options in Senegal.

In addition to Jatropha, the suitability of other bioenergy crops namely, sunflower, Pongamia and cotton were also assessed. The potential benefits of ensuring that all biodiesel crops meet environmental and socio-economic criteria and are cultivated in zones that have been demarcated via agro-environmental mapping are humongous. It provides basic minimum requirements of properly undertaking biodiesel activities that are socially acceptable and environmentally benign. Even though the government's NJP plan to cultivate 1000 ha in each of the 320 communities was not possible due simply to the right eco-geographical conditions or the lack of it in each community, agro-environmental mapping findings show Jatropha has the largest suitability of land areas. The suitability of land identified via agro-environmental mapping is twenty-seven (27) times more in comparison to original estimations in the government's NJP (Table 2). Findings from Pongamia and sunflower show a total of 6,796,000 ha and 5,298,900 ha respectively, regarding land suitability areas for biodiesel cultivation (Table 2). Total land availability for cotton seems to be the least and amounted to 29,512 ha. Rather than focusing all national biodiesel interest and policy solely on Jatropha, complimentary biodiesel crop options such as Pongamia and sunflower, could also be explored and utilized.

The *highly suitable* land area for Jatropha planted as single major crop is estimated to be 2,535,700 ha, although an additional intercropping of 614,500 ha with other food crops is available (Table 2).

The area of *fairly suitable* land is estimated to be approximately 2,860,200 ha, of which 2,751,600 ha can be added by intercropping Jatropha with suitable food crops (Table 2). Analysis revealed that several private initiatives have been implemented without a deep knowledge of the suitability of the land for Jatropha plantations. The agro-environmental mapping shows that the projects implemented in the south and southeast areas are located in *highly suitable* land areas for Jatropha, whereas the projects undertaken in the central areas are situated in *fairly suitable* land areas which potentially compete with land dedicated for food crop plantations (Map 1).

6. Policy considerations

A timely, comprehensive implementation strategy with clear principles and indicators along the Jatropha biodiesel value chain should be set in place. Even though, Senegal developed a Law for Biofuels that help promote NJP, however, such comprehensive strategy is yet to be established. The strategy should include blending mandate, estimated in-country utilization amount as well as exportation. Guiding strategies should include principles for implementing local partnerships as well as farmer involvement, rights, and land tenure after considering social, economic, and environmental sustainability to ensure mutually rewarding investments and generate employment [23-25]. The guidelines regarding the best practices for harvesting, processing, and marketing biodiesel products need to be developed. Such strategy could complement already determined safeguards stipulated in the NJP including guaranteed prices for farmers, secured prices for biodiesel sales, the provision of agricultural inputs and technical expertise to farmers, the prohibition of land transfers or leases, and in-country processing.

The strategic harmonisation of sectoral policies is required to ensure the successful implementation of Jatropha plans. This is because several ministries and institutions operating in different sectors are involved in the development of Jatropha biodiesel. Additionally, since the announcement of a governmental programme to develop Jatropha at a large scale, several ministries have taken on the responsibility of hosting the office/department in charge of the biodiesel policy and regulation. This situation has delayed the implementation of the programme; therefore, the implementation of a stable institutional framework is recommended to ensure the sustained supervision of the biodiesel sector and the revitalisation of the NJP. This implementation should be performed in consultation with all relevant government departments [25]. One possible option is the establishment of a separate and semi-autonomous regulatory authority to coordinate, monitor and regulate the sub-sector.

Table 2. Findings on suitability of land area for different biodiesel crop options (monocropping and intercropping) based on agro-environmental mapping.

Crop	*Jatropha* (monocropping) (ha)	*Jatropha* (intercropping) (ha)	*Jatropha* (total) (ha)	Sunflower (monocropping) (ha)	*Sunflower* (inter-cropping) (ha)	*Sunflower* (total) (ha)	Pongamia (monocropping) (ha)	Pongamia (intercropping) (ha	Pongamia (total) (ha)	Cotton seed (monocropping) (ha)	Cotton seed (intercropping) (ha)	Cotton (total) (ha)
Highly suitable	2535700	614500	3150200	419600	1705700	2125300	1050500	2204200	3254700	6885	12377	19262
Fairly suitable	2860200	2751600	5611800	2094300	1079300	3173600	2034200	1507100	3541300	4514	5736	10250
Total	5395900	3366100	8762000	2513900	2785000	5298900	3084700	3711300	6796000	11399	18113	29512

Source: Authors modifications based on [22].

*The amount of hectares indicated for jatropha, sunflower, pongamia and cotton are exclusive and not inclusive

.

Coordination of activities at the local level between the NJP agencies and private initiatives is highly recommended. This is due to the fact that the investors and farmers involved in private initiatives do not have sufficient knowledge of the agro-environmental potential of the land they selected for Jatropha plantations. This reveals a possible need of decision-making protocols and regulations for the land allocated for energy crop plantations. Overcoming the coordination challenge, would help improve the local management and marketing of Jatropha. Additionally, strategic cooperation among biofuel experts, farmers, agronomists, environmentalists, energy specialists, relevant government agencies and investors is required [25]. It is noteworthy that significant co-benefits (in addition to biofuels) such as biofertilizers from seed cake also provide revenue and employment for communities [26-27].

Incentives to encourage the participation of local entrepreneurs and farmer associations as business partners should be developed. Investment in processing facilities (refineries) should be promoted, possibly through public private partnerships and frequent involvements with foreign investments. Proper assessment of the true viability and competitiveness of Jatropha must be undertaken along with an assessment of the need for incentives such as tax holidays and levy rebates on machinery and parts or actual subsidies.

Land selection for biofuel cultivation requires rigorous scientific investigation that should have considered all possible crop options and not only Jatropha. No convincing scientific evidence seem to exist suggesting only Jatropha to be the most appropriate crop, especially considering its requirements for water and production yields. It therefore appears that the decision for Jatropha was actually made without adequate scientific consideration and it did not explore other alternative options. Several alternative energy crops options for example, could have been considered to fulfil the government's objectives for energy diversification including (but not limited to) sunflower, Pongamia and the use of residues. Crop choice should as much as possible be based on scientific criteria that recognises the entire value of biofuels.

Spatial distribution of land as set in NPJ for the large-scale Jatropha plantations should have been assessed in close cooperation with agronomists, energy and climate specialists, and decision makers. This is because findings from the agro-environmental mapping process suggests that achieving equal distribution across all localities as stipulated in the NJP does not seem possible (with the exception of only the south, southeast, east, and central regions of the country are suitable). Therefore, findings from the agro-environmental mapping if considered, could lead to successful execution of the NJP.

The mapping process based on the agro-environmental assessment indicated that enough land is available for Jatropha production to meet the NJP target; in fact, 614,000 ha were deemed highly suitable. The NJP assessment indicated that 3–5 million ha overall were suitable for Jatropha. This figure exceeds the planned NJP target area of 321,000 ha by 191%.

Findings from the agro-environmental mapping from this study appears to hold good promise in undertaking Jatropha activities and could be recommended for possible consideration by decision makers and relevant stakeholders. Undertaking a detailed mapping of land-tenure status (e.g., family property, local authority property and state land) to guide future use of land is highly recommended. This mapping would help to properly allocate land for Jatropha plantations and assess the financial and organisational needs to implement projects.

Land-use practices should be defined, and land-tenure options should be established to ensure food security and protect farmer interests. The practices and acceptability of intercropping should be carefully assessed.

Mappings of suitable areas for biofuel production must be made available to interested parties, both local and domestic investors, in order to avoid the use of pristine ecosystems such as forest land for biofuel plantations. Incentives should be provided to encourage biofuel production in designated areas and dissuade the use of pristine and 'sensitive' lands.

7. Conclusion

Three key conclusions could be drawn from the NJP case study in Senegal regarding its evolution, gaps and the realistic potential of biodiesel including the use of other bioenergy crop options.

Policies in the agricultural and energy sectors have been instrumental in framing the NJP. Specifically, the Guidance Law on Agriculture from the agricultural sector and from the energy sector; the Policy Paper for Energy Sector Development (LPDSE), the Renewable Energy Guidance Law and the Law for Biofuels, have contributed significantly to the preparation and formation of the NJP

Considerable gaps exist in the implementation of NJP such as institutional challenges that has resulted in duplicity of efforts and therefore the need to coordinate and streamline activities with clear roles being assigned to all relevant participating institutes. The current NJP tend to focus more on the upstream activities of Jatropha and weak on the downstream side of the value chain such as biodiesel distribution (for domestic utilization or export) and sectorial utilization. Potential market chain analysis would be useful in providing information towards possible refinements in this area. A range of biodiesel crop options informed by scientific assessments should be considered for petroleum diesel substitution in Senegal and not just Jatropha.

The benefits of ensuring that biodiesel crops meet environmental and socio-economic criteria and are cultivated in zones that have been demarcated via agro-environmental mapping are humongous. Agro-environmental mapping provides basic minimum requirements of properly undertaking biodiesel activities that are socially acceptable and environmentally benign. Even though the government's NJP plan to cultivate 1000 ha in each of the 320 communities was not possible due simply to the right eco-geographical conditions or the lack of it in each community. Agro-environmental mapping findings show Jatropha having the largest suitability of land areas which is twenty-seven (27) times more in comparison to original estimations in the NJP but only in designated areas. Pongamia and sunflower with a total of 6,796,000 ha and 5,298,900 ha respectively, also show great potential next to Jatropha regarding total land suitability areas for biodiesel cultivation. Rather than focusing national biodiesel interest and policy solely on Jatropha, complimentary biodiesel crop options could be considered such as Pongamia and sunflower.

Further, Jatropha development in Senegal under the NJP would require additional scientific information and experience with its cultivation as well as shaping existing policies and regulations that would resolve the present barriers. Other factors including good harvest and markets are also crucial to the success of biodiesel which needs to be further investigated. These aspects are prerequisites for the successful large-scale deployment of Jatropha biodiesel production in Senegal.

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Conflicts of interest

The authors declare no conflicts of interest.

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Part II

Sustainability indicators

Soybean cultivation in Argentina. Photo credit: Flickr

4. Sustainability indicators for biofuels in Argentina

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1. Introduction

Argentina is a large producer and exporter of biodiesel produced from soy, due to the country's considerable endowments of natural resources and its very efficient agro-industrial complex. As half of the country's agricultural land is already devoted to soy cultivation, expansion of soy biodiesel production implies an expansion in agricultural lands as well as a transformation of agricultural and livestock-raising activities. These developments could have profound impacts in several areas. At the same time, policy changes in developed countries, particularly those in the European Union (EU), indicate that sustainability criteria may constitute a significant barrier to realising this export potential [1].

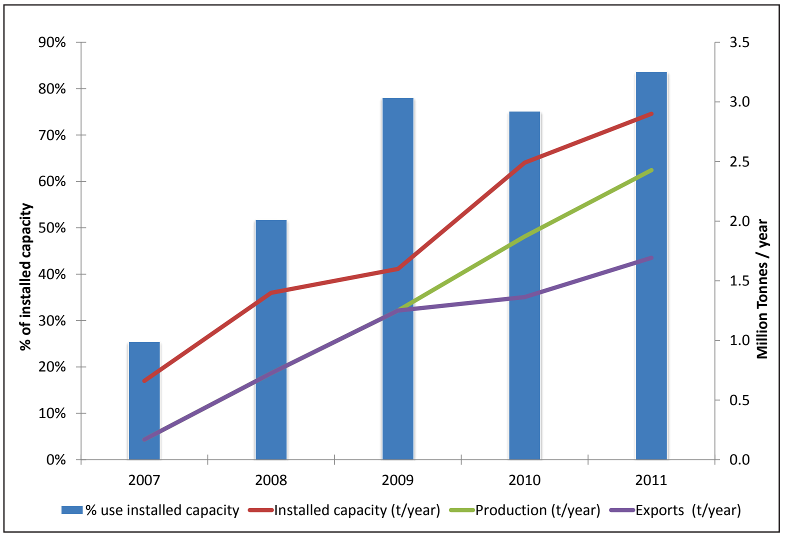
This study focuses mainly on soybean production because it covers so much of the country's arable land and is increasingly displacing traditional crops and livestock. The impacts associated with the production, distribution and use of other biofuels are less significant than those associated with soybean production. While there is also incipient growth in sugarcane cultivation in the country, resulting in another monoculture, the area that is potentially suitable for expansion of sugarcane cultivation is much smaller than that for soy. Furthermore, substitution of diesel with biodiesel from soy is highly relevant (compared with petroleum substitution with bioethanol) for both domestic consumption and export potential. Argentina's vast experience in the development of transgenic soybean also provides useful lessons for decision makers in other countries. Finally, the information currently available on other biofuels is limited.

Argentina has been producing considerable quantities of biodiesel since 2006 (Figure 1), mainly as a consequence of international demand (such as that of the EU) and the implementation of tax incentives in several Argentine provinces. Biodiesel exports in 2010 reached 1.4 million tonnes, making Argentina the fourth largest biodiesel producer in the world, yielding incomes totalling more than US$ 1,000 million. The Government levies taxes of 32% on soybean exports but only 20% on biofuel sales, which has the effect of promoting biofuels for their higher added value, helping to diversify the export market. As shown in Figure 1, the values for installed capacity, production and export in 2011 were 2.9 million tonnes, 2.4 million tonnes, and 1.7 million tonnes, respectively.

Argentina Law No. 26093, passed in 2006, with its associated regulatory decree No. 109/2007, is the most important tool in promoting biofuel production for the domestic market. This law offers an alternative to the uncertainty of the export market by creating a local market. As of 2010, when bioethanol started to be produced for the transport sector, the law has mandated the blending of diesel oil and petroleum with 5% biodiesel and 5% bioethanol, respectively. The law also regulates the implementation of tax incentives and the promotion of investment in production capacity. In the same year, the biodiesel blending mandate increased to 7% (B7). It is expected that blending of 10% will be mandated for both fuels in the future. Despite that law, however, by the beginning of 2011, blends of 5% had not yet been implemented throughout the whole country.

The biofuel requirements or quotas for the coming years are estimated by the Energy Secretariat, which then allocates them to producing enterprises according to their production capacity and biofuel availability. Production of the bioethanol quota was initially allocated to eleven producers, whereas that of the biodiesel quota was shared by nineteen producers.

Figure 1. Biodiesel trends in Argentina



The biodiesel industry in Argentina is divided into small-, medium- and large-scale segments, based on production capacity. The large-scale segment can be divided into independent producers and large oil crushers. The export sector represents close to 60% of total production and is mostly in the hands of the large oil crushers and large independent producers, though uncertainty concerning the future of biodiesel exports to the EU and of soybean oil exports to other places has prompted these producers to try to secure part of the domestic market as well. According to Law No. 26093, however, this domestic market should be operated mainly by small- and medium-scale producers (those with production capacities <50,000 tonnes/year) in different areas of the country to boost regional economies, support the role of small and medium enterprises (SMEs) in national development plans, and counteract the trend towards concentration of activities and economic benefits by large companies. To date, this requirement has only partially been met because SMEs supply only about 50% of the local demand and produce about 20% of all the biodiesel produced in Argentina.

Large-scale producers usually dominate the whole of the soybean supply chain, with biodiesel production plants located near crushers for oil production and near export ports on the Parana River. Medium- and small-scale producers depend on feedstock supplied by third parties, and as a result, some are trying to diversify their feedstock materials.

Analysing the energy context for biofuel production is particularly important. Argentina is a petroleum-producing country, but its reserve/production ratios are decreasing, imports are growing, and seasonal scarcities of diesel oil are occurring. One of the main motivations for the requirement concerning blending diesel oil with biodiesel is to increase energy security by reducing diesel oil imports – in fact, nearly 6% of the domestic demand for diesel in 2008 was met by local biodiesel. There would also be an increase in the current petroleum surplus with a higher ethanol mix. This would help develop the agro-industrial sector and associated regional economies, thus helping to modernise and diversify the sugar industry.

Domestic prices for biofuels are stipulated monthly by the Energy Secretariat. There is, however, considerable debate surrounding the differences between the domestic and international prices of biodiesel, the implications of its export to the EU and the prices of oil by-products used for reference.

An important agro-industrial chain has thus developed based on the large-scale production of biodiesel from soybean. The situation for bioethanol production from sugarcane has similar characteristics on a much smaller scale. Integration and concentration around a few stakeholders has permitted the rapid growth of these agro-industries. The advantages and disadvantages of this trend are considered here, subject to two serious limitations – the scarcity of data on the impacts of these industries and the difficulty of allocating the various impacts to biodiesel production.

The technological package responsible for the explosive soy development that has been occurring in Argentina since 1996 involves the use of genetically modified soybean and the use of glyphosate as herbicide. However, the extensive use of glyphosate is having negative impacts on human health and soil fertility and is threatening more fragile ecosystems into which soybean monoculture is expanding [2; 3]. Some instruments and frameworks are available for assessing the risks involved and deciding how to approach them. Nevertheless, little information is available on the national level for analysis, at least in the developing world. Three interesting examples are worth mentioning: the Global Bioenergy Partnership (GBEP), the OLADE/CEPAL/GIZ energy policy guide, and the Roundtable on Sustainable Biofuels (RSB).

The GBEP work provides indicators that covers all forms of bioenergy. However, these indicators do not represent directions, thresholds or limits and do not constitute standards, nor are they legally binding. The emphasis of the GBEP work is on providing measurements that are useful for national-level policy analysis and development [4]. Similarly but much earlier, CEPAL/OLADE and GIZ published a guide on energy policy for sustainable development, featuring indicators for assessing progress towards sustainable development. Additionally, it led to several national multi-stakeholders' dialogues and discussions in Latin America [5]. RSB is an international multi-stakeholder initiative concerned with ensuring the sustainability of biofuel production, processing, and use, by developing certification procedures and standards. Specifically, the Soil Impact Assessment Guidelines [6] mention that most agro-industrial developments are characterised by their potential to produce impacts associated with soil erosion and the application of fertilisers to maximise crop yields. The RSB guidelines are aimed at assisting in the identification, assessment and mitigation of these impacts, and the principles of RSB serve as the starting point.

In 2010, Argentina devoted approximately 13% of its arable land – four million hectares (ha) – to producing soybeans for biodiesel production (close to 1.9 million tonnes of BD100). Nearly 70% of this biodiesel was exported in that year, which is an indication of the attractive market that large-scale producers currently enjoy. Today, approximately 60% of Argentina's arable land is either partially or wholly devoted to soybean production [7].

In the case of sugarcane, as of 2011, the amount of land required to produce the ethanol needed to comply with the requirement for blending 5% in petroleum (280,000 m^3 of ethanol), approximately 45,000 hectares, had not yet been put into production (2011). The main impacts, in this case, have to do with the treatment of vinasse – a by-product of sugar production – and the burning and harvesting of the cane.

Liquid fuels that are authorised in Argentina for engine use:

Fossil:

- Gasoline (super and premium): light distillates from crude oil suitable for Otto engines.
- Diesel Oil: light distillate from crude oil suitable for diesel engines.
- Fuel Oil: medium distillate from crude oil suitable for heavy-duty engines (maritime and fluvial transport).

Non-Fossil:

- Bioethanol (E100): dehydrated ethanol, produced mainly from sugar cane.
- Biodiesel (BD100): vegetable oil methyl ester produced mainly from soybean.

Blends:

- E5: blend of gasoline with 5% E100 (volume basis). Most of the gasoline commercialised for transport is E5.
- B5: blend of diesel oil with 5% BD100 (volume basis). Authorised for electricity generation in one large power plant in Argentina.
- B7: blend of diesel oil with 7% BD100 (volume basis). Almost all the diesel oil commercialised for transport is B7.
- B20: blend of diesel oil with 20% BD100 (volume basis). Suitable for use in some types of agricultural machinery. Not commercialised yet.

Some of the most frequently mentioned motivations for the development of biofuels are the mitigation of greenhouse gas (GHG) emissions and the creation of jobs in the agricultural and agro-industrial sectors. These factors – whose magnitude and characteristics are now beginning to be studied – do not seem to control the development of the sector. Nevertheless, the issue of reducing GHG emissions by the soybean chain is particularly important because this has an impact on biodiesel exports. Soybean biodiesel production in Argentina must comply with the minimum GHG emission reduction requirements set out in the EU Renewable Energy Directive, and as of 2011, shipments headed for the EU must be

certified as complying with this Directive. According to the EU Renewable Energy Directive the default greenhouse gas emission saving for soybean biodiesel is below the minimum of 35% GHG emission savings established by their sustainability criteria. Several national institutions are currently studying the factors that influence emissions by the soybean biodiesel chain in Argentina and are presenting national calculations on GHG emissions savings to competent EU bodies, such as the Joint Research Centre (JRC), to avoid possible export barriers. As a result, exports to the EU and particularly to Spain have continued to grow, and the Directive has not yet affected shipments. Direct and indirect emissions resulting from land use changes are also key issues and have generated a debate in the EU, adding uncertainty to the future of the export market.

The characteristics of biofuel development described above generate both opportunities and threats for Argentina and point to the need for framing the analysis within the paradigm of sustainable development. Incentives implemented thus far, however, have not always been based on a thorough assessment of the impacts of biofuels on the multiple dimensions of development. This is exemplified by the lack of discrimination across the several feedstocks in current incentives and the almost complete absence of land use planning.

This paper assesses 1) liquid biofuel production as it impacts the cultivation of soybean for biodiesel, using key sustainability variables; 2) the concentration in land tenure and the displacement of rural populations; 3) changes in employment patterns; 4) the substitution of traditional crops; 5) the amounts of agrochemicals used; and 6) the potential for reducing GHG emissions through the adoption of biofuels. This paper models future scenarios to compare different trends in the production and use of biofuels to analyse the scope and magnitude of their impacts.

2. Methodology

To analyse the impacts of biofuels on the dimensions of energy, society and the environment, the energy sector in Argentina was modelled using 2008 as the base year for future projections. Demand and supply perspectives were considered for each of the following four scenarios: Baseline Low, Baseline High, Structural Low, and Structural High.

Under the two structural scenarios, rational and efficient energy use measures are anticipated that would reduce energy intensities, mainly through improvements to engines in the transport sector and through the implementation of measures related to rational energy use in the transport sector. The low and high structural alternatives relate to the extent of bioethanol and biodiesel penetration, which is lower for the first of the two. The percentage mix that are anticipated to be mandated by law under these scenarios is included. Table 1 shows the blending hypothesis under the high and low structural scenarios for different sectors of fuel consumption, expressed as percentages (of total volume). The blending mandate came into effect in 2010, and consequently, the penetration in the local market was zero for 2009.

Using these hypotheses, and hypotheses related to the main economic drivers (see the next section), the energy demand and supply trends were estimated. These estimations were made with the help of the LEAP model, as well as with a series of indicators that are analysed below. This process permitted an analysis of the social, environmental and energy impacts of the four scenarios.

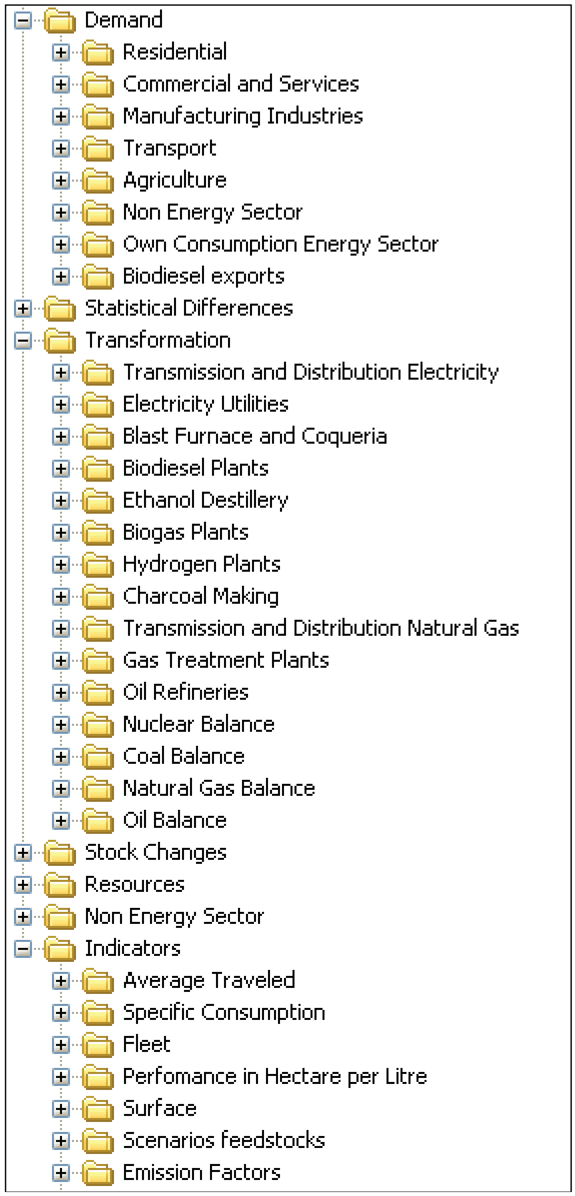
Table 1. Biofuel penetration hypotheses for Argentina

Biofuels	Low Scenario			High Scenario		
	Transport (% vol.)	Agricultural machinery (%vol.)	Electricity generation (%vol.)	Transport (% vol.)	Agricultural machinery (%vol.)	Electricity generation (%vol.)
Bioethanol	2009: 0% 2010: 4% 2015: 13% 2030: 20% No exports			2009: 0% 2010: 4% 2015: 15% 2030: 25% No exports		
Biodiesel	2009: 0% 2010: 4.8% 2015: 11% 2030: 15% With exports	2009: 0% 2010: 4.8% 2015: 15% 2030: 20%	2010: 0% 2011: 1% 2015: 5% 2030: 10%	2009: 0% 2010: 4.8% 2015: 13% 2030: 20% With exports	2009: 0% 2010: 4.8% 2015: 15% 2030: 25%	2010: 0% 2011: 1% 2015: 7% 2030: 15%

Notes: 1) Penetration of biofuels is presented as percentage mixes with conventional fuels by volume for easier comparison with Argentine policy targets. 2) Penetration of biodiesel in electricity generation refers to the blending percentage with diesel oil in some conventional power plants.

The tree structures designed with LEAP permit a disaggregation of the main consumption sectors, which were analysed with respect to technical coefficients using a "bottom-up" approach to determine the technology and energy intensity levels for each energy use. The representation of "transformation centres" permits the analysis of biofuel penetration in, for example, electricity generation. Figure 2 shows the LEAP tree structure constructed for the present study.

Figure 2. LEAP tree structure for long-term energy prospects in the demand and supply sectors



Source: authors' elaboration

3. Results and discussion

3.1 Energy supply and demand trends

This subsection presents an analysis of energy demand and supply trends, particularly those associated with biofuels – while the next subsection presents an analysis of the associated GHG emissions.

Anticipated values for the most important parameters are as follows:

- The demand growth rate will be 3% per annum in the Baseline Scenario and 2.2% per annum in the Structural Scenario.
- The Gross Domestic Product (GDP) growth rate will reach 3% per annum, which implies an energy demand elasticity with respect to GDP between 1 and 0.74 for the Baseline and Structural Scenarios, respectively. The 26% decrease in elasticity for all the scenarios is due to the inclusion of rational and efficient energy use measures in the Structural Scenario.

The energy results estimated by running the LEAP model, using the above assumptions, indicate that by 2030, the energy demand will reach 121 million tonnes of oil equivalent (TOE) under the Baseline Scenario and 103 million TOE under the Structural Scenario. The energy consumption savings across the Scenarios by 2030 will be approximately 15%, equivalent to 18 million TOE. The accumulated savings over that period will be 190 million TOE (equivalent to three times the energy consumption recorded in 2008).

Liquid biofuels will contribute between 3.1% (Structural Low) and 4.3% (Baseline High) of the total fuel consumption (cumulative 2008–2030). It can therefore be concluded that although biofuel penetration in the transport sector will be important in these scenarios (between 15% and 25% in 2030, depending on the scenario and the biofuel), its impact on the energy matrix as a whole will not be very significant. A strong dependence on natural gas and oil derivatives will still prevail, meeting 74% of demand, regardless of the scenario (Table 2).

Biodiesel penetration will be higher than that of bioethanol, which will help balance current diesel oil scarcity. Consumption by the transport sector (81% of the base-year diesel oil demand) and the agricultural sector (17% of the 2008 diesel oil demand) is much more significant than consumption for electricity generation.

Table 2. Demand trends by type of fuel (not including the export demand for biodiesel)

in million TOE		Baseline Low	Structural Low	Baseline High	Structural High
	2008	2030	2030	2030	2030
Bioethanol	**0.0**	**0.9**	**0.7**	**1.2**	**0.9**
Biodiesel	**0.0**	**5.7**	**5.1**	**7.6**	**6.8**
Biomass	2.2	2.5	1.6	2.5	1.6
Crude Oil	0.0	0.1	0.1	0.1	0.1
Electricity	9.6	21.6	17.9	21.6	17.9
Natural Gas	29.0	54.2	48.2	54.2	48.2
Gasoline	5.1	7.9	6.8	7.6	6.6
Diesel Oil	9.6	16.6	13.4	15.7	12.6
Rest of Oil Products	5.0	8.0	5.8	8.0	5.8
Other Fuels	1.6	3.0	1.9	3.0	1.9
Renewables	0.0	0.0	0.9	0.0	0.9
Solid Fuels	0.2	0.3	0.3	0.3	0.3
TOTAL	**62.3**	**120.8**	**102.7**	**121.8**	**103.6**

The structure of the energy demand by sector will not vary significantly between any of the scenarios. More than 50% of final energy demand will be concentrated in the industry and transport sectors.

On the basis of announced biofuel penetration by the Government, biodiesel will play a small role in electricity generation due to issues related to the approval of equipment that will need to be technologically modified to burn this biofuel, a process that also requires new investments. It is also likely that biodiesel will be exported to the EU and/or USA (three and four million tonnes in the Low and High Scenarios, respectively).

All scenarios anticipate that biodiesel penetration will be higher than bioethanol. Approximately 75% of the domestic demand for biofuels for end-use energy consumption derives from the transport sector.

Total biodiesel demand comprises both domestic demand (for end-use consumption and for consumption in electricity plants) and exports. In the case of bioethanol, only end-use consumption is expected and no exports are considered.

By 2030, whichever the scenario under analysis, approximately 50% of demand will come from exports of biodiesel (Table 3). This means that half of the environmental impacts and externalities generated from biodiesel development policies will be a consequence of exports. By implementing adequate policies, however, the Government will be able to collect a portion of the revenue[1] derived from biodiesel exports to mitigate these impacts. For example, land-use policies could be implemented and feedstocks could be diversified. These aspects are addressed below.

Table 3. Biodiesel demand trend

in thousand m^3

Baseline High	2008	2015	2020	2025	2030
Sectorial Demand	0	1,991	2,790	3,754	5,034
Electricity Generation Demand	0	97	159	237	339
Export Demand	833	3,334	3,909	4,255	4,599
Total Demand	**833**	**5,422**	**6,858**	**8,246**	**9,973**

in thousand m^3

Baseline Low	2008	2015	2020	2025	2030
Sectorial Demand	0	1,741	2,297	2,955	3,824
Electricity Generation Demand	0	69	110	161	227
Export Demand	833	2,875	3,066	3,258	3,450
Total Demand	**833**	**4,685**	**5,473**	**6,374**	**7,501**

1 The “revenue” category includes income from the sale price (tonnes of biodiesel at international prices) once ordinary costs and benefits have been subtracted.

in thousand m^3

Structural High	2008	2015	2020	2025	2030
Sectorial Demand	0	1,851	2,462	3,145	4,011
Electricity Generation Demand	0	82	120	159	200
Export Demand	833	3,334	3,909	4,255	4,599
Total Demand	**833**	**5,267**	**6,491**	**7,560**	**8,811**

in thousand m^3

Structural Low	2008	2015	2020	2025	2030
Sectorial Demand	0	1,616	2,026	2,472	3,042
Electricity Generation Demand	0	59	83	107	134
Export Demand	833	2,875	3,066	3,258	3,450
Total Demand	**833**	**4,550**	**5,175**	**5,837**	**6,626**

At the two extremes in terms of demand are the Baseline High and Structural Low scenarios. The highest demand among all the scenarios in 2030 is 9.9 million m^3 for biodiesel (projected from 0.8 million m^3 in the base year) and 2.2 million m^3 for bioethanol (projected from no demand in the base year). The difference in volume across these extreme scenarios for the period under consideration is 50% for biodiesel and 60% for bioethanol. Such high variability across the scenarios suggests a series of impacts that are analysed later in this paper. For instance, there will be impacts related to the land area necessary for production and cultivation from the use of feedstocks other than soybean alone.

3.2 Greenhouse gas emission trends

This section analyses GHG emissions for the energy sector and the trends suggested by the different scenarios. For this purpose, two variants related to energy are considered, in addition to the other elements of the Baseline and Structural Scenarios. The possibilities of using conventional sources for biofuel in Argentina (soybean and rapeseed for biodiesel and cane and corn for bioethanol) are compared to diversifying the types of crop used (that is, by using soybean, rapeseed, microalgae, recycled cooking oil, Jatropha, animal fat, safflower and spurge for biodiesel and cane, corn, beetroot, sorghum and lignocellulose from forest waste for bioethanol). Note that there are different GHG emission factors for these different feedstocks[2].

In the context of biofuel emission factors, two estimates were made for future GHG emissions, based on two different sources of data regarding emission factors applicable in the soybean energy chain. One of these estimates is based on an international source [8], referred to here as "JRC factors"[3]. The other estimate is based on a national study developed by the National Institute of Agricultural Technology (INTA) on soybean biodiesel [9].

2 Emission factors used by the LEAP model for biofuels include GHG emissions from all along the production chain of the biofuels, from the agricultural stage to burning in final use.

3 Note that emissions in the international transport stage were subtracted from these emission factors.

Irrespective of the data source for soybean emission factors, there are practically no differences in total GHG emissions across the scenarios with or without diversification, because of the limited penetration of biofuels in the national energy matrix.

In the energy sector[4], GHG emissions in the Baseline Low Scenario by 2030 will be between 301 and 306 million tonnes CO_2eq (equivalent) (Table 4). The biofuel penetration policy would thus bring about a 2% decrease in GHG emissions by 2030, compared with emissions in the Baseline Low Scenario, or a 3.5% decrease using the JRC and INTA GHG emissions savings factors.

Table 4. Greenhouse gas emission trends for the energy sector (in millions of tonnes of CO_2eq)

		Without Diversification JRC factors		With Diversification JRC factors	
		Low	High	Low	High
	2008	2030	2030	2030	2030
Baseline	160	306	305	305	304
Structural	160	235	235	234	233

		Without Diversification INTA factors		With Diversification INTA factors	
		Low	High	Low	High
	2008	2030	2030	2030	2030
Baseline	160	301	299	302	300
Structural	160	230	229	231	230

A larger percentage of emissions savings is projected for the transport sector: without biofuel penetration, emissions are projected to total 81 million tonnes of CO_2eq by 2030. With biofuel penetration, emissions would be reduced by 7% under the Baseline Low scenario and using the JRC factors and by 9% using the INTA factors.

If the same analysis is carried out for biodiesel and bioethanol, for which emissions are compared according to the different scenarios and emission factors, a reduction of approximately 50% is projected for the biodiesel case using the INTA emission factors for soybean (Table 5).

4 The agriculture sector and LULUCF are also significant GHG emission sources in Argentina.

Table 5. Greenhouse gas emission trends for biodiesel (in millions of tonnes of CO_2eq)

		Without Diversification JRC factors		With Diversification JRC factors	
		Low	High	Low	High
	2008	2030	2030	2030	2030
Baseline	0.41	9.8	13.1	9.1	12.0
Structural	0.41	8.7	11.5	8.0	10.6

		Without Diversification INTA factors		With Diversification INTA factors	
		Low	High	Low	High
	2008	2030	2030	2030	2030
Baseline	0.41	5.1	6.8	6.2	8.2
Structural	0.41	4.5	6.0	5.5	7.3

In terms of the soybean emission factors that were considered, a scenario with diversification of biodiesel production would produce an average reduction of emissions of approximately 8% based on the JRC factors and a 20% increase based on the INTA factors.

The factors studied by INTA apply to soybean and are significantly lower than those suggested by JRC. For example, the INTA emission factors for CO_2 are approximately 63% lower. The emission factors for the other crops are not different, so based on the INTA emissions factors, the scenario with diversification produces higher emissions than the scenario without diversification. The following section analyses the impacts of these scenarios on land use and the areas affected.

In the scenarios that use INTA and JRC factors, the emissions for bioethanol coincide because, as already noted, the INTA emissions factor studies are focused on soybean.

Table 6. Greenhouse gas emissions trends for bioethanol (in millions of tonnes of CO_2eq)

		Without Diversification JRC factors		With Diversification JRC factors	
		Low	High	Low	High
	2008	2030	2030	2030	2030
Baseline	0.0	0.86	1.08	0.94	1.18
Structural	0.0	0.67	0.84	0.74	0.92

		Without Diversification INTA factors		With Diversification INTA factors	
		Low	High	Low	High
	2008	2030	2030	2030	2030
Baseline	0.0	0.86	1.08	0.94	1.18
Structural	0.0	0.67	0.84	0.74	0.92

Table 6 shows that, due to crop diversification, emissions will increase by approximately 10% as a consequence of the higher penetration of corn in the scenario with diversification, because the emission factors for this crop are higher than those for sugarcane.

3.3 Land use

The use of land for biofuel production has a large range of impacts, such as substitution for other productive activities (agricultural, livestock and forest activities); displacement of populations with informal land tenure rights (e.g., indigenous populations without title deeds); expansion of the agricultural frontier, with consequent risks to biodiversity and the triggering of emissions from sequestered carbon; and pollution associated with biofuel production, such as that resulting from the use of agrochemical substances.

Total land use depends not only on the mix of feedstocks used for biofuel production but also on characteristics that may vary significantly for each feedstock, such as those related to soil, climate, water supply, plant varieties, agronomic practices and the use of agrochemical substances. These factors are determinants for substantially differing agronomic yields, both geographically and seasonally. This effect is more noticeable in the case of experimental crops (such as Jatropha, safflower and spurge) than in the case of more traditional ones (such as soy, rapeseed and sugarcane). Experimental crops should not be assumed to offer an alternative for marginal land cultivation, because on such land, a reduction in yield with respect to pilot or reference measures will most likely result.

In this analysis, representative yields for oil and ethanol production – even higher than the Argentine average – have been adopted, with the result that land use estimates are conservative. Some of these yields have been adjusted to reflect the technological trend.

It is important to note that actual land used for a certain crop at a given time of the year may differ from the amount estimated on the basis of average productivity (due, for example, to crop rotation throughout the year). These estimates should be interpreted as the area of land that would produce an annual amount of oil/ethanol equivalent to the actual production with a yield that is close to the country average. In the case of soybean, for example, there are at least four factors that affect yield: 1) first-crop soybean; 2) second-crop soybean (because this oil crop can be cultivated twice a year); 3) no-till; and 4) conventional farming systems. Together with soil and climate characteristics, these are important determinants of variations in oil yield per unit area. In the present work, average agricultural yields for Argentina that are representative of the most productive areas of the country for each energy crop are used.

Figures 3 and 4 show the projected areas of land used for biofuel crops associated with average yields, based on the four energy scenarios already discussed. Figure 3 shows the situation for a conventional mix of feedstocks (with very little diversification), and Figure 4 shows the situation for an alternative, diversified mix of feedstocks.

Figure 3. Land involved in biofuel production by scenario – conventional feedstock mix

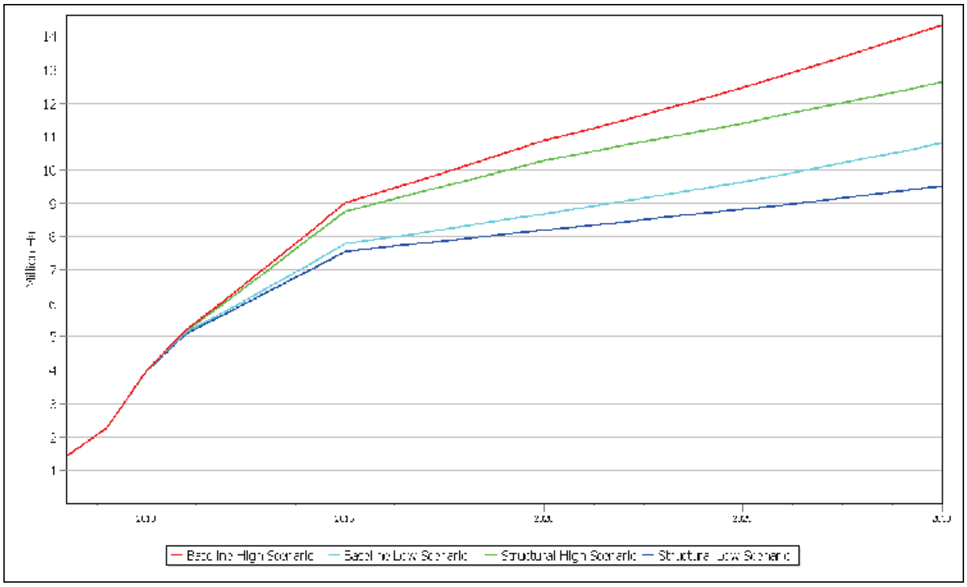
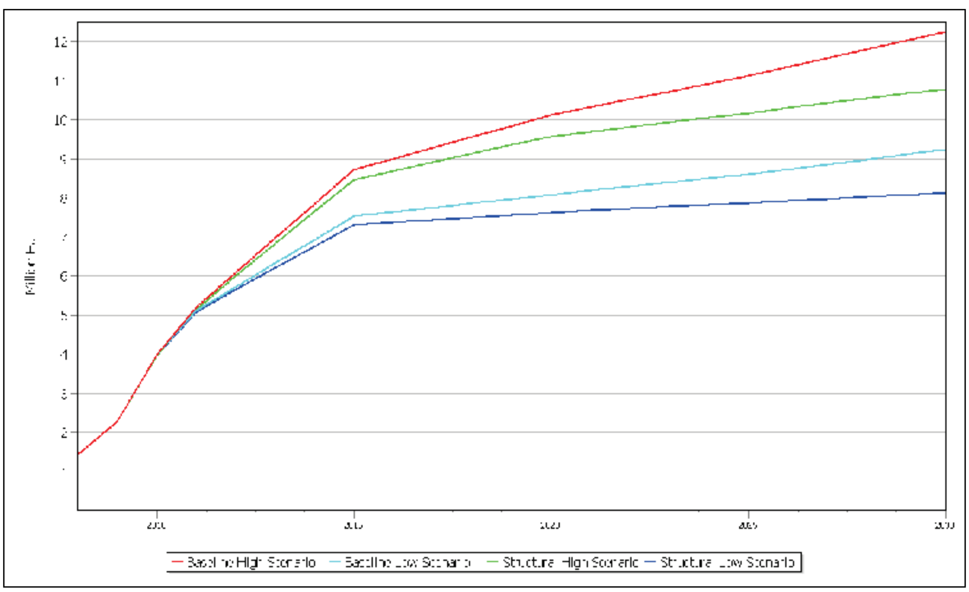


Figure 4. Land involved in biofuel production by scenario – alternative feedstock mix



In the conventional scenario with little crop diversification, the extent of land used by 2030 ranges from 9.5 to 14.3 million hectares for the Structural Low and the Baseline High scenarios, respectively. For reference, cultivation in 2010 totalled 32 million hectares, half of which were devoted to soybean. In the Structural High and the Baseline Low scenarios, intermediate values are projected: 10.8 and 12.6 million hectares, respectively. In this conventional scenario, land use is distributed as follows: 88% soybean, 9% rapeseed, 1.5% sugarcane and 1.2% corn.

In the alternative scenario with diverse alternative feedstocks, some of which use practically no land at all, the extent of land use by 2030 ranges from 8.1 to 12.3 million hectares. In this alternative scenario, land use is distributed as follows: approximately 65% soybean, 10.5% rapeseed, 13% spurge, 4% Jatropha, 4% safflower, 1% corn and 1.2% sugarcane.

Irrespective of the feedstock mix, land use variation for biofuels between the largest and smallest energy scenarios approaches 34% in 2030. In contrast, for any given energy scenario, the variation associated with the feedstock mix is approximately 17% because, even in the diversified feedstocks scenario, the extent of soybean cultivation is significant.

The differences between the Baseline and Structural scenarios are approximately 12% with respect to land use for the same feedstock mix and penetration percentages.

Between 2008 and 2030, a five-fold to ten-fold increase (from 1.5 to 8 to 14.5 million hectares) is calculated for the area devoted to biofuel production in the Alternative and Conventional feedstock scenarios, respectively. The area devoted to biofuel production in 2030 represents, depending on the scenario, between 25% and 45% of the total cultivated area in Argentina in 2010.

As mentioned in the introduction to this chapter, land use for biofuel production could be broadly linked to some negative impacts. These impacts could be mitigated by a reduction in the land devoted to biofuel production, although these impacts do not depend exclusively on the demand for biodiesel or ethanol. Additionally, a diversification strategy could bring about advantages from the point of view of reduced vulnerability and the treatment of residues. The scenarios described in this chapter indicate that a biofuel feedstock diversification strategy and energy efficiency and rational use measures could significantly reduce agricultural land use for biofuel production, which in all scenarios will require a large fraction of the currently productive land by 2030.

3.4 Sector concentration

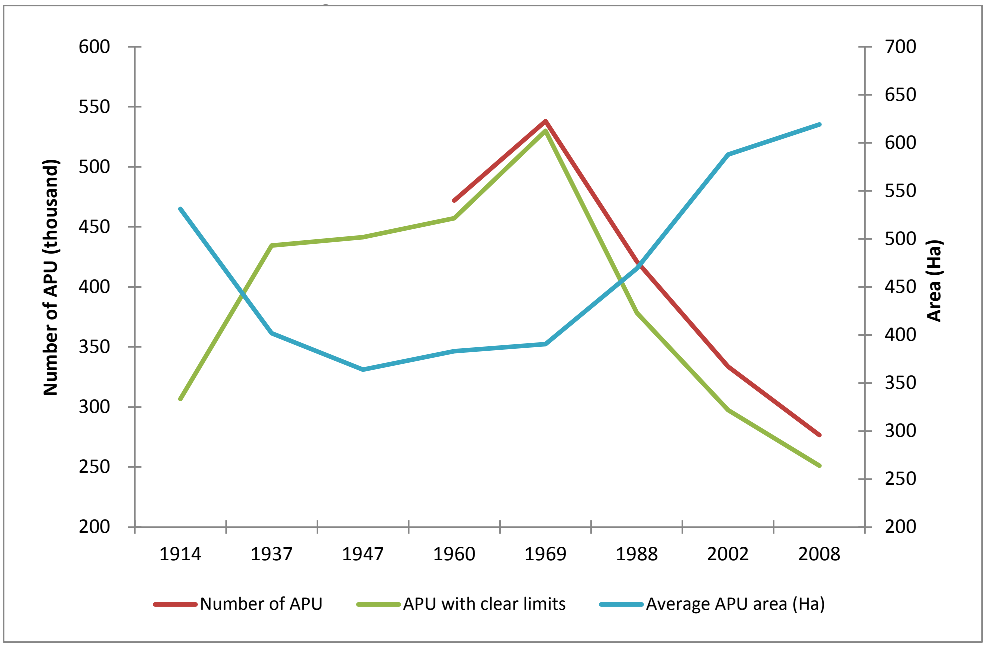
Apart from the total area of land used, it is also important to consider the scale of agricultural production units, a variable that pertains to ownership concentration. This concentration is increasing as the average size of agricultural production units increases. There is, however, a considerable difference in this respect between the core agricultural area and the agricultural frontier located in the north of the country. The concentration is generally greater in the core agricultural provinces (Buenos Aires, Santa Fe, Córdoba, and Entre Ríos).

This process of concentration applies not only to feedstock production but also to the agro-industrial stage of biofuels, the provision of inputs, services and trading, which includes exports. This trend is also noticeable elsewhere in Latin America, where successful production of significant volumes of biofuel by small-scale producers is rare. This is explained by the lack of regulation of land use and the lack of policies regarding ownership concentration, as well as the lack of other policies to promote the development of associations. At times, this results in farmers withdrawing from biofuel feedstock production to pursue production for the conventional food/feed market.

Between 1969 and 2008, the number of agricultural production units (APU) fell from 538,000 to 277,000, and their average size grew from 391 to 619 hectares (Figure 5) [10,11]. In addition, there has been an increase in the leasing of land compared to owner utilisation, as well as an increase in the cultivation of annual fruit trees and vegetable crops and of crops that require little rotation. This concentration process

started before the development of transgenic soybean, which has been encouraged by the spread of no-till farming techniques, because it is difficult for small-scale producers to obtain access to tilling practices. In this respect, national indicators conceal serious regional differences.

Figure 5. Trends in the number of agricultural production units (APU)



Source: authors' elaboration based on [10,11]

The shift to new agricultural practices has also increased dependence on the supply sector for the provision of seeds and agrochemical products, whose production is concentrated in a few large companies. Apart from the decrease in the number of producers, there has also been a significant decrease in the number of grain stockpiling services, brokers and cooperatives, with increased concentration and integration around the milling and oil industries, and export activities.

Increased concentration has allowed Argentina to efficiently produce large volumes of biofuel for the local and export markets at competitive prices. However, with significant regional differences, this increased concentration has also had negative impacts on traditional rural livelihoods and is also strongly related to changes in employment patterns, the concentration of revenues and the low diversification of agricultural production. These changes can be expected to continue if no policies are implemented to regulate the development of the agricultural sector, and land exploitation and ownership.

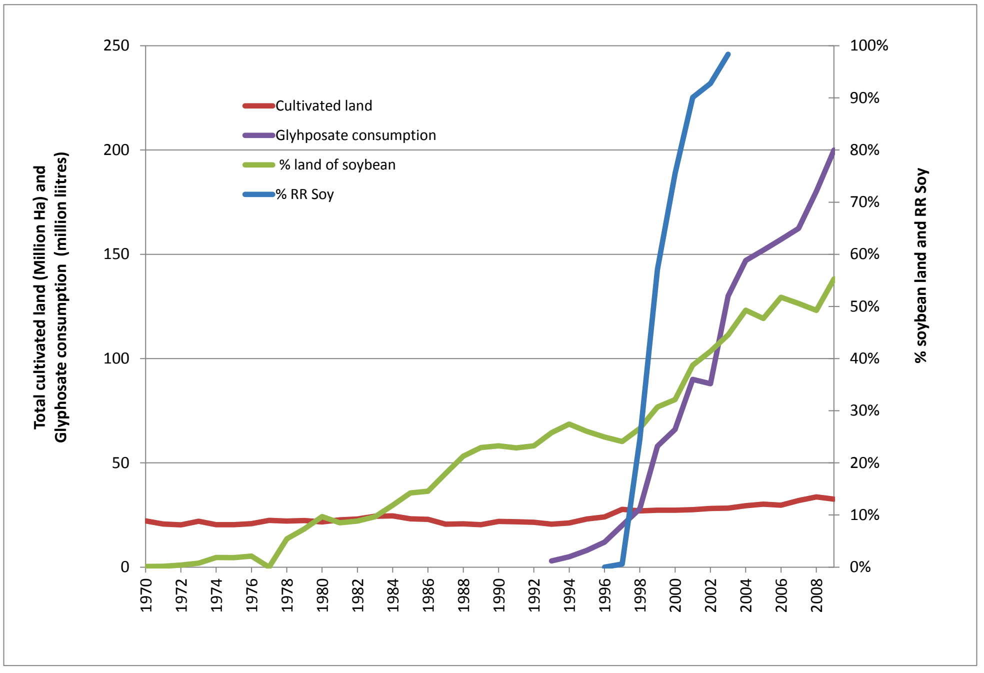
3.5 Glyphosate use

Glyphosate is the main herbicide used to kill weeds that are known to compete with genetically modified soybean (RR soybean, engineered to be tolerant to glyphosate). Together with no-till farming, which reduces labour and preserves soil organic content by not removing crop residues after harvest, the use of glyphosate has been responsible for exponential growth of this crop since 1996. This reveals the important role of this herbicide, one of the most widely used, to both productivity and income generation for the agricultural, agro-industrial and service-supplier sectors. The use of glyphosate, however, most likely

impacts human health and biodiversity negatively, which has led to considerable debate and research on the issue.

The use of agrochemical products has grown significantly in Argentina over the last 15 years. The use of glyphosate-based herbicides, in particular, increased from 1 to 200 million litres between 1991 and 2009 (Figure 6)[5]. For reference, the cultivated area grew from 22 million hectares to 32 million hectares in the same period. Unfortunately, only scattered data is available suggesting an increasing trend in glyphosate use per unit of soy production.

Figure 6. Soybean cultivation and glyphosate use trends



Source: Authors' elaboration based on [12-13]

Note: glyphosate consumption is measured in litres of the different formulations commercialised.

The increased scale of glyphosate use correlates with the growth in the cultivation of transgenic soybean cultivation since 1996[6]. Use of glyphosate-based products per unit of land area has increased twelve-fold on average between 1996 and 2009 (from 0.5 to 6.1 litres/hectare), while soybean production increased three-fold (Figure 7). In 2003, genetically modified soybean cultivation exceeded 98% of total soybean cultivation. Between 2003 and 2009, the use of glyphosate per hectare increased by approximately 30%, however, the launch of RR corn in 2004 and the appearance of resistant weeds might be responsible for this increase[7].

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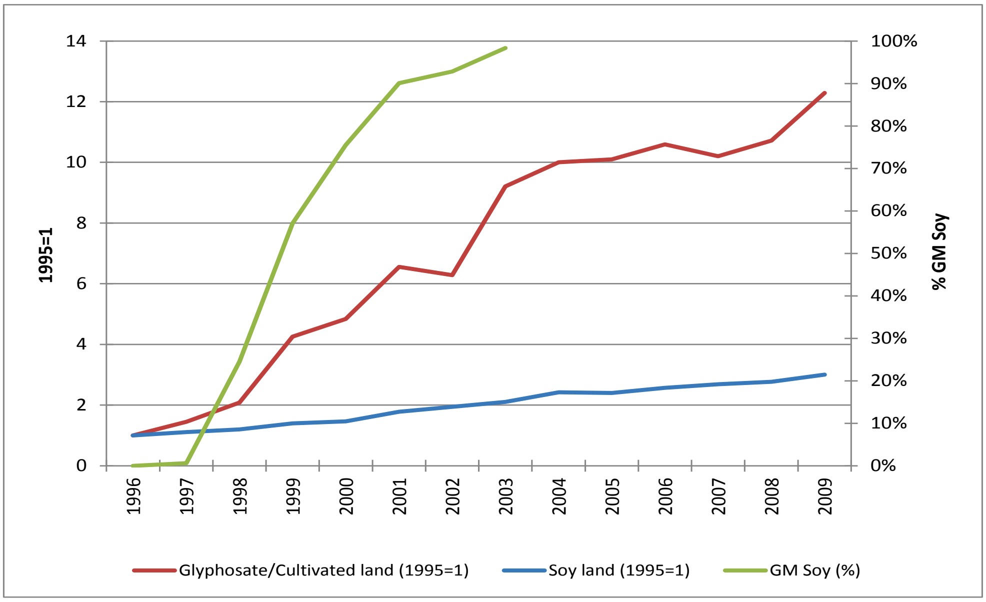
5 Glyphosate-based formulations typically contain 48% of this compound (as used in 56% of the Argentine market in 2007). The average glyphosate content in 2007 was 53%, which means the average dose was 2.7 kg acid equivalent/hectare/year. The average dose for RR soybean cultivation is 2.6 kg [13].

6 Glyphosate is frequently used in agriculture. In 2007, it was used for chemical fallow (49% for several crops), soybean cultivation (36%), corn (4%), pasture, wheat, sunflower, fruit containing stones and pits, citrus trees, cotton and other crops.

7 Unfortunately, data on glyphosate use is scarce and corresponds to different formulations and crops; for 2008 and 2009, the data is only approximate and estimated.

Figure 7. Soy cultivation and herbicide use



Source: authors' elaboration based on [12-14]

Future glyphosate requirements for biofuel feedstock cultivation may be estimated by considering an average of the specific consumption of glyphosate-based formulations for 2009, namely, 5 litres/ hectare, which is equivalent to 2.6 kg of acid equivalent/hectare [15] for traditional crops and 2 litres/hectare for spurge and safflower. Figures 8 and 9 show these projected increases, but larger doses that might have been used if resistant weeds appeared are not taken into account. INTA recommends that the measures that should then be used include crop rotation and rotation of herbicides with different practices, such as controlling the doses applied [15].

Figure 8. Glyphosate use – low diversification scenario

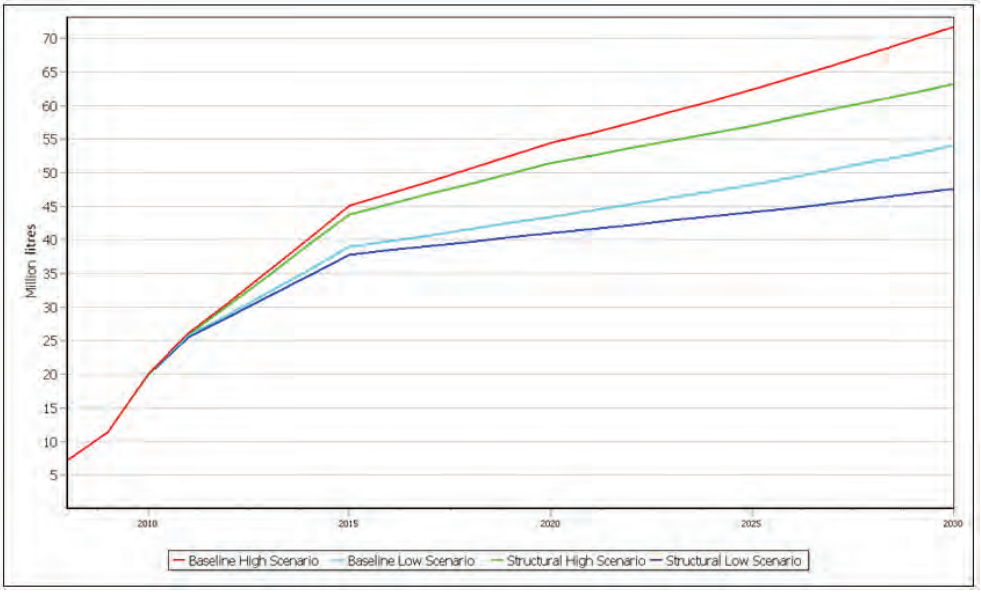
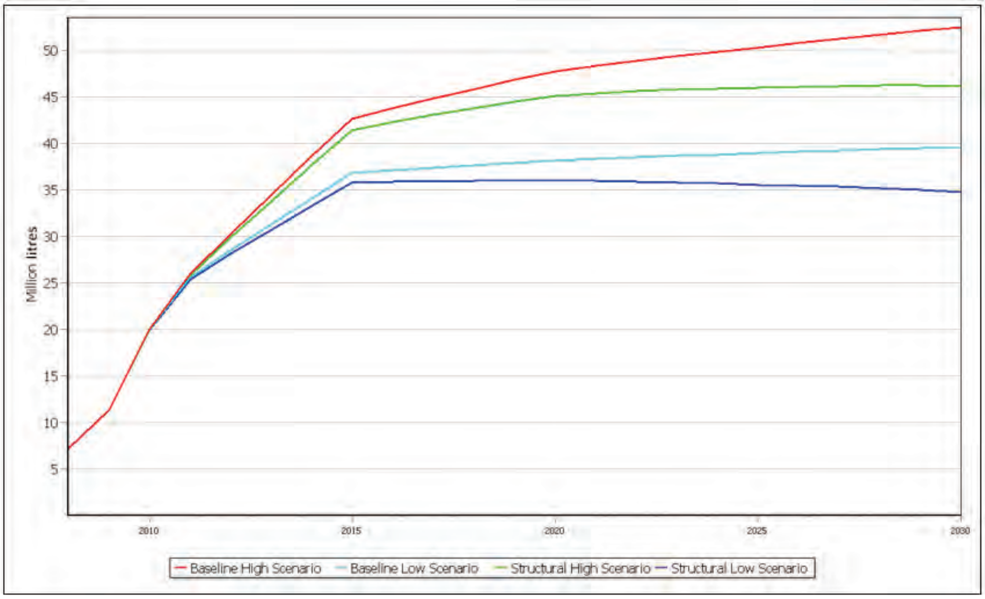


Figure 9. Glyphosate use – high diversification scenario



The low diversification scenario suggests an increase in glyphosate use for biofuels from seven million litres to 48–72 million litres between 2008 and 2030, depending on the energy scenario. For reference, almost 200 million litres of glyphosate-based formulations were used in 2009. For the diversified feedstock scenario, a five-fold to seven-fold increase over the base year is anticipated, compared with a seven-fold to ten-fold increase for the conventional low-diversification scenario.

Finally, it should be noted that glyphosate is not the only chemical compound being studied for its probable negative impacts on human health and the environment. Chemical use may pose risks because of intrinsic characteristics or because of the way chemicals are used. There is a wide range of agro-chemicals being used to support the high levels of productivity in Argentine agriculture and some of these are used to help improve the absorption of glyphosate, making its use more effective.

Glyphosate has transformed into one of the pillars of increased agricultural productivity in Argentina since the introduction of genetically modified (GM) seed varieties. Consequently, compared to previous agricultural technological packages, glyphosate use has made it possible to produce more in the same land area. Its use has brought about increased revenues and consequently an expansion in the area of land devoted to soy cultivation, which in turn has raised serious health and environmental concerns linked to the characteristics and volume of herbicide used and to herbicide application practices. This section has shown the large impacts that feedstock diversification and rational energy use could have on glyphosate demand for biofuel feedstock production. Thus, together with modified agricultural practices, feedstock diversification and rational energy use could constitute parts of a strategy for the reduction in glyphosate use in coming years.

3.6 Soil quality and macronutrients

Soil quality is related to, amongst other factors, the content of organic matter and the structure and availability of micro and macronutrients. The nutrient balance depends mainly on the types of agricultural practices and crops, as well as on soil and climate characteristics.
Soybean and corn cultivation may bring about a negative balance for some nutrients (nitrogen, phosphorus and potassium), mainly in marginal or unsuitable land, or when good agricultural practices regarding land use rotation (for instance, by traditional alternation with husbandry or grass) are not employed. Indeed, the yield is higher when traditional rotation practices are followed than when fertilisers are used without rotation.

In the case of the Pampas, the main area of soybean cultivation in Argentina, the balance of nutrients was negative for the period 1970–1999 (and deteriorated during the period), in the areas used for both corn and soybean production. During this period, the region lost 23 million tonnes of nutrients, 45.6% of which is accounted for by soybean crops and 26% by wheat. The cost of these nutrients represents almost 20% of the average gross margins of this production for that period [16]. In the case of soybean, the average losses during the 1990s for nitrogen, phosphorus and potassium were 64, 12 and 41 kg/hectare/year, respectively. Applying these values only to the projection of soybean and corn crops for biofuel production, an estimated 15 to 24 million tonnes of nutrients will be lost between 2008 and 2030, depending on the energy scenario and the feedstock mix (Figures 10 and 11).

The need to maintain productivity and soil fertility levels through the application of agrochemicals could also have negative impacts on water quality, depending on agricultural practices, for example, due to fertiliser runoff.

Figure 10. Loss of macronutrients – low diversification scenario

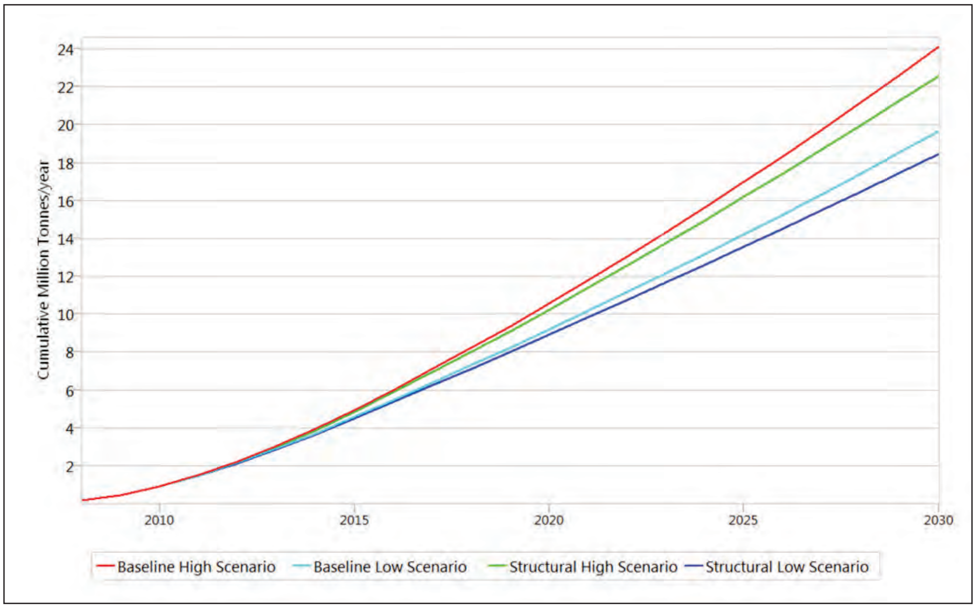
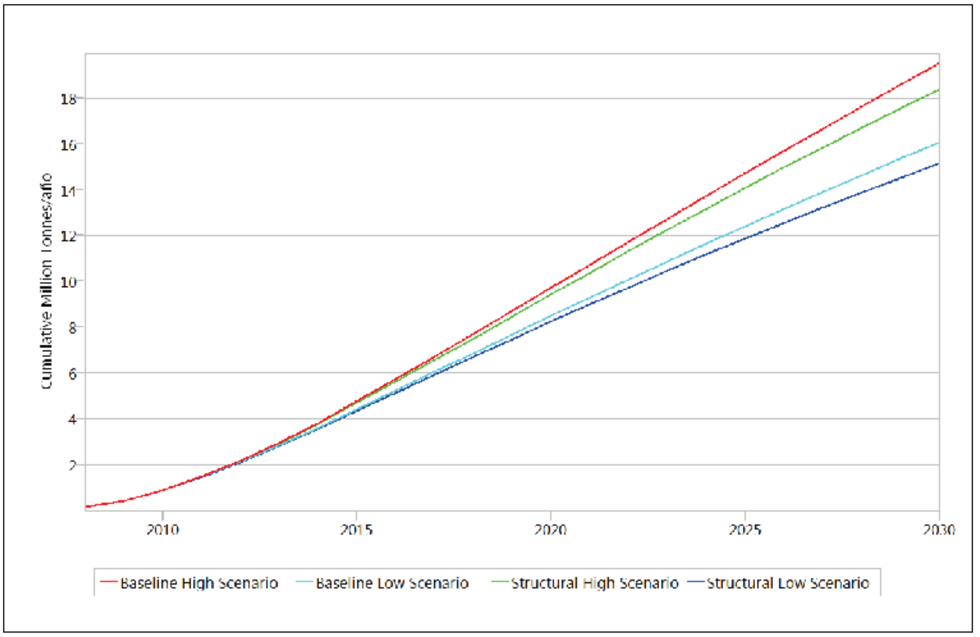


Figure 11. Loss of macronutrients – high diversification scenario



According to the scenarios discussed, if the present trend continues, the lack of proper agricultural practices for biofuel feedstock production could lead to significant losses of macronutrients, the magnitudes of which depend greatly on the mix of feedstock materials and rational energy use in the transport sector.

3.7 Employment

The significant increase in the productivity of soybean cultivation since the introduction of the package of technological developments previously mentioned (i.e., RR soybean, glyphosate, and no-till farming) has had a significant impact on the structure of rural employment.

Using the scarce quantitative data available, the effects of soybean cultivation for biofuels on employment – at the agricultural stage as well as for the associated agro-industrial activities and services – can be analysed on at least three different levels: 1) in relation to other agricultural practices related to the same crop, 2) in relation to alternative land uses and 3) in absolute terms. The last of these three levels does not reflect the real impacts of the introduction of biofuels on the labour sector because it takes into account only the jobs that are created and not the jobs that are displaced.

In the case of soybean cultivation, the difference between conventional and no-till farming systems lies in the loss of four out of five jobs at the agricultural stage, arising from a reduction of labour intensity from three man-hours to 40 man-minutes per hectare [17]. These reductions, which can be interpreted as increased productivity, do not lead to better wages. On the contrary, there is an increase in the percentage of temporary workers and a high incidence of undeclared work, which implies precarious working conditions. In turn, with respect to conventional farming systems, the implementation of the technological package generates jobs in related service sectors that require better qualifications but are fewer than those displaced at the agricultural stage [18]. Bearing in mind that no-till systems involve

nearly 16 million hectares of soybean cultivation in Argentina, the adoption of this approach in place of traditional farming represents a loss of approximately 29,000 jobs at the agricultural stage, each of which implies 160 daily wages/year.

With respect to alternative land uses, soy cultivation has displaced both traditional crops and cattle raising activities. In the latter case, cattle raising practices have transformed from extensive breeding to use of feed lots, most likely resulting in changing labour patterns. Unfortunately, quantitative data on labour intensity for these activities is scarce. One activity for which there is some data, is the displacement of fruit and vegetable growing activities, which implies fewer jobs at both the agricultural and agro-industrial stages [19]. Between 59 and 79 daily wages/hectare/year are estimated to be lost in the San Pedro department when soybean no-till systems displace fruit orchards. Similarly, between 149 and 199 daily-wages/hectare/year are lost when plant nurseries are replaced. Based on the land area displaced by soybean cultivation, it is estimated that 4.2 million daily wages were lost between 1991 and 2002 (equivalent to some 4,200 jobs at the agricultural stage or a loss of 65 jobs for every 100 hectares of fruit trees displaced)[8]. Furthermore, oil crops create fewer jobs for the same volume of production than fruit trees because jobs are also lost at the agro-industrial stage [20]. It is also significant that the conversion of land away from fruit trees is not easily reversible because they require several years to grow.

Between 1988 and 2002, the number of people living in APU decreased from 1,447,365 to 1,233,589, while those working there decreased by 257,000 over the same period.

However, it must be taken into account that there might be methodological deficiencies in analysing the technology and labour situation in relation to the use of transgenic soybean in Argentina. The main limitations are the following:

- Employment reductions eventually materialising in other activities (through land use competition) indicate the need for a thorough analysis of the labour situation affecting the agricultural sector as a whole.
- Contractual aspects, such as the number of working hours and the quality of work, are not considered.
- Indirect employment estimates can be inaccurate (some estimates indicate that indirect benefits can be quite large).

As a result of these limitations, the employment estimates for the soybean production chain presented in Table 7 should be considered tentative and hardly comparable with typical employment estimations. Similar considerations apply to other crops.

8 Considering that cultivating 55,000 hectares of soybeans required some 55,000 daily wages/year in 2003 (345 jobs), soybean production took up around 40 jobs in the displaced fruit hectares.

Table 7. Employment estimates for the soy production chain in Argentina (2003–4) in number of jobs (14.3 million hectares; 31.6 million tonnes)

	Activity	No. of Main Firms	Minimum (jobs)	Maximum (jobs)
Inputs	1. Seeds	5	1,250	1,250
	2. Fertilisers and pesticides	5	1,878	10,500
	3. Farming machines		19,350	23,000
Primary/ agricultural occupation	4. Rural farmers, producers		91,498(*)	108,500
	5. Contractors		37,700	56,500
Other activities	6. Storing and conditioning		36,961	55,036
	7.Transportation		19,000	38,000
	8. Milling or crushing	11 (95%)	7,000	11,000
	TOTAL		214,637	303,786

Source: Summarised from [21]

Note: (*) this figure is in the range of the labour intensity per ha mentioned in [20].

The introduction of a new technological package for the cultivation of GM soy generated a deep transformation of employment patterns in the agricultural sector. The net effect on employment figures and quality is difficult to assess because it depends on the activities that are displaced and involves taking into account different skill levels and working conditions. Nonetheless, from the scarce data available, it can be concluded that the introduction of GM soy has most likely produced a net decrease in low-skilled jobs and in the number of families that inhabit the rural areas in the main agricultural region. Because this process will most likely continue, it is advisable to implement policies to ensure adequate capacity building and reconversion of low-skilled labour to other activities and to guarantee adequate and fair labour conditions for all rural workers.

4. Conclusions

The mechanisms described in this paper have brought about the development of an important agro-industrial complex for the production of biodiesel from soybean, and to a lesser extent, ethanol from sugarcane. This complex is highly integrated and concentrated and has developed around agro-industrial activities that were already operational, such as sugar production from sugarcane and oil from soybean.

The high degree of integration and concentration of this agro-industrial complex is the reason that Argentina has a very low level of diversification with respect to feedstocks. This low level of diversification has both advantages and disadvantages. The advantages include economies of scale and increased levels of specialisation. The disadvantages include the vulnerability of crops competing with weeds and extreme climate conditions. Due to the low diversification of buyers (biodiesel to Europe and oil to China), there is also the danger that their imports might be discontinued. Other disadvantages derive from health, environmental and social impacts, mainly at the agricultural stage (sowing, maintenance tasks, harvesting).

The transformation of the agricultural sector over the last 15 years in Argentina has occurred hand-in-hand with the introduction of a package of technologies to boost soybean cultivation (transgenic soy and agro-chemicals), which has had important economic, social and environmental impacts. On the upside, earnings from soybean exports have revitalised some regional economies in the main agricultural areas (Santa Fe, Cordoba and Buenos Aires). On the downside, it has prompted the displacement of rural populations as a consequence of the increase in mechanisation and the subsequent qualitative and quantitative changes in rural employment patterns. The expansion of the agricultural frontier has contributed to this process, giving rise to conflicts with people who have only precarious ownership in the north of Argentina and to disputes over competing land uses in Patagonia. Soybean expansion has also displaced other crops and traditional animal husbandry, which has led to the use of feed lots for breeding cattle.

From an environmental point of view, extensive soybean cultivation has created concerns related to soil degradation and the effects of glyphosate on human health and biodiversity and of fertilisers on water quality. Advanced agricultural practices, such as no-till farming systems and the selective use of agro-chemicals, are attempts to reduce some of those impacts. The effects of these impacts as a whole are neither clear nor easy to compare. More extensive research is needed, along with a debate at the national level to prioritise objectives and agree on the scope, costs and benefits (not only monetary benefits) that the expansion of these activities is to have. Several indicators and studies indicate the need to perform further research to improve our knowledge of the potential negative impacts of large-scale biofuel development and also to promote a debate based on scientific evidence and the prevention of irreversible damage to human health and the environment. The available information points to the fact that additional measures are required if agriculture is to be sustainable.

An increase in domestic demand for biodiesel is expected. This may be met by a combination of fewer exports, a larger proportion of oil or beans being devoted to biodiesel production and increased soy production. The last alternative would imply an increase in the area of farmland devoted to soybean production (with consequent displacement of other agricultural activities), an increase in productivity or the expansion of the agricultural frontier (into pastures or shrub lands). All these options have impacts that need to be studied and compared in greater detail. This paper is a first approximation in that sense.

Although there is uncertainty regarding their potential level of penetration, the introduction of alternative feedstocks could modify some of the impacts associated with current biofuel production. In the case of bioethanol, there might be some potential for corn, sorghum, sugar beet and lignocellulose waste. For biodiesel, rapeseed, and to a lesser extent, other experimental crops such as Jatropha, safflower, paper spurge and seaweed could be added.

Argentina is developing the technology to use biodiesel in sectors other than transport, such as in agriculture (equipment capable of using B20, for instance) and electricity generation (equipment to use B5 has been authorised in an 845 MW turbo-steam plant). In addition, in 2010, the GENREN government programme, which promotes the use of renewable fuels, allotted the generation of 110.4 MW of installed capacity to four plants that will use biodiesel for electricity generation. The vehicle industry remains somewhat suspicious of the penetration of this biofuel and of the national government's explicit decision to mandate, in the short term, blending percentages approaching 10%, because of the uncertainty associated with the effects of biofuels on vehicle performance.

This paper has shown that in the case of two of the most commonly cited arguments for the development of biofuels (GHG emissions mitigation and employment creation), the benefits are questionable. In the first place, GHG emissions reduction is low (between 2% and 3.5%) when compared to total national

emissions, even excluding potential emissions from direct and indirect land use changes. This raises the issue of finding alternative ways of achieving these emissions reductions with fewer negative impacts. Second, while employment may be produced in absolute terms by the biofuel industry, when compared with traditional farming practices or some alternative land uses, the number of jobs is significantly reduced (four out of five jobs are lost in the agricultural stage in the former case). Thus, the positive impacts brought about by liquid biofuel development (e.g., increased productivity and revenues, skilled labour, reduction of diesel oil imports, and technological development) must be weighed against the negative impacts brought about by increased dependence on agrochemicals to sustain agricultural production, the reduction of diversified agricultural activities, the concentration of activities along the biofuel chain, and the displacement of alternative land uses. For example, it has been shown that the effective balance of major nutrients is negative under some current agricultural practices, leading to the continuous depletion of soil nutrients that could reach between 15 and 24 million tonnes between 2008 and 2030. Glyphosate use has intensified in recent years (from 0.5 to 6.1 litres/hectare), and its consumption for biofuel production could reach between 48 and 72 million litres in 2030. This projected growth in glyphosate use creates increasing concerns about its impacts on human health and the environment.

Several trade-offs must be found to address the negative impacts while preserving some of the positive impacts of biofuel development in Argentina. This in turn requires a careful assessment of the positive and negative impacts of the different biofuel energy chains that are relevant for Argentina to provide a sound basis for formulating and implementing promotion measures. Incentives that do not distinguish between feedstock materials, practices and local conditions should be carefully reviewed to avoid promoting unsustainable practices. Land use planning and zoning is needed for the whole country. In the meantime, diversification and the adoption of a precautionary approach seem advisable. This could imply the promotion of feedstocks that can be grown on marginal lands (along with a clear definition of these lands) or that constitute the residues of other industries, as well as the adoption of measures to increase energy efficiency and rational energy use in the transport sector. The broad scope of these recommendations points to the fact that this is a very complex issue that encompasses many sectors of the national economy and international trade and that has multiple and case-specific impacts, both positive and negative, over several development dimensions.

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Part III

Cross-cutting sustainability issues for first and second generation biofuels

Transporting harvested sugarcane in Kenya. Photo credit: Flickr

5. Potential of Liquid Biofuels in Kenya

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1. Introduction

1.1 Brief overview of the study

Liquid biofuels are high on the agenda of development discussion and research, attracting equally strong negative and positive assessments. On the positive side, liquid biofuels have been touted as having the potential to significantly reduce Africa's dependence on imported petroleum products. On the other hand, critics have highlighted the negative consequences of biofuel development, which include: the clearing of virgin forests and the conversion of land from food production to biofuel production, which contributes to food insecurity. Both perspectives have generated a significant amount of debate, with questions being raised as to whether fuel production should be prioritised over food production in a region that has been facing declining per capita food production.

This study follows up on a previous GNESD study prepared by AFREPREN/FWD that reviewed the status of bioenergy development in Kenya. That study focused on the development of solid biomass cogeneration in the country. The current study reviews the potential and status of liquid biofuel development in Kenya. The focus in this study is on the development of "first-generation" biofuels, specifically ethanol, and to a lesser extent, biodiesel.

1.2 Justification and scope of the study

This study is timely. Like the economies of many other developing countries that are net importers of oil, the Kenyan economy is feeling the adverse impact of high and unstable world oil prices. Most biofuel research studies undertaken in Kenya have focused on estimating liquid biofuel production in the country. There have been very few widely disseminated studies that have assessed the implications of large-scale biofuel production or critically examined the policy dimension of biofuel development.

- This study aims to partly redress this gap, with a special emphasis on the sustainability of liquid biofuel production in Kenya and its potential for improving rural livelihoods. Specifically, this study investigates the potential of selected biofuels in Kenya and analyses key plans of the Government of Kenya for developing the biofuel industry. The scope of the study includes the following:Analysing biofuel production activities in Kenya from environmental, economic and social perspectives.
- Identifying and suggesting opportunities presented by the synergies between the environmental, economic and social dimensions specific to biofuels in Kenya, through the adoption of an effective and integrated approach.

- Minimising any trade-off between biofuel and food production that results from the conversion of land used for food.
- Recommending biofuel production that would result in significant reduction of net greenhouse gas emissions on a life-cycle analysis basis.
- Estimating, where possible, the potential quantitative and qualitative benefits and costs of biofuels from environmental, economic and social perspectives.

1.3 Study challenges and limitations

The key challenges and limitations in undertaking this study included the dynamic nature of energy and agricultural policy development in Kenya, particularly at a time when the government is under pressure to ensure an affordable and sustainable supply of fuel. While the author was fortunate to gain access to relevant policy documents, access to reliable data and information on the potential for liquid biofuel production in Kenya was difficult to obtain. In addition, various surveys and reports provide different and often conflicting findings and perspectives. An effort was made to reconcile data differences and conflicts to provide a sound empirical basis for undertaking a balanced assessment of liquid biofuel development in Kenya.

2. Background to Kenya's energy and agro-industry sectors

Kenya's energy and agro-industry sectors are the two principal pillars of the future development of the country's liquid biofuel industry. The following subsections review these two sectors, starting with a brief examination of Kenya's energy supply and consumption patterns, followed by a brief analysis of energy sector developments and ending with a short assessment of key agricultural performance indicators.

2.1 The energy sector

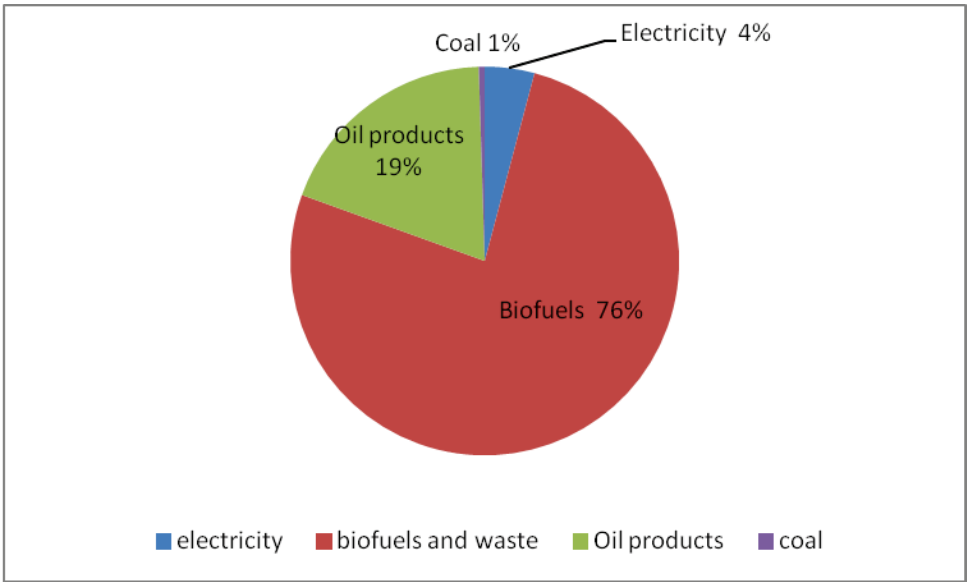
2.1.1 Brief overview of the energy sector

Kenya's local energy resources include biomass, hydropower, geothermal power and other renewable sources of energy such as solar energy, wind energy, small-hydropower and biomass-based cogeneration. Until recently, there were no proven economically viable oil reserves in the country. Recent discoveries of oil fields in a remote part of the country could take up to a decade to reach full production potential. In the meantime, Kenya will need to continue importing a substantial amount of crude oil and refined petroleum products to meet the country's growing demand for fossil fuels.

The country's energy consumption is characterised by an overwhelming dependence on traditional biomass energy resources at the household level (Figure 1), with fuel wood for the rural population and charcoal for urban households accounting for 76% of this consumption (see figure 1). Petroleum products are consumed across all sectors and constitute the second most important sources of energy in the country. The major consumers of petroleum products are the transport, manufacturing and commercial sectors. On the other hand, the manufacturing sector and the urban-based middle and upper classes are the major consumers of electricity.

At the national level, an estimated 23% of the population has access to electricity, with access rates for urban areas being substantially higher than those of rural areas, at 49% and 7.2%, respectively [1,2]. The bulk of the Kenyan population, 77% – close to 31.3 million Kenyans – has no access to electricity[3,4].

Figure 1: Consumption of energy resources[1] in Kenya (2009)



Source: [3]

Figure 1 shows that modern energy consumption (electricity, coal and petroleum products) in Kenya is low. This is due in part to suppressed demand as a result of low incomes and is compounded by inadequate access to modern energy options such as electricity and petroleum products. According to the latest World Bank statistics [5]. Kenya's modern energy consumption per capita is estimated at 485 kilograms of oil equivalent (kgoe), which is lower than the average of 662 kgoe per capita for Sub-Saharan Africa and approximately a quarter of the world average of 1,819 kgoe per capita.

Although renewable energy development in Kenya is relatively modest and in certain respects still at an embryonic stage of development, it has the potential to reverse the low levels of access to modern energy options.

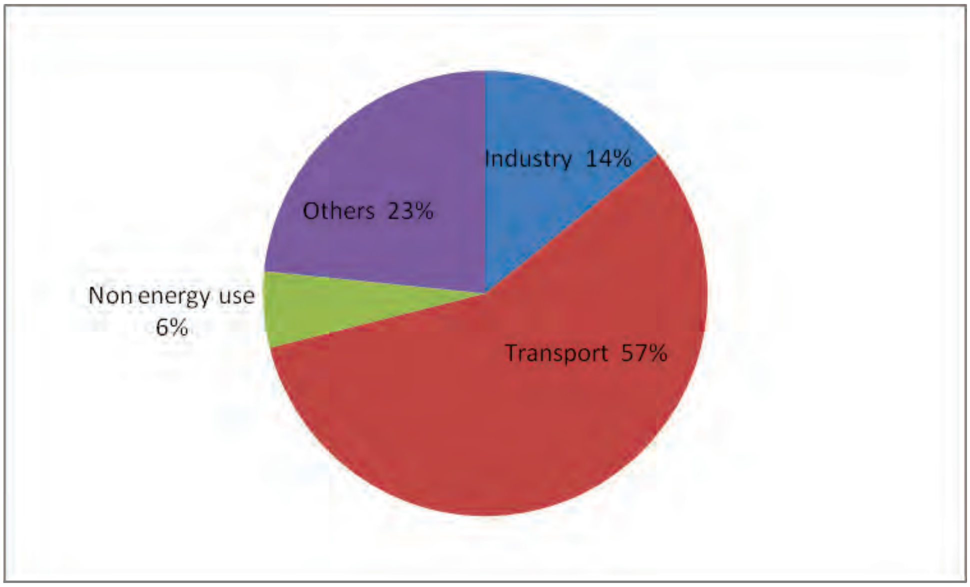
2.1.2 Key characteristics of the oil sector

As mentioned earlier, until recently, Kenya had no proven economically viable oil reserves. However, a major oil discovery was recently made in Kenya using exploratory wells, and this discovery could change the face of the nation. However, experts are quick to mention that it could take up to five years for oil production in Kenya to commence [6] and perhaps a decade or more to reach full production potential.

Meanwhile, Kenya imports crude oil and refined products to meet its demand for petroleum. As shown in figure 2, the transport sector consumes the bulk of oil products in the country. This is followed by the industrial sector, which uses oil primarily for burning in boiler furnaces for heat applications. Other consumers include commercial and public services, agriculture/forestry and non-specified uses, which together account for 23% of the consumption of oil products.

1 Based on total final consumption.

Figure 2: Consumption of oil products in Kenya by sector (2009)



Source: [3]

In 2008, expenditure for imported petroleum products accounted for 25.7% of the country's total import bill [7]. The adverse effect on Kenya of high and unstable world oil prices is significant. For example, Kenya's expenditures on crude oil imports in 2008 were 62.3% higher than in 2007 [12], mainly due to increases in world oil prices, as actual volumes of oil imports declined. The high world oil prices experienced in 2008 led to a decline of 4.5% in total oil product imports, from 3,691.8 thousand metric tonnes in 2007 to 3,523.2 thousand metric tonnes in 2008 (Table 1) [12].

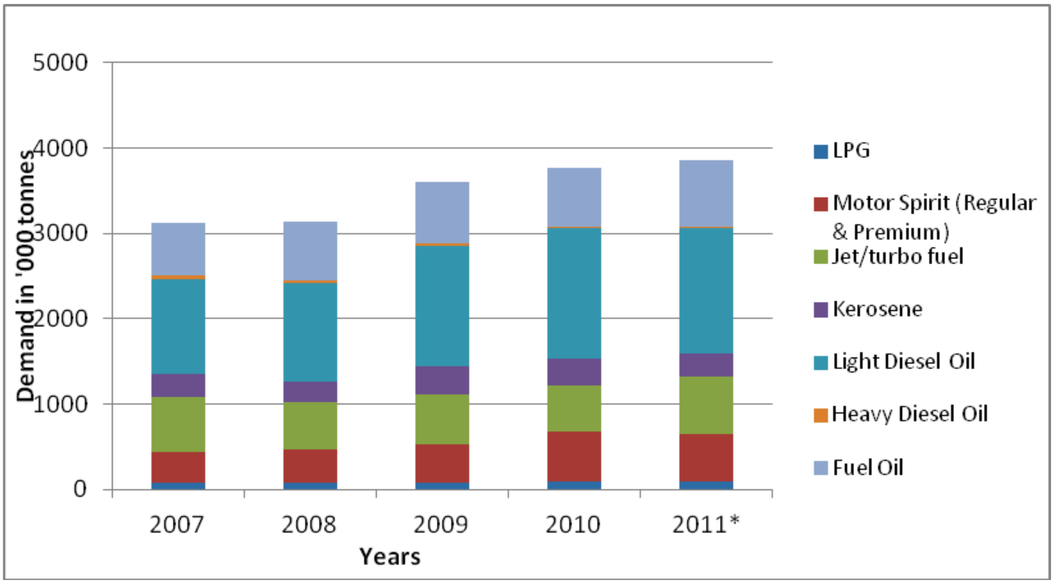
Table 1: Imports of petroleum by Kenya (2004 to 2008)

IMPORTS	Quantity ('000 Tonnes)							
Year	2004	2005	2006	2007	2008	2009	2010	2011
Crude petroleum	2,043.8	1,774.0	1,643.2	1,598.7	1,687.7	1,610.1	1,551.5	1,772.1
Petroleum fuels	1,491.7	1,130.9	1,402.7	1,999.9	1,704.5	2,259.0	2,071.9	2,337.9
Lubricating oils	11.9	0.4	2.6	-	12.4	17.0	3.0	-
Lubricating greases	29.7	66.8	124.4	93.2	118.6	265	218.2	278.0
TOTAL	**3,577.1**	**2,972.1**	**3,172.9**	**3,691.8**	**3,523.2**	**4,151.1**	**3,844.6**	**4,388.0**

Sources:[1,12]

Crude oil imports also decreased by slightly more than 4% in 2009, from 1,687.7 thousand tonnes in 2008 to 1,610.1 thousand tonnes (KNBS, 2009; PIEA, 2010a). Nonetheless, the demand for motor spirit (regular and premium) at the national level increased by slightly over 21%, from 381.3 thousand tonnes in 2008 to 461.7 thousand tonnes in 2009, as shown in Figure 3 [9].

Figure 3: Petroleum demand in Kenya (2007–2011)



*provisional data

Source: [10]

A portion of the imported crude oil is refined at the country's only refinery in Mombasa. Kenya Petroleum Refineries Ltd (KPRL) is a joint venture between the government and several oil majors. In 2008, the total throughput of the refinery was 1,582.7 thousand tonnes (Table 2) [10].. This represented a decline of approximately 5% in comparison with the previous year. This decline is attributed to high world oil prices [10].

Table 2: Crude oil intake at Kenya's refinery by type (2004–2008)

Crude Intake	A.P.I. Gravity**	2004	2005	2006	2007	2008	2009	2010	2011*
Arabian medium	31.0	408.9	418.8	457.4	249.8	252.6	84.0	83.9	0
Murban	39.6	1,295.4	1,227.9	1,201.0	1,403.4	1,334.9	1,545.5	1,495.1	1,736.5
Slops[2]		-1.40	-1.52	-7.27	9.6	-4.80	-24.4	23.3	5.7
TOTAL		1,702.9	1,645.2	1,651.1	1,662.8	1,582.7	1,605.0	1,602.3	1,742.2

*Provisional

** A.P.I. Gravity refers to the density relative to water

Note: Negative numbers imply that the product was used for blending

Source:[10]

2 A mixture of crude and pure products created during processing and recycling (KNBS, 2009)

Most of KPRL's production is transported via the Mombasa-Nairobi oil pipeline. The supply chain of petroleum products runs from the refinery to depots, retail outlets and consumers. The retail outlets are predominantly owned by private entities and to a lesser extent by state-owned corporations that supply the products to consumers. In 2010, Total Kenya had the largest share of market sales, at slightly over 27%, compared to its closest competitors, KenolKobil (18.3%), Kenya Shell (16.9%) and Libya Oil Kenya Ltd (12.6%) [12].

The government has tried to encourage consumption of liquefied petroleum gas (LPG) to reduce reliance on traditional biomass energy fuel and to conserve forests, which function as key carbon sinks and water catchment areas for the country. Evidence of the government's efforts to increase LPG consumption can be witnessed in sales figures. For example, in 2011, LPG demand was 91,600 tonnes, compared to 64,600 tonnes in 2006, a 42% increase[12].

With this brief review of Kenya's energy sector, we now turn to the second pillar of biofuel energy development in Kenya, agriculture and agro-industries.

2.2 Overview of the agro-industry

Farming practices in Kenya are largely reliant on bimodal rainfall. The two rainfall seasons are March to April (long rains) and October to December (short rains). As a result of increased climate variability, which is believed by some analysts to be due to climate change, some regions of Kenya have been receiving above-average rainfall in some years, while others have been receiving below- average rainfall. This has adversely affected agricultural output, as much of the sector is rain-dependent.

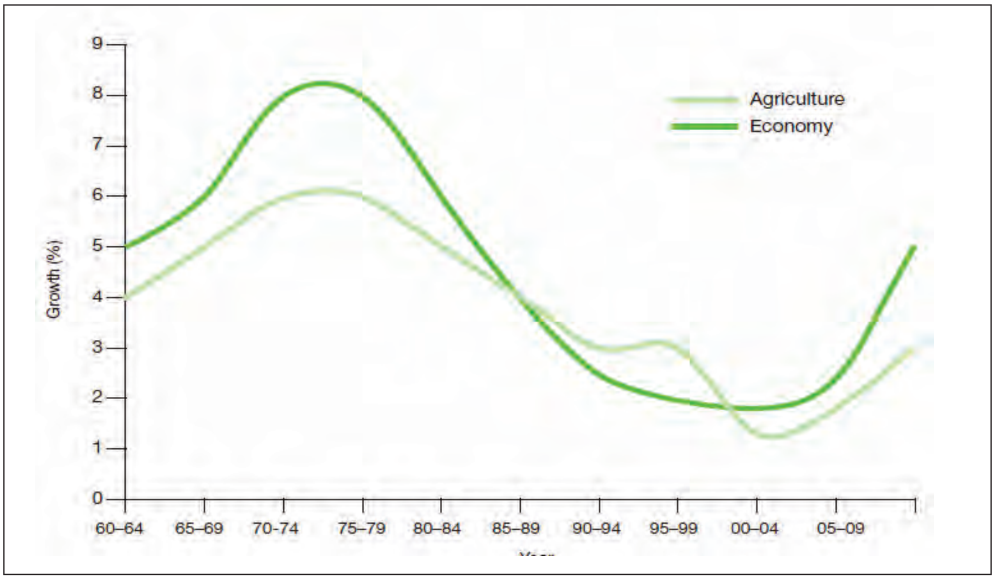
Irrigation in Kenya is mainly carried out in a few large-scale schemes such as that for rice in the western and central areas. Various individual farmers have developed their own systems of irrigation, especially for horticulture and export crops such as coffee. Of the irrigated land in the country, 40% is held by large commercial farms, while smallholder farmers account for 42% and government-managed schemes account for just 18%[11].

Crop production is classified into three types, namely; food, cash/industrial and horticultural crops. Kenya's food crops consist largely of maize, rice, wheat, sorghum, potato, cassava, vegetables and beans. The main industrial crops are tea, coffee, sugarcane, cotton, sunflower, pyrethrum, barley, tobacco, sisal, coconut and bixa. These crops contribute 55% of agricultural exports[13]. Alongside crop production, there are three non-crop sub-sectors, namely livestock, fisheries and forestry.

2.2.1 Socio-economic implications of agriculture

Agriculture is the principal pillar of sustainable and economic development of Kenya. Currently, agriculture directly contributes 24% of GDP[12]. This represents a decline, however, from the 31.1% contribution of agriculture to GDP in 1995[9], which is largely attributed to the efforts made to diversify the economy into other sectors. The agricultural sector, however, remains central to Kenya's economy. Figure 4 shows the correlation between agriculture and the rate of GDP growth in the country.

Figure 4: Trends in agricultural and economic growth (1960–2008)



Source: [13]

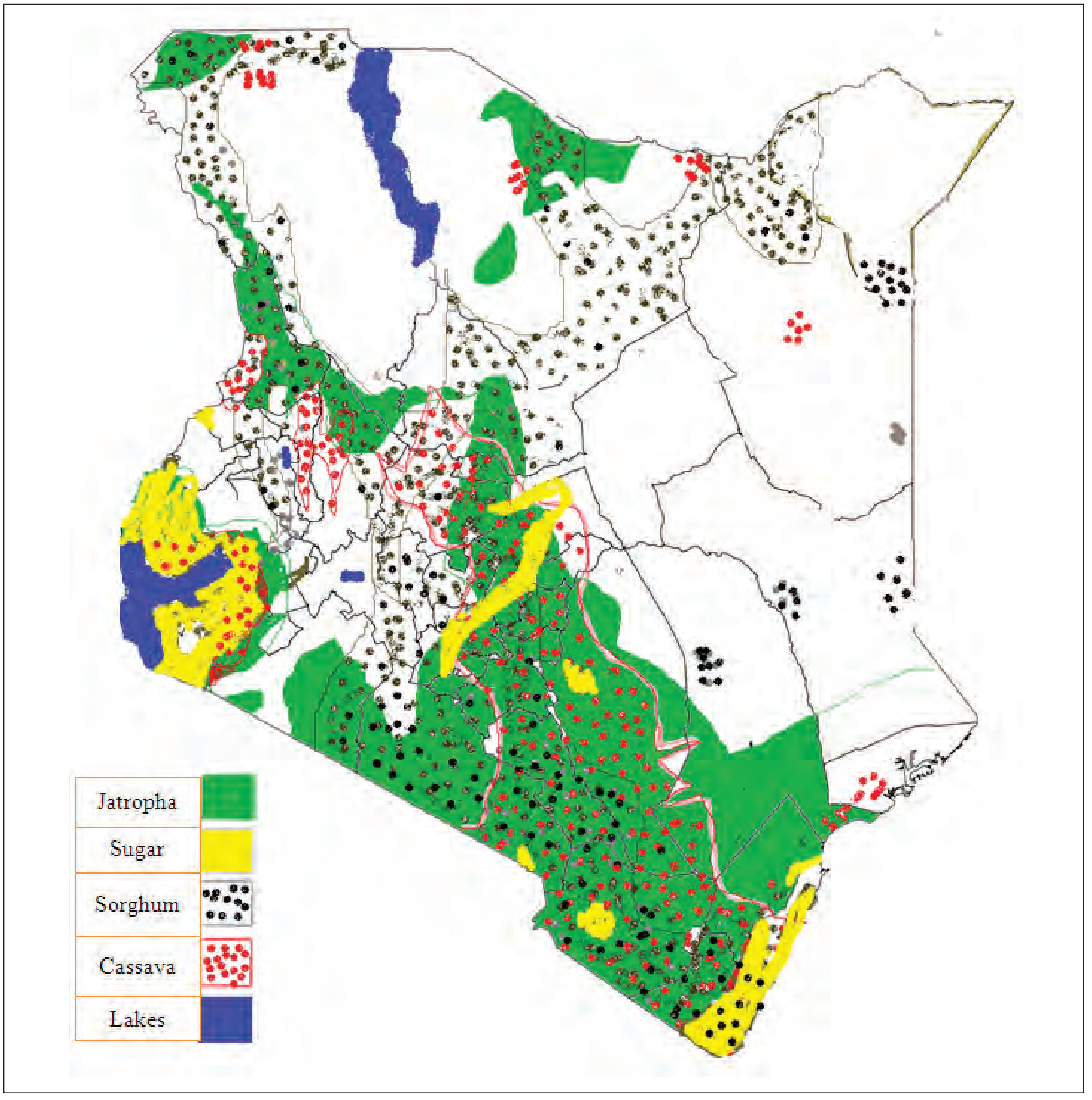
Agriculture generates 65% of Kenya's total exports. More than a third of Kenya's agricultural produce is destined for export. The sector accounts for more than 18% of formal employment and more than 70% of informal employment in rural areas[13].. In total, agriculture employs over 80% of Kenya's workforce[13]. The tea and sugar sub-sectors alone support – directly or indirectly – nearly a quarter of Kenya's population[10]. Currently, the sugar industry has approximately 250,000 small-scale farmers, and over six million Kenyans are reported to be directly or indirectly dependent on this industry[10]. . The tea industry employs over three million people, directly or indirectly[12].

2.2.2 Agriculture and biofuels

Kenya has seven ecological zones: coastal lowland, tropical alpine, upper highland, lower highland, upper midland, lower midland and lowland. Of these seven zones, three are considered the country's main productive zones, based on the amount of annual rainfall. These high-rainfall zones receive more than 1,000 mm (millimetres) of rainfall annually, occupy less than 20% of the productive agricultural land and are home to approximately 50% of the country's population [13]. These areas account for most of the country's output of tea, pyrethrum, potatoes, coffee, vegetables, milk and other agricultural produce and livestock. The remaining areas occupy nearly 80% of the country's land area and are home to the remaining half of the country's population [13]. These areas are categorised as medium-rainfall zones, which receive between 750 mm and 1,000 mm annually, and low-rainfall zones, which receive 200–750 mm of rainfall annually.

2. A mixture of crude and pure products created during processing and recycling (KNBS, 2009)

Figure 5: Potential of selected biofuel crops in Kenya

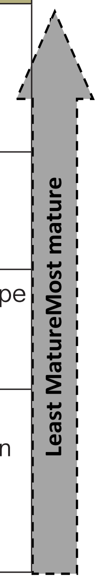


Source: Adapted from[13]

According to the Agricultural Sector Development Strategy (2010), Kenya has vast opportunities for expansion, especially in the production of biofuels from sugar cane, maize, millet, sorghum, Jatropha and other oil-bearing seeds. Figure 5 shows locations in the country where some of these biofuel crops can be grown without unduly disrupting intricate patterns of land use and nutrient balances. Table 3 presents the level of development of selected crops that are suitable for liquid biofuel production. Several of these crops (e.g., sugar cane) are already widely grown in the country.

Table 3: Liquid fuels from biomass

Fuel	Source	Benefits	Maturity
Grain/sugar ethanol	Corn, sorghum, wheat, sugarcane	High-octane fuel for petroleum blends Widely available renewable sources	Commercially proven
Bio-diesel	Vegetable oil, fats, greases	Reduce emissions Increase diesel fuel lubricity	Commercially proven
Green diesel and petroleum	Organic oil and fats, blended with crude oil	Superior feedstock for refineries Low-sulphur fuels	Commercial trials in Europe and Brazil
Cellulosic ethanol	Grasses, wood, chips, agricultural residues	High-octane fuel for petroleum blends Probably the only viable scenario for sustainable ethanol production	Demo-plant in Sweden; commercial demonstration in US by 2012



Source: [14]

Dedicated energy plantations are not yet widespread in Africa, so there is little empirical evidence of their benefits for the poor. Nonetheless, to better understand how energy plantations might affect the poor, it is useful to distinguish between direct and indirect impacts.

Energy plantations have direct impact primarily on nearby rural communities. Negative impacts include possible dispossession of land among the poor in areas with insecure land tenure, which may result in increased poverty and food insecurity. Global markets for biofuels can be restricted due to unforeseen regulatory development or dramatic changes in global market prices for key feedstocks or major changes in land use. These developments can have a devastating impact on poor communities that have invested in energy plantations or rely on food imports from countries that may be experiencing abrupt price changes or major land use changes. Without appropriate, sensitive, and equitable management, large-scale modern biomass energy development can lead to further marginalisation of the rural poor.

It is, however, possible that the growth and development of dedicated biofuel plantations could lead to increased incomes for the poor (such as smallholder sugar farmers) if a well-designed revenue-sharing scheme is established. Positive impacts could also include potential increase in employment (in agriculture or bioenergy production). Management of energy plantations by individual households or community groups can yield significant benefits to the poor. Community-managed energy plantations are particularly attractive because they allow smallholder farmers to work together and enjoy the benefits of large-scale farming.

As dedicated large-scale biofuel energy plantations are not yet widespread in Kenya, this study focuses on the efficient exploitation of existing agricultural wastes, which offer significant potential for developing bioenergy without unduly disrupting existing agricultural practices and food production or requiring

that new land be put into production. Some of the most common crop wastes suitable for bioenergy development are sugarcane bagasse, sisal waste, coffee husk, rice husk, maize cobs, and banana leaves. Unlike many other crop wastes, these waste products are generated during agro-processing and are rarely returned to the field. Consequently, the use of such agricultural wastes for energy generation is unlikely to have a detrimental impact on soil management and food production and indeed could potentially be an additional source of revenue for the poor. This study focuses on ethanol produced from a by-product of sugarcane processing, namely, molasses. As shown in table 3, ethanol production from sugarcane is a mature technology with a solid track record in many developing countries. As ethanol from molasses relies on a waste product, it has positive impacts on the poor and could actually be very beneficial if appropriate revenue-sharing mechanisms are in place.

3. Status of liquid biofuel development in Kenya

This section briefly examines Kenya's past biofuel experience and provides a rationale for the recent developments in the biofuel sub-sector in the country.

3.1 Kenya's past experience with biofuels

Kenya's past experience with biofuels can be traced back to the 1980s, when the country began producing ethanol for blending with petroleum as a response to the oil crisis. The goal of Kenya's first ethanol programme was to promote widespread use of a 10% ethanol blend in transport fuel.

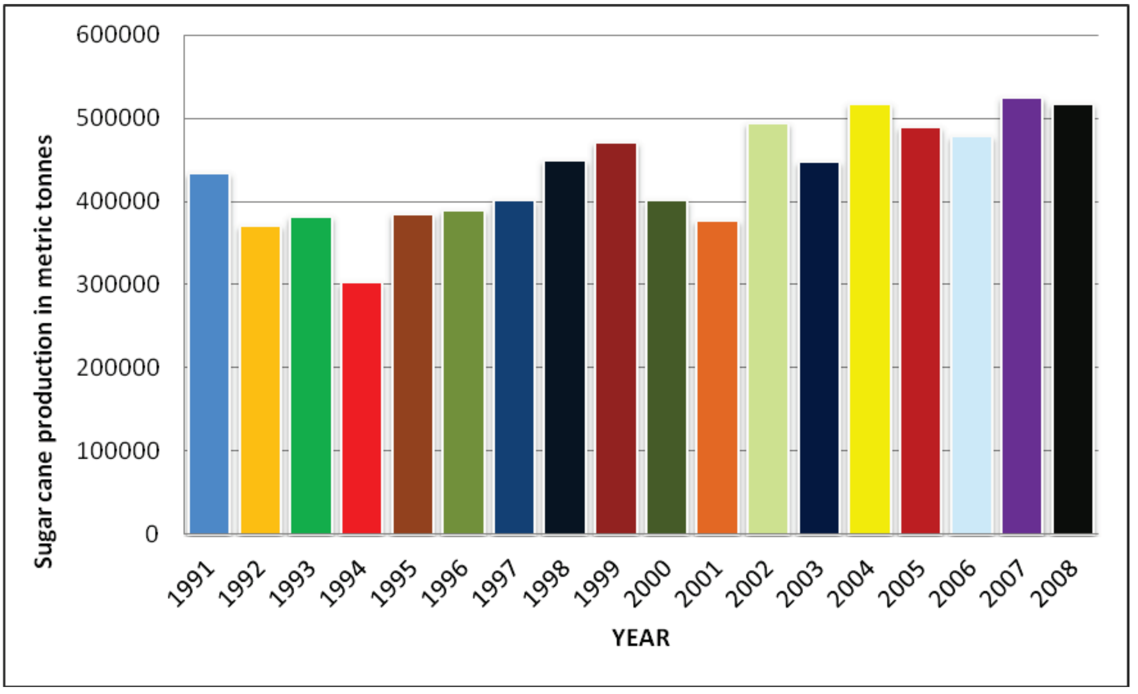
A single, private company, Agro Chemical Food Company, produced all the ethanol used for blending [1]. The ethanol produced by the company was transported to the Nairobi fuel depot from the Muhoroni-based factory and blended with petroleum for the retail market. By the late 1980s, it was not feasible to blend petrol, as the gasohol (petroleum blended with ethanol) price was higher than the price of the refined unblended fuel. This was made worse by a surge in the price of ethanol for use in alcoholic beverages and a deterioration of the ethanol production and transportation infrastructure in Kenya. As a result, ethanol blending was discontinued, but ethanol continued to be produced for the alcohol beverage market as well as for other non-transport fuel applications.

3.2 Motivation for biofuel development

High world oil prices motivated Kenya to join many other Sub-Saharan African countries in encouraging bioenergy development. Most of the existing biofuel initiatives are driven by non-governmental organisations (NGOs), and to a limited extent, the public and private sector. More than thirty institutions in Kenya are involved in biofuel initiatives (Kalua, 2008), including government ministries, private companies, NGOs, community-based organisations (CBOs), and research and training institutions.

Kenya has significant potential for biofuel development from various crop sources. However, this paper is focused on ethanol production from sugarcane because of Kenya's experience with this type of ethanol production and its established industry, despite some challenges such as the availability of water. Kenya has a total of nine operational sugar factories, both privately and publicly owned, with a crushing capacity of 9.286 million tonnes per year [21]. The country's annual sugarcane production has been growing, and it is projected that by 2014, cane production will be 8,010,834 tonnes, in comparison to 5,165,786 tonnes of cane delivered in 2008. Figure 6 presents available data on sugarcane production in Kenya between 1991 and 2008.

Figure 6: Total sugarcane production in metric tonnes



Source: [21]

Based on the 2008 production of 180,000 tonnes of molasses from the sugar production process, it is estimated that approximately 40 million litres of ethanol could be produced annually from molasses[15,16,17]. This is equivalent to slightly over 8% of Kenya's petroleum consumption in 2008 and could reduce Kenya's bill for petroleum imports by about US$ 21 million per annum[3] [10].

Table 4 shows how fluctuations in world crude oil prices can adversely impact the road transport sector. Increases in the price of fuels have a concomitant impact on transportation costs. These prices are listed in Table 4.

3 This figure does not take into account the production facilities and expertise that may need to be imported.

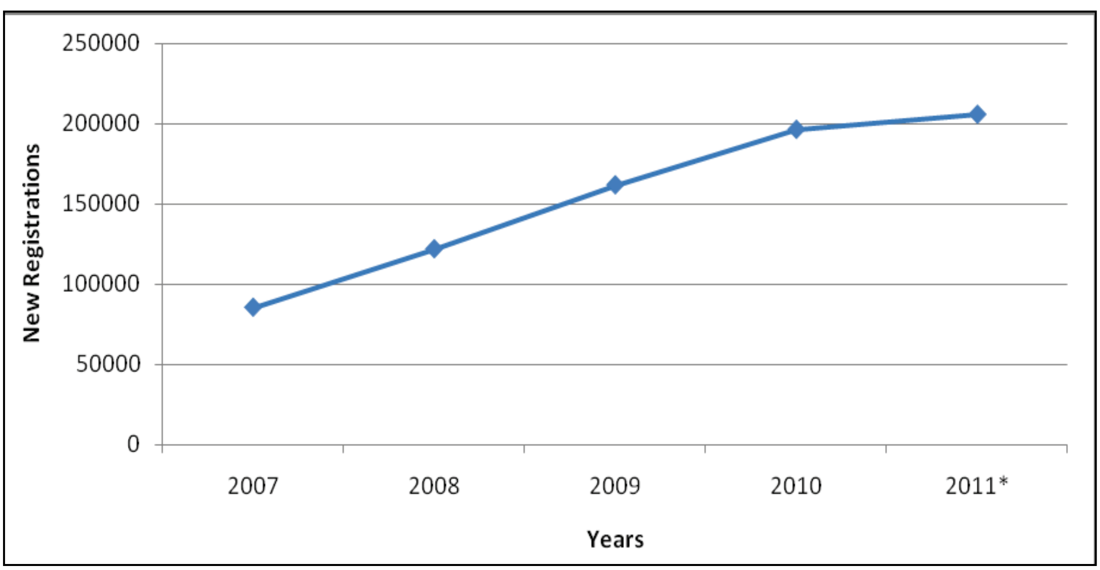
Table 4: Super and diesel pump prices (USD) in Nairobi

Year	2005		2006		2007		2008		2009	
Month	Super	Diesel	Super	Diesel	Super	Diesel	Super	Diesel	Super	Diesel
January	0.82	0.69	0.89	0.77	0.89	0.77	1.08	0.96	0.88	0.85
February	0.81	0.68	0.88	0.76	0.89	0.77	1.09	0.97	0.88	0.77
March	0.80	0.67	0.89	0.77	0.90	0.79	1.15	1.03	0.87	0.75
April	0.85	0.73	0.89	0.78	0.95	0.83	1.17	1.05	0.89	0.82
May	0.85	0.73	0.91	0.79	0.95	0.83	1.19	1.08	0.90	0.82
June	0.86	0.74	0.95	0.83	0.96	0.84	1.21	1.14	0.94	0.89
July	0.85	0.73	0.99	0.87	0.96	0.84	1.27	1.22	0.99	0.89
August	0.76	0.76	0.99	0.86	0.97	0.85	1.29	1.23	0.99	0.89
September	0.90	0.77	1.01	0.88	0.98	0.86	1.26	1.21	0.99	0.89
October	0.89	0.76	0.94	0.82	1.01	0.89	1.17	1.14	0.99	0.89
November	0.88	0.76	0.92	0.79	1.03	0.91	1.09	1.03	0.99	0.89

Source[12]

High fuel prices are compounded by growth in Kenya's vehicle fleet, which has increased demand for transport fuel (Figure 7). For example, 205,841 new vehicles were registered in 2011, compared to 85,324 units registered in 2007[10,18].

Figure 7: New registration of road motor vehicles (2007–2011)



*Provisional

Sources: [10,27]

This substantial increase in new motor vehicles increases consumption of petroleum products. Petroleum statistics indicate that petroleum and diesel sales increased from 1,225,851 m^3 in 2003 to 2,273,591 m^3 in 2009, an increase of 85%[12]. Blending of petroleum with ethanol and diesel with biodiesel could reduce the consumption of these fuels by 10% and 5%, respectively.

Sugar market protection measures that were imposed in Kenya by the Common Market for East and Southern Africa (COMESA) benefit Kenyan sugar companies. The measures are slated to cease by 2014 [19]. Sugar factories perceive ethanol production as an alternative avenue for revenue generation that can compensate for the expected lower revenues from sugar production arising from removal of sugar market protection measures in Kenya and stiffer competition from other leading sugar producers in the region, whose production costs are much lower than those of most Kenyan sugar companies. The higher production costs in Kenya are a result of inadequate investment in efficient factory equipment. A number of sugar sector analysts believe only three Kenyan sugar companies (West Kenya, Mumias Sugar Company, and Kibos & Allied Industries) would survive if the COMESA sugar market protection measures were lifted in Kenya because these companies can produce sugar at costs similar to competing sugar factories in other COMESA countries. Diversification into biofuels would allow more local sugar companies to compete more effectively with the regional COMESA competitors.

3.3 Key recent developments in biofuel development

3.3.1 Biodiesel

With approximately 80% of the country's land mass considered arid or semi-arid, there is significant interest in the development of *Jatropha curcas* – a plant that is said to do well in marginal land and that can be used to produce biodiesel as a cleaner substitute for crude, oil-based diesel. Jatropha is mainly grown in Kitui, Thika, Namanga, Kajiado, Malindi, Nyanza, Nakuru, Marakwet, and Naivasha, in the coastal regions, and in Meru. A study carried out in 2008 estimates that 3,860 acres of Kenyan land are under Jatropha cultivation[20].

In comparison to ethanol, biodiesel production is still in its infancy stage in Kenya. Most of the biodiesel initiatives underway are based on Jatropha. The entrance of Japanese firms Hydronet Energy Company Ltd., and Biwako Bio-Laboratory Inc., marked the commencement of commercial biodiesel development in Kenya from the Jatropha plant [21,24]. In addition, international partnerships, such as the partnership of Autoterminal Japan Ltd., and Green Africa Foundation, support the planting of *Jatropha curcas*. The Japanese firm contributes a dollar for every vehicle inspected in Japan that is built for export to Kenya, while Green Africa Foundation uses the funds to plant Jatropha [12]. However, it has recently become apparent that the prospects for Jatropha are not as promising as originally thought [22].

A recent assessment of the performance of Jatropha conducted by the FACT[4] Foundation at the request of an international NGO brought to light some disappointing revelations with regard to Jatropha cultivated in the Gwassi Hills areas of Kenya since the year 2009. The enthusiasm of most Jatropha farmers in the region has been dampened after registering yields far below expectations. The seed yield of Jatropha has also been found to be very low, making this crop unattractive to farmers. The negative experience to date with Jatropha contributed to the decision by the National Environmental Management Authority (NEMA) to advise the Kenyan government to halt biofuel production in the coastal region of Kenya. NEMA's decision was also driven by fears expressed by environmentalists that biofuel production threatens eco-sensitive woodlands and other coastal habitats [23,24].

4 http://www.fact-foundation.com/en?cm=79%2C239%2C303%2C348&listciid=1191

3.3.2 Ethanol

Kenya has over three decades of experience in the ethanol production industry. Currently, there are two companies producing ethanol, the Agro Chemical Food Company and Spectre International, with a combined production capacity of 46 million litres per year[1]. These companies are dependent on molasses from the sugar factories operating in western Kenya. The Mumias Sugar Company is the major supplier of molasses to the Agro Chemical Food Company and Spectre International. Mumias is, however, developing its own ethanol plant to utilise the molasses it currently sells to those two companies, although it does plan to continue supplying molasses to the two companies at reduced volumes.

4. Review of energy and agricultural policies affecting biofuel development

The development of liquid biofuels is guided by the policies governing the energy and agricultural sectors, although policies and regulations in other sectors (e.g., infrastructure) can have an indirect impact. This section presents the key policy, legal and regulatory frameworks that affect liquid biofuel development in Kenya.

4.1 Review of biofuel-related energy policies and regulation

In Kenya, the key energy policy document is the Sessional Paper No. 4 of 2004 (Energy Policy). This document outlines the government's aspirations for the energy sector through 2024. The Energy Policy strongly supports liquid biofuel development, namely, ethanol and biodiesel.

The 2004 Energy Policy recognises Kenya's experience with biofuels, particularly its 10-year ethanol-blending programme that was discontinued in 1993, in part due to mismanagement and an unsustainable pricing regime that resulted from low world oil prices[25]. The Energy Policy calls for reintroduction of ethanol for petroleum blending and urges that any new ethanol-blending initiative include measures that are necessary to avoid the management and pricing problems that led to cessation of Kenya's first ethanol-blending programme.

With respect to biodiesel development, the Energy Policy appears to support its advancement, albeit with a measure of caution. The policy acknowledges that in spite of the existing potential, Kenya has no known experience in biodiesel production or use. The policy recognises that biodiesel development is faced with the challenge of a shortage of arable (high-potential) land, as most of it is used for food production. The policy recommends that the production of trees and crops for biodiesel be confined to low- and medium-potential lands, subject to prevailing land use policies, to avoid competition with food-producing land. In addition, the Energy Policy highlights the importance of research and development and learning from other countries as crucial prerequisites to the successful implementation of biodiesel development.

- While the Energy Policy explicitly supports biofuel development, it does not identify relevant activities in its Action Plans for the short, medium and long terms. Nonetheless, a few key policy statements are made that provide sufficient assurance of the Kenya government's commitment to biofuel development. In particular, there are indications that the government will do the following:Re-introduce ethanol as a motor fuel in its long-term policy to enhance the security of supply and redress the trade imbalance arising from petroleum imports.
- Review the viability of production, marketing and use of biodiesel in the long term.
- Promote the cultivation of appropriate tree species for the production of feedstock for the manufacture of biodiesel.

Another important biofuel policy document for Kenya is the Strategy for the Development of the Biodiesel Industry in Kenya (2008–2012), compiled by the Ministry of Energy in 2008 to direct the development of biodiesel in the country. The compilation of a dedicated strategy for biodiesel confirms the cautious approach towards biodiesel development that is contained in the Energy Policy. The Biodiesel Strategy favours *Jatropha curcas* as the main source of feedstock. The key objectives in the Strategy include[12, 24] the intentions to do the following:

- Enhance the security of energy supply by reducing vulnerability resulting from dependence on imported diesel.
- Diversify rural energy sources by promoting the substitution of kerosene with biodiesel and encourage biodiesel use for decentralised energy systems.
- Contribute to poverty alleviation through diversification of income sources, especially in rural areas.

In terms of energy regulation, the following legal instruments govern the development of liquid biofuel development in the country:

a) Liquid biofuel development guidance stipulated in the Energy Act (2006).

b) Legal Notice for biofuel blending enacted by the Ministry of Energy.

c) Licensing guidelines for biodiesel established by the Energy Regulatory Commission.

d) Standards established for the ethanol to be used in petroleum blending.

The Energy Act (2006) explicitly supports the promotion of liquid biofuel development, and to some extent, its regulation. According to Section 115 of the Energy Act (2006), the entire process of liquid biofuel development (from production to end use) is subject to standards and specifications to be stipulated by the Kenya Bureau of Standards. The Energy Act (2006) stipulates the following:

> *No person shall use or employ for or in connection with any of the purposes of producing, generating, transforming, transmitting, distributing, supplying, or importing, exporting, transporting, refining, storing, selling or using, any form of energy, any mode, material or apparatus other than that which complies with the specification or standard of the Kenya Bureau of Standards or where no such standard exists, any international standard approved by the Kenya Bureau of Standards.*

The Act also expressly defines the role of the Minister for Energy with regard to liquid biofuel development. For example, the Act states that "The Minister shall promote the development and use of renewable energy technologies, including but not limited to … biodiesel, bioethanol …." Furthermore, the Energy Act (2006) empowers the Minister of Energy to do the following:

- Promote the production and use of gasohol and biodiesel.
- Promote the use of fast-maturing trees for energy production, including biofuels.
- Formulate a national strategy for coordinating research, efficient and sustainable production, and distribution and marketing of renewable energy, including biomass technologies that include liquid biofuels.

In addition to the role of the Minister of Energy, the Act requires the Rural Electrification Agency to promote the use of biofuels for electricity generation. This requirement is important, as it encourages the

development of local electricity generation off the grid and in mini-grids where liquid biofuel production is viable.

In line with the Energy Policy, the Ministry of Energy has already begun to establish a legal framework for biofuel blending. Specifically, Legal Notice No. 60, enacted by the Minister for Energy in 2010, sets forth regulations for blending ethanol with petroleum. The regulations stipulate the standards to which such ethanol must conform and authorises the Kenya Pipeline Company to take responsibility for the blending and storage of blended fuel, i.e., gasohol[26].

The Energy Regulatory Commission (ERC) also supports liquid biofuel development. In its Strategic Plan 2008–2012, the regulatory agency outlines the development of standards and practices for biofuels as one of its key outputs[27]. In 2009, the ERC invited the public to comment on the proposed regulations for licensing of biodiesel development operations. Unlike Section 115 of the Energy Act (2006), the ERC regulations for biodiesel licensing explicitly allow the production, importation, storage and transport of biodiesel for consumption without a license, subject to an annual limit of 5,000 litres[3].

The quality standards for ethanol used for blending with petroleum are established by the Kenya Bureau of Standards (KEBS). The KEBS has established standards for 10% ethanol blending, based on the 1990 standards (KS 515) (KEBS, 2010).

4.2 Review of biofuel-related agricultural policies and regulation

The key liquid biofuels earmarked for development in Kenya – ethanol and biodiesel – are expected to come from plant-based feedstocks that offer little or no competition for arable land for food production. In the case of ethanol, it is anticipated that sugarcane, cassava, switchgrass, sugar beet, maize, sweet sorghum, wheat, biomass waste and woody fibres can be used as feedstock. At the moment, the major feedstock used for ethanol production is molasses, a waste product from sugarcane processing.

For biodiesel, options for feedstock include *Jatropha curcas*, sunflower, castor, rapeseed, coconut and croton. All these plants require careful consideration in terms of land use to control any adverse impact their cultivation may have on food security and pricing. By 2008, more than 500,000 seedlings of Jatropha had been planted in the Eastern Rift Valley, Coast and Nyanza provinces under Green Africa's auspices. These provinces suffer from severe forest degradation, and Jatropha is being used to stabilise forests as well as produce farm income. With regard to exports, the Kenyan government is cognisant of the need to satisfy the local market before commencement of exports.

With the hindsight of lessons learned from other countries in which biofuels have contributed to food insecurity and high prices, the Ministry of Agriculture has taken into consideration the potential changes in agricultural practices and produce for biofuel development. Consequently, the Ministry has developed two key policy documents on liquid biofuel development, namely, the Agricultural Sector Development Strategy and the National Emerging Crops Policy.

These policy documents for the agricultural sector were informed based on key background studies, including the *Roadmap for Biofuels in Kenya*, which was commissioned by GIZ (previously GTZ) in conjunction with the Ministry of Agriculture. This study provides a comprehensive overview of the national potential and challenges facing biofuels, with the goals of elucidating benefits and analysing viability. The document also examines the experiences of other countries from which Kenya could learn lessons in liquid biofuel development. The document concludes that there is a strong economic case for biofuels in

Kenya. With regard to ethanol production from molasses, the document highlights the fact that Kenya has a lower cost of molasses than other ethanol-producing countries such as Brazil, Columbia, Central America, India and Thailand. However, poor infrastructure and inefficient ethanol plants have led to higher operating costs in Kenya than in these other countries.

The *Roadmap* study also included an assessment of potential crops for use in ethanol and biodiesel production and identified the most appropriate crops for biofuel development, taking into consideration several factors, including competition for land with food production and the impacts on social development, food security and prices [1].

The Agricultural Sector Development Strategy (2010) is the overarching policy document governing the agricultural sector. This document provides guidelines for overcoming challenges, ensuring food security and enhancing income and employment, particularly in rural Kenya. The Agricultural Sector Development Strategy acknowledges the vast opportunities for production of liquid biofuels, notably sugarcane, maize, sorghum, *Jatropha curcas* and other plants bearing oil-generating seeds. The strategy also considers the important role biofuels can play in income and employment creation. For example, commercial tree planting for biofuel production is identified as a useful source of income. In addition, the strategy outlines the promotion of biofuels through research and planning, in line with the Strategy for the Development of the Biodiesel Industry in Kenya [29].

The objective of the National Emerging Crops Policy is to "promote emerging crops as an alternative source of livelihood for rural communities through empowering farmer-based associations, encouraging value addition, product diversification and utilisation." In line with the Strategy for the Development of the Biodiesel Industry in Kenya (2008-2012), the National Emerging Crops Policy identifies *Jatropha curcas* as the main feedstock for biodiesel production. In addition, the policy highlights the Ministry of Agriculture's need to promote the biodiesel industry through establishment of extension offices and other facilities [13].

The Agricultural Act of 1955 is the key legal instrument in the legal and regulatory framework in the agricultural sector. This act empowers the Minister for Agriculture to declare specific crops for biofuel production to be "special", thereby encouraging their promotion for the purpose of ensuring the sustainable supply of feedstock. In addition, the Minister may establish an authority to promote special crops in designated areas of the country [30]. This provision could therefore benefit liquid biofuel development.

The Agricultural Act (1955) also empowers the Minister for Agriculture to determine certain crops as "scheduled crops". A number of scheduled crops are identified that can be used for biofuels, namely, wheat, barley, oats, millet, sorghum, rice, sunflower and sugarcane. Designation as scheduled crops implies that significant importance is attached to their development to ensure the production of sufficient quantities. Consequently, the Minister for Agriculture may control the quantity of production as well as the sale, strategic storage and pricing of such crops. This legislation gives the Minister autonomy that can potentially be used to promote biofuels in an effective fashion.

Although the Agricultural Act (1955) could be considered supportive of biofuel development, it is outdated and in dire need of review to reflect the prevailing conditions of the agricultural sector. The planned enactment of the Agricultural Sector Development Strategy (2010) sets the stage for a review of the Act. In the meantime, it is unclear to what extent the government will enforce the outdated Act in the development of biofuels.

Another important piece of legislation concerning Kenya's agricultural sector that could influence liquid biofuel development (especially ethanol) is the Sugar Act (2001). This Act establishes the Kenya Sugar Board (KSB) as the apex body for policy formulation and implementation in the sugar industry. The KSB is an advisor to the Minister for Agriculture on issues pertaining to the promotion of all aspects of producing, processing and marketing sugarcane, sugar and molasses, as well as on pricing and necessary legislation for the industry [31].

As the key regulator of the sugar industry, the KSB can influence sugarcane production and concomitant supplies of molasses by-product, which is the feedstock for the production of ethanol. For example, pushing the pricing of sugarcane higher can encourage farmers to grow more sugarcane but also increases the cost of ethanol production. In addition, as the custodian of the Sugar Levy Fund, the KSB could use the Fund to promote biofuel development, especially ethanol, by making low-interest or interest-free loans to sugar factories for the installation of ethanol distilleries.

KSB's Strategic Plan 2010–2014 supports biofuel development in the country and emphasises that ethanol development in the sugar industry is an important initiative that could ensure diversification of sugar factory revenues, especially after February 2014, when the COMESA sugar market protection measures lapse and the Kenyan sugar market is liberalised. To enhance the sugar industry's post-2014 competitiveness, the Kenya Sugar Board has envisaged that approximately a quarter of the estimated investment of Kshs 51.1 billion (approximately US$ 601 million) required by the sugar industry during the period 2010–2014 should be allocated to ethanol development[32].

Meanwhile, in the short term, a key impediment to the development of ethanol in the sugar industry is the pending privatisation of the state-owned sugar factories, which have been dogged by an accumulated debt of Kshs 58 billion (approximately US$ 682 million) [21]. Although the government has already established a privatisation commission to oversee the privatisation of its sugar factories, the process has dragged on for many years, with potential investors taking a sceptical view due to a lack of clarity as to who will take responsibility for the huge debt involved, which is mainly owed to small-scale sugarcane farmers.

5. Potential for liquid biofuel development in the country

This study draws on Kenya's past production figures for liquid biofuel and examines the country's potential for commercial development of the industry.

5.1 Current status of biofuel production

Compared to its estimated potential, current levels of biofuel production in Kenya are miniscule. Currently, for example, only 19 million litres of ethanol are produced per year, compared to a potential of 620.5 to 1,022 million litres per year (Endelevu Energy and ESDA, 2008; KSB, undated). Green Power East Africa Ltd is estimated to produce only 365,000 litres of biodiesel per year, while the national potential stands at 8,103 million litres per year[1].

There is significant potential for scaling up biofuel production if one considers the recent developments in the sugar industry and the increasing number of initiatives for the cultivation of Jatropha in the country. For example, the two existing ethanol companies in Kenya – Agro Chemical and Spectre International – are working on expansion plans for alternative feedstocks and on increasing production capacity. Spectre International plans to increase its production from 23.72 million to 83.98 million litres of ethanol per year from sweet sorghum and other crops as alternatives to using molasses[1] .

In addition, current and planned sugar factories have plans for investment in ethanol plants within the foreseeable future. For example, the Mumias Sugar Company plans to commission an ethanol plant with a production capacity of 22 million litres of ethanol per annum (MSC, 2010). Meanwhile, one planned sugar factory, Kwale International Sugar Company, plans to build a plant that will produce 10.95 million litres of ethanol per year [33].

There has been a burst of interest in biodiesel development in both the public and private sectors, especially with regard to Jatropha. For example, key research institutions, such as KEFRI, ICRAF and the Aga Khan Foundation, are contributing to coordinated research and agricultural development to find high-yielding Jatropha plants[1] .

As noted earlier, this study focuses on ethanol development because past experience in the country has indicated that this is a more attractive option than producing Jatropha-based liquid biofuel. Ethanol is produced using molasses, a by-product of sugar production, and hence does not require new land or result in significant food-fuel conflicts. Biodiesel, in contrast, faces the major challenges of ensuring that significant benefits flow to small-scale farmers and food production is not adversely affected.

The latest available statistics for the Kenyan sugar industry, based on the actual quantity of molasses produced in 2008, indicate that sugar factories have the potential to produce approximately 40 million litres of ethanol annually [KSB, undated (a)]. As mentioned earlier, based on petroleum consumption in that year, nearly 48 million litres of ethanol would have been required to meet the requirement of the ethanol-blending initiative. In that case, the sugar industry would have had an ethanol shortfall of approximately 20%. This gap in ethanol production could easily be filled, however, by any one of the revived or new sugar factories that are currently envisaged. For example, the aforementioned Kwale International Sugar Company plans an annual production of over 10 million litres of ethanol, which would be more than enough to fill the eight million litre gap. Table 5 presents the planned new and revived sugar factories in the country.

Table 5: Planned new and revived sugar factories

Sugar factory	Crushing capacity (TCD)	Status
Miwani	800	Revived sugar factory
Kwale International	3,000	Revived sugar factory
Butali	1,000	New entrant
Transmara	1,000	New entrant
TARDA	9,000	New entrant
Total crushing capacity	14,800	

Source: [21]

The current potential of approximately 40 million litres of ethanol per annum, however, is only approximately 39% of the sugar industry's full potential for ethanol production. As noted earlier, the majority of existing sugar factories in the country (including the defunct ones) are state-owned and plagued with mismanagement, undersupply of sugarcane and inefficiency due to aging sugar production equipment. As shown in Table 6, the technical potential for ethanol production in the country is far above the present requirements for E10 blending.

Table 6: Estimated ethanol production by Kenya's expanded, revived and new sugar factories

Sugar factory	TCD	Estimated annual cane crushed capacity*	Potential molasses production**	Potential ethanol production in litres**
Operational sugar factories				
1. Mumias	9,600	2,880,000	100,800	22,176,000
2. Chemelil	4,200	1,260,000	44,100	9,702,000
3. Nzoia	7,000	2,100,000	73,500	16,170,000
4. SONY	6,500	1,950,000	68,250	15,015,000
5. West Kenya	3,500	1,050,000	36,750	8,085,000
6. Muhoroni	5,500	1,650,000	57,750	12,705,000
7. Kibos & Allied Sugar Industries	1500	450,000	15,750	3,465,000
8. Soin	600	180,000	6,300	1,386,000
Revived sugar factories				
9. Miwani	800	240,000	8,400	1,848,000
10. Kwale International Sugar Co.	3,000	900,000	31,500	6,930,000
New entrants				
11. Butali	1,000	300,000	10,500	2,310,000
12. Trans Mara	1,000	300,000	10,500	2,310,000
13. TARDA	9,000	2,700,000	94,500	20,790,000
Total	**39,440**	**13,260,000**	**464,100**	**102,102,000**

Source: [21,36]

*Estimated annual cane crushed capacity is based on 300 days of sugar factory operation

**Potential ethanol production is estimated, assuming 1 tonne of molasses can yield approximately 220 litres of ethanol.

Looking to the future, the prevailing capacity of sugar factories, together with that from the anticipated expansion of sugar factories, could potentially meet all the requirements for ethanol blending, including the projected increase in petroleum consumption in the foreseeable short to medium term. It is estimated that by 2013, Kenya's petroleum consumption will reach 618 million litres [1] , which will require 61.8 million litres of ethanol for blending, under the current blending policy. Based on the existing cane crushing capacity, at their full potential, sugar factories can meet this requirement. In addition, with the expansion of existing sugar factories, privatisation of state-owned factories and construction of new sugar factories, the total technical potential of the sugar industry could reach 102 million litres of ethanol per annum (Table 6), well above the country's blending requirements. If the estimated potential is achieved, the country could comfortably accommodate flex-fuel vehicles – cars that can run purely on ethanol. Alternatively, the country could potentially supply neighbouring countries with ethanol to meet any blending targets that they have in force.

6. Economic impacts of ethanol development

Ethanol development in Kenya would have several types of impacts on the national economy, including the following:

- Economic impacts.
- Social impacts.
- Environmental and food security impacts.

6.1 Economic Impacts

Ethanol production would have impacts on the national economy as well as on sugar factories that produce ethanol, feedstock (sugarcane) farmers and end users of ethanol.

Perhaps the most important economic impact of local ethanol production would be the reduction of petroleum imports by 10%. This would not only enhance the security of the fuel supply but also cut down the spending of precious foreign exchange reserves to import petroleum, by a similar proportion. In Kenya, 100% of the fuel used by petroleum-consuming vehicles and other gasoline-powered devices (e.g., generators, water pumps, lawn mowers, and chainsaws) is imported. Based on the recent data available on the levels of petroleum consumption, 10% ethanol blending in petroleum could reduce Kenya's consumption of petroleum products by approximately 40 million litres annually, generating savings of approximately US$ 21 million.

It is worth noting that blending ethanol at a proportion of 10% is based on technical and economic considerations, as this blend proportion does not significantly change the combustion characteristics of the vehicle and therefore has no cost implications for the owner. With modifications to existing engines, however, it is possible to use higher proportions of ethanol in the fuel and further reduce dependence on imported petroleum. In Brazil, for example, engines that are equipped with flex-fuel technology can run on up to 100% ethanol or any lower proportion of gasohol [34.]

As a net oil importing country, Kenya is subject to fluctuating oil prices. The country does not have significant control over the price of imported fuel, which is based on world oil prices that are partly influenced by pricing by the Organisation of Petroleum Exporting Countries, global demand, and more importantly, key economic and political developments in oil-producing countries. In this context, ethanol production ensures that at least a small proportion of the cost of oil can be controlled locally. Where the price of ethanol for blending is controlled locally, it is possible to stabilise fuel prices partially and cushion consumers to some extent from erratic and unstable oil prices.

A study in the United States titled "The Impact of Ethanol Blending on U.S. Gasoline Prices" categorically concluded that ethanol blending in the US was keeping US retail gasoline prices approximately 17 cents per gallon lower than they would be with no ethanol and that ethanol has the potential to moderate fuel prices worldwide by reducing dependence on crude oil. More than 70% of the gasoline in the US is blended with ethanol, and the results of this study and previous similar studies support the development of a viable biofuel industry in Kenya [35].

Fluctuating world oil prices can also pose a risk to ethanol development. In fact, this was one of the key reasons for the discontinuation of the gasohol programme in Kenya in 1993. Therefore, the management of ethanol and gasohol production costs and end-user pricing must ensure that ethanol blending can survive relatively low world oil prices. One way to ensure the sustainable production of ethanol is to

provide fiscal incentives for sugar factories to produce ethanol that would translate into lower ethanol production costs.

The availability of a guaranteed market and a guaranteed price for ethanol would have an impact on sugar factories. It would enable them to increase the prices at which they purchase sugarcane, thus attracting a guaranteed supply of feedstock. Sugar factories in Kenya will be subject to the opening up of the market in 2014. Imported sugar will be cheaper than that produced in Kenya because of the high production costs in the country. It is anticipated that the only way sugar factories in Kenya will be able to survive this competition and remain profitable is by lowering their prices and generating extra revenue from the conversion of molasses and bagasse into premium products such as ethanol, electricity and paper.

Increased revenue in the sugar industry as a result of ethanol production will also avail the country of higher tax revenues. As ethanol production increases the profitability of sugar factories, they will attract larger corporate taxes, benefiting the country as a whole. The development of ethanol locally in the country will also lead to other benefits, such as employment creation and rural development

As mentioned earlier, ethanol production can lead sugar factories to increase the buying price of sugarcane to guarantee steady supplies. An increase in sugarcane prices can greatly benefit outgrower farmers' livelihoods and help to improve their nutrition, health, education and housing. Observations by the AFREPREN/FWD Cogen for Africa project indicate that the farmers who supply the sugar factory that offers the best prices for sugarcane generally enjoy higher living standards. These farmers also tend to increase the area of land that they cultivate with sugarcane.

Ethanol development in Kenya can play an important role in technology transfer, rural industrialisation and skills development. By collaborating with global leaders in ethanol production, such as Brazil, the country could benefit from the adoption of advanced technology and best practices. In addition, wide-scale ethanol production is likely to lead to skills development and the emergence of ethanol production specialists in the country. Furthermore, the establishment of ethanol plants in rural areas where sugar factories exist could provide much-needed employment and contribute to the industrialisation of these areas.

There are some potentially negative impacts. For example, it is anticipated that the high demand for ethanol for petroleum blending could lead to an increase in its price. This could increase the production costs for users of ethanol outside of the energy sector, such as pharmaceuticals, other chemical industries and producers of alcoholic beverages. Consequently, end users could be faced with price increases for products that depend on ethanol. This could be averted, however, by establishing quotas and specific price regimes for ethanol's non-energy uses, together with expanded production of ethanol from different feedstocks.

Ethanol development could also be affected to some extent by the fact that there are two ethanol producers that are not linked to sugar factories. Both companies, the Agro-Chemical and Food Company (originally under the Ministry of Energy and now under the Ministry of Agriculture) and Spectre International (a privately owned company), rely on procuring molasses from sugar factories. It is probable that they could face challenges in securing molasses if sugar factories were to install their own ethanol plants. The options for these two current producers of ethanol include growing their own sugarcane and/or subcontracting sugarcane farmers to supply sugarcane for ethanol production. This could mean the conversion of arable land to sugar production for biofuel purposes, which is a contentious issue. Alternatively, these two companies could partner with sugar factories to process their molasses. The viability of this option,

however, will depend on the cost implications of transporting molasses from the sugar factory to the ethanol plant, the ethanol production costs at the plant and the selling price of ethanol.

In the short to medium term, it is proposed that ethanol production in Kenya be concentrated in sugar factories because of the sustainability of feedstock supply. This would also create an alternative income stream for the sugar factories, enabling the factories to raise considerable amounts of revenue, as shown in table 7 below, and avoid the contentious issue of using arable land for biofuel crop production.

Table 7: Income generation from ethanol production

YEAR	CANE DELIVERIES	MOLASSES PRODUCED	POTENTIAL ETHANOL PRODUCED	COST PER LITRE	POTENTIAL REVENUE
	Tonnes	Tonnes	Litres	USD	USD, millions
2008/09	5,165,786	180,802	39,776,332	0.65 – 0.82	26 – 32
2009/10*	5,110,632	182,000	40,040,000	0.65 – 0.82	26 – 32
2010/11*	5,808,049	203,281	44,721,021	0.65 – 0.82	29 – 36
2011/12*	6,286,269	220,019	48,404,271	0.65 – 0.82	32 – 40
2012/13*	7,192,730	251,745	55,384,021	0.65 – 0.82	35 – 46
2013/14*	8,010,834	280,379	61,683,422	0.65 – 0.82	40 – 50

*Estimated projection
Source: [21]

6.2 Social implications and land grabbing concerns

Ethanol development in the sugar industry is likely to offer several positive social benefits to farmers and the general population in the sugarcane-growing regions of Kenya. Perhaps the most important benefit is the potential for increased prices of sugarcane. Increased sugarcane prices can result in two primary ways. First, existing sugar factories must increase their cane-crushing capacity and shift to large-scale production of ethanol to benefit from economies of scale. The factories will, therefore, require an increased supply of sugarcane and will need to secure their supplies by paying higher prices to small-scale outgrower farmers.

Second, the adoption of a more equitable payment system, such as the revenue-sharing mechanism used in Mauritius, could lead to higher income levels for farmers. In Mauritius, sugar factories share the revenues from the sale of sugar, electricity and other by-products. The concept behind this revenue-sharing mechanism is that the sugarcane from the farmers facilitates the production of the by-products. The revenue-sharing mechanism is very important to farmers; it is estimated that a substantial proportion of the revenue of Mauritian sugar factories comes from the sale of these by-products, especially electricity, and more recently, ethanol. A similar revenue-sharing mechanism in Kenya would benefit the country's small-scale outgrower farmers.

The combination of increased demand for sugarcane and higher sugarcane prices can enhance employment levels in the sugarcane-growing areas, as existing farmers expand their acreage and employ

more people. In addition, attractive sugarcane prices can encourage new and returning sugarcane farmers who previously found the prices unattractive.

The improved financial position of sugar factories arising from the sale of ethanol can greatly benefit the populations living around them. Based on anecdotal evidence, it appears that more prosperous sugar factories invest more in the surrounding communities. Typically, prosperous sugar factories invest in communities through the improvement of health and education facilities, the construction of roads and the electrification of houses for workers living around the sugar factory, as well as by drawing government services closer to the people by offering space and facilities for government officials such as police chiefs and district officers.

The major concern with respect to biofuels in Kenya is the availability of land. Of the 576,000 square kilometres of land mass (57.6 m ha) in the country, only approximately 16% is of high or medium suitability for agriculture. Approximately 84% of Kenya is arid and semi-arid and is not suitable for rain-fed agriculture.

The current trend of agricultural investments in Kenya has resulted in an outcry from the general public that such investments can trigger unfair acquisition of land from local people. For instance, according to tanariverdelta.org (a website developed by green NGOs to raise awareness for and opposition to threats faced by the Tana River Delta), Bedford Biofuels, a multinational company incorporated in Canada, has begun the process of acquiring over 90,000 ha of land in the Tana Delta for cultivation of biofuel crops, including Jatropha. Bedford Biofuels confirms on its websites that 160,000 ha of land in Kenya's coastal region has been acquired for Jatropha cultivation and that the firm is in the process of acquiring another 200,000 ha. The Bedford farm land is to be acquired from five local groups around the Tana Delta [36] , a move that green NGOs fear will endanger wildlife species around the Tana Delta and lead to unfair acquisition of community-owned land from the indigenous people.

6.3 Environmental implications

Ethanol development has several environmental impacts. In the sugar industry, ethanol is produced from molasses, a fluid that is potentially hazardous to the environment. In the first instance, untreated molasses that comes into contact with rivers and other water bodies can contaminate them and severely affect aquatic life, as molasses increases the biological oxygen demand (BOD) levels of the water. Where molasses is not in demand, sugar factories are forced to dump it into treatment lagoons – where it should be treated well, although this does not always happen – before releasing it into nearby rivers. In addition, if not properly stored, molasses can contaminate ground water, cause increased BOD levels and discolour the water [37]. The conversion of molasses into ethanol helps to avert these environmental hazards.

The consumption of gasohol by motor vehicles and other gasoline-powered devices reduces the amounts of greenhouse gases emitted. There are also local environmental benefits to using gasohol, including reduced emissions of carbon monoxide, carbon dioxide, hydrocarbons, benzene (a known carcinogen), volatile organic matter and fine particulate matter [38,39]. Reducing these emissions would improve air quality, especially in towns and cities with traffic congestion. The public health and economic benefits of better air quality, including reducing the costs of treating respiratory ailments caused by vehicular air pollution, are enormous. In addition, improved health reduces absenteeism from work and school. For the urban poor, who are often paid daily wages, these added benefits of biofuel are substantial. A key potential negative impact of biofuels, as highlighted in this paper, is that the selection of inappropriate crops for biofuel production can lead to competition with food production for land.

As in the case of Mozambique, where a land certificate is required for a biofuel investor as a way of ascertaining that the investor fully utilises the land for the intended purpose, Kenya's Energy Regulatory Commission recently released guidelines to guide biofuel development in the country. These regulations are called the Energy (Biodiesel Licensing) Regulations, 2009. These regulations are designed to enhance the sustainability of biodiesel projects in the country. Among the specifications of the guidelines are the following:

> *No license shall be granted for the production, importation, storage, exportation, wholesale, transport or retail of biodiesel unless the site has been approved in accordance with the Physical Planning Act, No. 6 of 1996,the Environment Management and Coordination Act,No.8 of 1999 and the Local Government Act, Cap 265 and other applicable Kenya Laws.*

It is hoped that with these regulations in place, the biodiesel industry in the country will have solid guidance that will prevent many unfair land acquisition practices.

6.4 Project assessment tools

The Danish International Development Agency (DANIDA) is one of the institutions that has developed an evaluation tool that can be applied across the board to ensure sustainable development of liquid biofuel projects in countries such as Kenya. The DANIDA assessment checklist (adapted from DANIDA/MFA) includes the following:

- Contribute to social and economic development in communities where feedstocks and fuels are produced. This includes the generation of additional incomes and employment through growing and local processing of feedstocks and biofuels, through increased productivity in agriculture, and through improved infrastructure, e.g., improved access to markets and to energy services. The projects must not compromise local communities' land and resource access and tenure, including the access of migrating pastoralists to water and fodder, and future economic development options. Local baselines should be established and applied.
- Do not compete with food production and ensure that food security is not reduced by the production of biofuels. If biofuels are produced on land and/or using water that is currently used for food or fodder crops, such conditions should be compensated by increased and sustainable production of food and fodder by the project elsewhere in the community or by improved access to (affordable) food markets. Priority should be given to integrated biofuel production that makes maximum use of waste and supplementary cropping or intercropping that increases overall biomass production. Local baselines should be established and applied.
- Contribute to mitigation of climate change by significantly reducing net emissions of greenhouse gases, compared with the fossil fuel uses they replace or avoid. Emissions due to possible indirect land use change, which can be quite significant, should be taken into account. Production of feedstocks on land with high carbon contents, such as wetlands, peat lands and forests, must be avoided. The use of crops and production methods that increase carbon content in soil should be encouraged. Local baselines should be established and applied.
- Avoid negative impacts on environment, e.g., from increased air and water pollution and waste generation. Local baselines should be established and applied.
- Preserve biodiversity and avoid negative impacts on areas with high conservation value or habitats for rare and endangered species. The production of biofuels should not contribute to erosion of local genetic diversity. An understanding of the local baseline should be established.

- Follow the relevant policies and laws of the country and international agreements and do not violate legal or customary land rights, human rights or labour rights. The project should contribute to decent working conditions and gender equality and should not expose workers to occupational health hazards. This should also apply to outgrowers and subcontractors.
- Follow a process of transparent consultation and decision making to ensure that local communities to be impacted by biofuel projects are fully informed of the advantages and disadvantages and are involved in the planning and decision-making processes, leading to free, prior and informed consent.

Other assessment tools that have been developed include the following:

a) Decision Support Tool (DST) for Sustainable Bioenergy

This tool was prepared by FAO and UNEP as a UN Energy publication. This tool sketches out typical steps that can serve as a basis for adaptation to specific country contexts. Bioenergy strategies are dynamic and constantly evolving, with new tools being developed to help guide processes and decisions. The DST is also dynamic in nature. The tool is therefore a work in progress, as these new ideas, lessons learned and tools are made available. The screening tool questions are grouped into three main categories[40]:

1. Environment and natural resources: potential impacts on ecosystems, biodiversity, water, forest resources and products, soil, GHG balances, and air quality.
2. Socio-economic effects: land tenure and displacement risk, income generation, potential exclusion of certain groups/individuals, employment, labour conditions, increased energy access, local governance.
3. Food security impacts: food availability, access, stability and utilisation.

b) GEF Project Screening Tool

A biofuel screening tool for GEF project proposals has been developed with the objective of enabling the GEF and its implementing agencies (IA) to assess rapidly whether project identification forms (PIF), i.e., brief project proposals to the GEF, meet the goals set forth by the GEF. These goals are called global environmental benefits (GEB) and indicate whether a project will provide positive, concrete benefits to the environment. The tool can also be used by applicants in GEF-eligible countries to improve their applications and PIFs.

The project screening tool categorises projects into four groups: projects that are definitely eligible for funding, projects with ambiguous eligibility for funding, projects with insufficient information for an assessment, and projects that are not eligible for funding. The categories are labelled according to the colours of a traffic light, with “white” added as a category for projects lacking sufficient information in the project description.

Non-GHG environmental impact issues considered are issues pertaining to biodiversity, water and soil. The social issues considered include land tenure, labour, human health and food security [41].

7. Barriers to ethanol development in Kenya

This section discusses the past barriers to the development of ethanol, although some of these may have been fully or partially redressed by the National Energy Policy and its associated legal and regulatory framework. Four categories of challenges are addressed:

- Policy, legal and regulatory frameworks
- Institutional development
- Financing and economic issues
- Human resource development and capacity building

7.1 Policy, legal and regulatory frameworks

Kenya now has energy and agricultural policies and the legal and regulatory frameworks needed to promote the development of ethanol, but these developments are relatively recent, and their implementation is yet to be fully achieved. The country's first official Energy Policy came into force a little over 10 years after the ethanol-blending programme was terminated. The Energy Policy was enacted seven years ago, but since then, not a single sugar factory has installed an ethanol production plant.

This slow pace in the development of ethanol production can be partially attributed to the fact that the Policy's Implementation Plan did not include substantive steps for the development of ethanol production, with the exception of commissioning a study to reconsider its viability by 2012.

The Energy Policy does not provide explicit policies, fiscal incentives or investment guidelines for ethanol development. In addition, the Energy Regulatory Commission has introduced licensing guidelines for biodiesel but none for ethanol. Lack of such guidelines creates a significant level of uncertainty among the sugar factories, who are the primary potential investors in ethanol production plants.

7.2 Institutional development

Ethanol production, along with investment in biomass cogeneration, has long been seen as crucial to the survival of the Kenyan sugar industry after 2014, when the sugar market is opened up to competition from cheap imports, in line with the agreement amongst the COMESA member countries of which Kenya is one. With most sugar factories being state-owned, inefficiently run and insolvent, the government decided to privatise them to attract much-needed capital and efficient management and make the sugar factories profitable. However, this process has been long and troubled. Consequently, the state-owned sugar factories continue to incur losses and do not have the capital to invest in ethanol production.

Another key institutional issue that has been affecting the sugar industry is the lack of a dedicated institution to drive the ethanol development agenda. Interestingly, the government has now registered the Kenya Bio-Diesel Association (KBDA) for the purposes of coordinating biodiesel development and bringing together research institutions, suppliers of planting materials, growers, processors, and marketers and distributors involved in biodiesel development. The experience of the Rural Electrification Agency indicates that the presence of a dedicated government agency can aid the efficient achievement of a specific objective in a short time frame. Therefore, a dedicated government agency would help to ensure ethanol development and coordinate the relevant activities of the Ministry of Energy and Energy Regulatory Commission, as well as those of oil marketers, sugar millers, sugarcane farmers and consumers, through their respective umbrella associations.

7.3 Financing and economic issues

As mentioned earlier, there are no explicit fiscal incentives for ethanol development in Kenya. In 2009, however, the government offered a tax rebate of up to 150% on capital investments for major investments in satellite towns around the major cities of Nairobi, Mombasa and Kisumu. Nevertheless, in the absence of clear guidelines and incentives for ethanol, such as explicit pricing and market guarantees, other than MSC (its ethanol plant is in the final stages of installation), no other sugar factory has taken advantage of the rebate to install ethanol plants. Further, MSC is one of the factories that has taken advantage of the rebates for development of biomass cogeneration because of the presence of explicit pricing and market guarantees for the electricity generated.

In 2010, the government reintroduced petroleum price controls to protect the public from exploitation by vendors. At the time that this study was prepared, the petroleum price control mechanism had been in force for about two years and was facing serious challenges due to unexpectedly steep global oil price increases and partly due to procurement problems. In fact, if the oil vendors were to adhere to the price control mechanism, they would be forced to sell petroleum products at a loss. In such a scenario, it is not yet clear whether the price of ethanol would also be controlled and whether this would take into account the potential impact on the selling price of petroleum. Unless the problems of implementing the petroleum price control mechanism are sorted out soon, it is unlikely that ethanol development will be as rapid as expected.

Another challenge that could affect ethanol development is the pricing of sugarcane supplied by farmers. According to the Sugar Act (2001), the price of sugarcane is determined by the Sugar Cane Pricing Committee, which consists of representatives from the Kenya Sugar Board, the Kenya Sugar Manufacturers Association and the Kenya Sugarcane Growers Association. However, in the 10 years since the Act came into force, this Committee has been unable to enforce the stipulated pricing and payment for sugarcane, which calls into question the Committee's effectiveness. To date, sugarcane is still priced and paid for on the basis of its weight and not on the basis of the sucrose content, as stipulated by law. This lack of effective control could hinder ethanol development in the country and hamper agricultural investments that could increase the productivity of sugarcane, thus slowing ethanol development in the country.

If the Sugar Cane Pricing Committee were to enforce proper pricing of sugarcane, farmers would benefit from the proceeds that accrue from the sale of ethanol and other by-products of sugar production. Section 4 (2i) of the Sugar Act (2001) clearly stipulates the following:

> *The object and purpose for which the Board is established is to … facilitate an equitable mechanism for the pricing of sugar-cane and appropriation of proceeds from the disposal of the by-products of sugar production between millers and growers as stipulated in the guidelines.*

This stipulation alludes to "revenue-sharing", which is akin to the very attractive revenue-sharing system in Mauritius, whereby a part of the proceeds from the sale of by-products of sugar production is paid to the farmers supplying the sugarcane. In addition, the Second Schedule of the Sugar Act (2001), which provides the sugarcane pricing formula, appears to account for the proceeds that accrue from the sale of ethanol or any other by-product, viz:

Price of Sugarcane = (Pol % cane x KR x farmers' share x monthly average net price of sugar)/(1 + E%)
Plus a % of the value of by-products

where:
- Pol % cane is a measure of the sucrose content of cane
- K is the expected mill extraction
- R is the expected boiling house recovery
- farmers' share is a fixed part of the net sugar cane price as set by the Sugar Cane Pricing Committee (SCPC).
- monthly average net price of sugar is the previous month's average net price of sugar after deducting taxes and levies
- % of value of by products is the percentage of the value of the by-products as fixed by the SCPC
- E % is the proportion of extraneous matter delivered as cane

If this pricing formula were adhered to, sugarcane farmers would enjoy the additional income that accrues from ethanol sales. It is expected that this would give sugarcane farmers a clear price signal and motivate them to grow sugarcane, thereby ensuring a sustainable supply of feedstock required for sugar and ethanol production.

7.4 Human resource development and capacity building

In Kenya, there is no specialised training available for the personnel involved in ethanol development. Training in the development of skills is lacking in the following areas: conducting feasibility studies, design and construction, supervision of construction, commissioning and testing, and operation and maintenance of ethanol plants. The limited skills available constrain ethanol development in the country and will initially require reliance on external expertise, possibly from Brazil, India or South Africa. It is likely that this could increase the cost of ethanol production.

It is worth noting, however, that Kenya already has two ethanol production plants that are not directly linked to the sugar factories, and these plants have experience in the operation and maintenance of ethanol plants. The sugar industry in Kenya could benefit from their experience.

It is expected that ethanol plants will be installed in sugar factories located in rural parts of the country. Sugar factories would need to provide higher remuneration that would attract qualified personnel to these remote rural areas. This could increase the overhead costs of ethanol production and decrease profitability, depending on the market price of ethanol.

The country is also likely to experience skill constraints in the handling and blending of ethanol by the Kenya Pipeline Company (KPC), the entity mandated by the Minister for Energy under Legal Notice No. 69. Although the company might have gained considerable experience during the 10 years in which the ethanol-blending programme was run (1983–1993), it has now been nearly 20 years since that programme was terminated. KPC may initially also need to seek external expertise in this area, which could adversely impact the final cost of gasohol.

8. Policy options for successful biofuel development in Kenya

8.1. Bioethanol

Having discussed the prospects for and challenges to ethanol development in Kenya, this paper concludes by highlighting some of the key policy options that could lead to the successful implementation of an ethanol-blending programme.

One of the factors that contributed to the failure of the previous ethanol-blending programme was an unsustainable pricing mechanism. To ensure the success of future ethanol-blending programmes, there is a need for a clear price indicator if sugar factories are to invest in ethanol distilleries. One possibility is for the government to set fixed prices for a limited period of time for the sale of ethanol to the Kenya Pipeline Corporation, which has been mandated to blend and store gasohol.

This approach would be similar to the power purchase agreements that power utilities and independent power producers have for electricity sales. The benefit of establishing fixed prices upfront is that they minimise uncertainty for investors interested in financing ethanol plants. Fixed prices also enable financial institutions to calculate the expected cash flow from ethanol sales and thus ascertain whether loan repayments by the sugar factories are feasible.

The sustainability of the ethanol-blending programme is dependent to a significant extent on the availability of the primary feedstock – sugarcane supplied by small-scale farmers. Therefore, the farmers require suitable price incentives for their sugarcane to motivate them to ensure its continued supply. One way to ensure suitable price incentives is to incorporate into the pricing of sugarcane a revenue-sharing mechanism that delineates which part of the sugar factory's revenues from selling ethanol should benefit small-scale sugarcane farmers. Interestingly, the Sugar Act (2001) already provides for such a revenue-sharing mechanism, but it has never been implemented. This is also the case with respect to paying sugarcane farmers by the sucrose content of their sugarcane. The revenue-sharing mechanism could provide an incentive for outgrower farmers to invest in expanding their sugarcane plantations

Mauritius provides a model of a revenue-sharing mechanism. The proceeds from the sale of cogenerated electricity are shared equitably among the key stakeholders, which include small-scale farmers who provide the sugarcane to the factories. A similar revenue-sharing mechanism could be adopted in Kenya for sales of ethanol.

Policies are also needed to ensure the sustainability of the ethanol-blending programme by preventing competition for land between the raw materials for biofuel production and food. This can be achieved by ensuring that, in the short to medium term, sugar factories continue to focus on sugar as their primary product and use only molasses for ethanol production.

The enforcement of mandatory blending[5] is important for the ethanol programme. Ensuring mandatory blending of petroleum with ethanol, even when world oil prices fall, is important because it reduces uncertainty among investors in ethanol production. With this reassurance that there will be a market for ethanol even when world oil prices are low, sugar factories will be encouraged to invest substantially in its production.

5 Mandatory blending does not, however, guarantee the economic stability of the ethanol programme.

Some pre-feasibility studies undertaken at MSC on the viability of ethanol production have shown promising results. The annual production estimates suggest that ethanol production will not displace sugar production but rather utilise the molasses output. Mumias sells its molasses at an average price of Kshs 1,200 (US$ 14.11) a ton. A ton of molasses can be converted into 220 litres of ethanol. However, it is not easy to estimate the potential ex-factory price of ethanol, although one can use a prudent benchmark such as the pre-tax price of petrol. Conservative estimates indicate that ethanol will cost between US$ 0.65 and 0.82 per litre [21]. This range is lower than the price of petroleum in Kenya.

Sugar factories that invest in ethanol production can also tap into international and regional financing facilities and initiatives. For example, the Global Environment Facility (GEF) can provide funding for ethanol projects. The Kyoto Protocol's Clean Development Mechanism (CDM) can be used to help developers buy down the initial costs of their investments and help make cheaper ethanol available. The CDM tends, however, to have high transaction costs and requires specialised skills, which could limit the participation of individual sugar factories.

The Kenyan government should put in place environmental policies that promote green energy investment such as ethanol blending, in line with international environmental and climate change agreements. These policies will attract more investors in biofuel production, which will reduce reliance on highly polluting fossil fuels and contribute to global efforts to reduce greenhouse emissions. In addition, to conserve natural ecosystems, there should be explicit environmental policies that safeguard against encroachment on non-agricultural areas for biofuel crop production, especially land areas with rare or endangered plant species. Policies such as these will lead to sustainable use of resources without jeopardising future generations.

According to the Global Agricultural Information Network, as of 30 March 2011, the government of Kenya was in the process of developing an air quality regulation that is likely to be beneficial to the biodiesel industry [42]. This draft policy, called "The Environmental Management and Coordination (Air Quality) Regulation, 2008", will hopefully be the first of many environmental policies to come that will have a positive impact on the biofuel industry in Kenya.

8.2 Biodiesel

The following are some of the suggested policy options for revitalising the biofuel industry in Kenya, based on the best practices employed in other countries:

1. Large-scale public investment in coordinated national research and development programmes on the most appropriate feedstocks for the production of biofuels, including feedstock suitability for different regions of the country, to avoid the use of biodiesel feedstocks that will lead to illegal acquisition of public or community land.
2. Establishment of a national registry of feedstock availability, processing facilities and uptake to provide necessary data for price reviews and thereby avoid a mismatch between supply and demand. This will ensure that there is enough biofuel production in the country to meet the demand.
3. Development of regional and national biofuel standards and certification requirements based on other global standards, such as ASTM D-6751 and EN-14214 (e.g., standards used in Brazil, India, EU, Malaysia, South Africa, Mozambique, and Nigeria) to ascertain biofuel sustainability.

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Worker transporting palm fruits in Thailand. Photo credit: Flickr

6. An Assessment of Thailand's Biofuel Development

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Article

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1. Introduction

Asia is emerging as an important biofuel producer, with an annual average growth rate of 33% during 2005 to 2010 [1], based largely on first generation biofuels. Thailand is one of the major producers of biofuels in Asia, along with India, China, Indonesia and Malaysia. These countries have accelerated their biofuel production, thereby establishing themselves as global players in the biofuels market. Thailand, one of the rapidly growing Asian economies, has seen its primary energy consumption increase from 69.1 million tons in 2001 to 106 million tons in 2011 [2] and also increases in its oil imports. Between 2002 and 2007, the expenditure on imported energy (electricity, coal, natural gas, petrol and crude oil) increased from 360 billion Baht (8.37 billion US Dollars) to 912 billion Baht (24 billion US Dollars) [3].

The total energy consumption of Thailand's transportation sector is dominated by petroleum products, as shown in Table 1 [4]. Realizing the country's over-reliance on fossil fuel and imported energy, the Thai government initiated policies to diversify its energy resources and to develop, promote and utilize renewable energy sources [5]. Biofuels is one of the priority areas of national renewable energy policy of Thailand, particularly for the transport sector.

Table 1. Energy consumption in transportation sector by type (kt and %) in Thailand [4]. LPG, liquefied petroleum gas; NGV, natural gas vehicle.

Year	LPG	Unleaded Gasoline	Gasohol E10[a]	Gasohol E20[b]	Gasohol E85[c]	Jet Fuel[d]	Diesel	Biodiesel[e]	Fuel Oil	NGV	Electricity	Total
2007	667	4,080	1,314	-	-	4,031	11,228	543	1,539	208	5	23,615
	(2.8%)	(17.3%)	(5.6%)			(17.1%)	(47.5%)	(2.3%)	(6.5%)	(0.9%)	(0%)	(100%)
2008	904	2,706	2,505	22	-	3,789	7,586	3,260	1,593	659	5	23,024
	(3.9%)	(11.8%)	(10.9%)	(0.1%)		(16.5%)	(32.9%)	(14.2%)	(6.9%)	(2.8%)	(0%)	(100%)
2009	778	2,228	3,254	61	-	3,623	6,722	4,735	1,466	1,260	5	24,132
	(3.2%)	(9.2%)	(13.5%)	(0.3%)		(15%)	(27.9%)	(19.6%)	(6.1%)	(5.2%)	(0%)	(100%)
2010	794	2,204	3,157	101	1	3,852	7,054	4,462	1,366	1,597	6	24,594
	(3.2%)	(8.9%)	(12.8%)	(0.4%)	(0%)	(15.7%)	(28.7%)	(18.1%)	(5.6%)	(6.5%)	(0%)	(100%)
2011	1,073	2,265	2,962	165	7	4,150	11,179	595	1,028	2,036	9	25,469
	(4.2%)	(8.9%)	(11.7%)	(0.7%)	(0%)	(16.3%)	(43.9%))	(2.3%)	(4%)	(8%)	(0%)	(100%)

[a,b,c] Gasoline with Ethanol 10%, 20% and 85% by volume, respectively; [d] including aviation gasoline; [e] including diesel with palm oil 10% by volume and 5% bio-oil by volume, respectively.

The rapid growth of biofuel production in recent years in Thailand has been largely policy driven [6,7]. The Thai government has continuously formulated and modified its policies and plans to increase the production and consumption of biofuels. The current 10-year Alternative Energy Development Plan (AEDP) (2012–2021) targets the renewable energy share to increase from 7,413 kt in 2012 to 25,000 kt in 2021, *i.e.*, using renewable energy at 25% of total energy consumption by 2021, while biofuel is to replace 44% of oil consumption in the transport sector by 2021 [8].

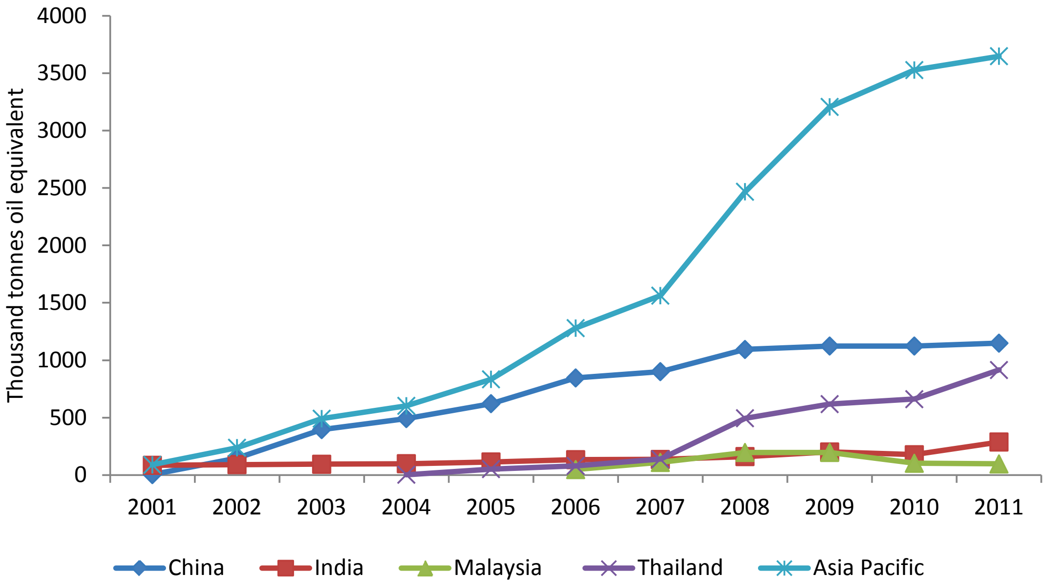
This article presents an overview of biofuel development in Thailand, an assessment of its biofuel potential, including estimation from agricultural residues, the role of policies in biofuel development and sustainability issues of biofuel production. The study is based on the review of available literatures, information and analysis of secondary data obtained from online sources, published reports and statistics. The paper is organized as follows. Section 2 discusses the biofuel production and potential of Thailand, particularly the production of first generation biofuels and the estimated potential of second generation biofuels from agricultural residues. Section 3 elaborates on the biofuel policies of Thailand. Section 4 discusses the sustainability aspects of first generation biofuels in Thailand, and Section 5 provides concluding comments.

2. Liquid Biofuel Production and Potential

2.1. Current Practices and Production of First Generation Biofuel

The production of biofuels in Thailand increased more than ten-fold within five years from 2005 to 2010, and the share of its production in the Asia Pacific region increased considerably from around 6% in 2005 to 19% in 2010 [9] (Figure 1). Ethanol is produced in Thailand mainly by the fermentation of molasses, a by-product of sugar manufacturing and cassava (also known as tapioca); while biodiesel is manufactured by transesterification of vegetable oil, mainly palm oil [10]. Ethanol blended with gasoline (petrol), is called gasohol.

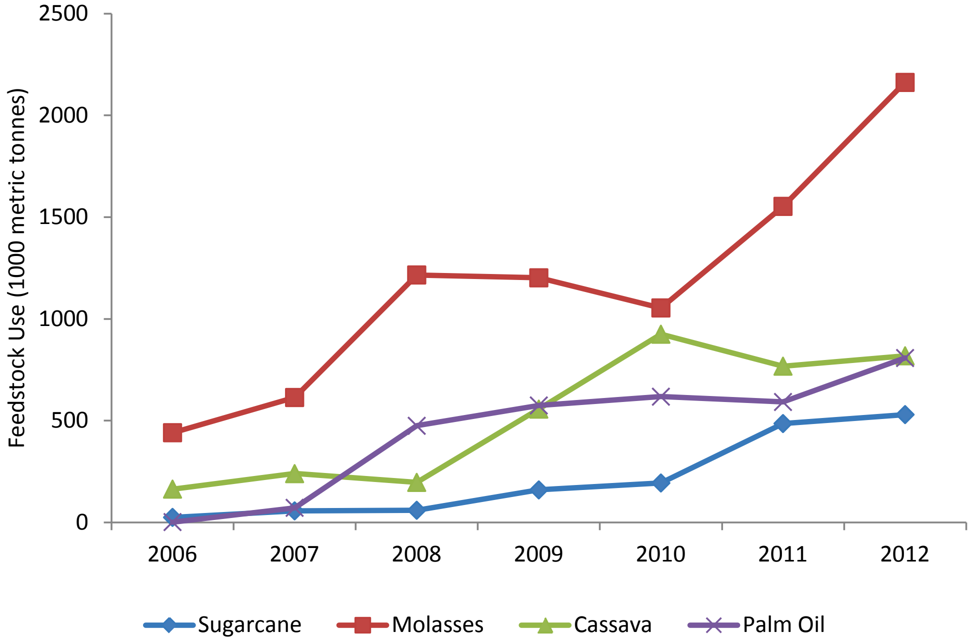
Figure 1: Biofuel production in Thailand in the Asia Pacific [9].



Sugarcane and cassava are the base crops for ethanol production, while palm oil and jatropha are used for biodiesel production. Sugarcane can be directly used to produce ethanol, whereas molasses, a by-product during sugar production, is fermented by yeast to produce ethanol [11]. Molasses-based ethanol dominates ethanol production in Thailand, amounting to 1.17 million liters/day in 2011, up 54.5% from the 2010 average production of 0.76 million liters/day. This accounts for 80% of the country's total ethanol production [12]. Cassava-based ethanol production was 0.28 million liters/day in 2011, down 12.8% from the average 0.33 million liters/day in 2010, due to record high cassava prices [13].

The biodiesel production was favored by increases in the harvested palm crop area by 33,600 hectares in 2008, 48,700 ha in 2009 and an estimated 45,000 ha in 2010, compared to the annual target of 80,000 ha [12]. In spite of fluctuating Crude Palm Oil (CPO) yield, it is estimated that the CPO production should be enough to meet demand for use in biodiesel production [14]. The government is also promoting jatropha production by encouraging small farmers to grow it on small tracts of land without affecting their primary cash crops [3]. Figure 2 shows the quantities of various feedstocks for biofuel production in Thailand during 2006–2011.

Figure 2: Feedstock use for ethanol and biodiesel production in Thailand [14].



Note: The data for 2012 is an estimate [14].

The prioritization of sugarcane, cassava, oil palm and jatropha as feedstock is primarily based on their production potential, which is dependent on soil characteristics, climate, water availability, the farming system and farm management. Apart from the biophysical conditions, other socio-economic and environmental parameters, such as competing uses of biofuel crops, the threat to food security, economic risks to producers and small farmers, and the impact on land use and climate change are also considered (Table 2). Among the four basic feedstocks of biofuels, oil palm appears to have negative impacts on food security, farm practice issues, land use and marginalization of small farmers.

2.1.1. Ethanol Production

Although ethanol and biodiesel were promoted at the same time in Thailand, ethanol had penetrated the market successfully before biodiesel, because of its feedstock supply readiness [15]. The Thai government set the National Ethanol Program and Gasohol Strategic plan on December 6, 2003 with an ethanol production target of 1.0 million liter/day by the end of 2006 and of 3.0 million liters/day by the end of 2011. At the same time, the government also made provisions for excise tax incentives, investment promotion incentives to manufactures of ethanol and promotion for ethanol [16].

Table 2: Qualitative basis for prioritizing biofuel crops in Thailand [3]

	Social Risks		Economic Viability		Environmental Impact		
Feedstock	Uses as Food, Feed and Fuel	Threat to Food Security	Risks to Primary Producers	Marginalization of Small Farmers	Changes to Existing Farming Practices	Land use Change and Potential for Conflicts	Favorable Impact on Climate Change
Sugarcane	Competing	Little	Yes	No	No	No	No
Cassava	Competing	Little	No	No	No	No	No
Oil Palm	Competing	Considerable	Yes	Possible	Yes	Yes	Yes
Jatropha	Competing	Little	Yes	No	No	Yes	Yes

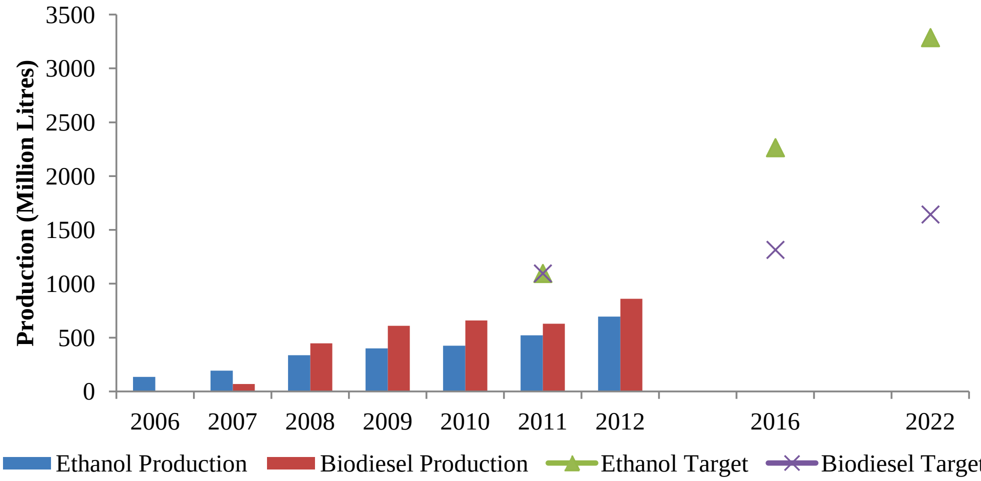
Ethanol production further increased in line with an upward trend in domestic gasohol consumption following its relatively cheaper price compared to regular gasoline. Unlike biodiesel, the government did not regulate compulsory use or sale of gasohol to substitute regular gasoline. Instead, gasohol prices remained 10%–15% below regular gasoline prices due to the excise tax, plus a price subsidy for E20 and E85 (a mixture of 85% ethanol and 15% premium gasoline) gasohol derived from the State Oil Fund and increasing the number of gasoline stations that could accommodate E20 gasohol [17].

Although ethanol production steadily increased over the years, it fell short of achieving the target production of 3.0 million liters/day in 2011. The actual production was only around 1.42 million liters/day (Figure 3). The consumers have substituted both gasoline and gasohol for the highly-subsidized liquefied petroleum gas (LPG) and natural gas vehicles (NGVs) [13]. However, ethanol consumption is likely to continue its growth, due to an increase in the number of E20 vehicles and E20 gasohol stations and the government's tax incentives for eco-car manufacturers, and as the price subsidy for E20 and the phase out of gasoline 91 from the market bear fruition.

2.1.2. Biodiesel Production

Thailand began a campaign to promote biodiesel production and consumption in 2005, but the initial production of biodiesel was insignificant until February 1, 2008, when the government adopted a policy requiring replacing all regular diesel with B2 biodiesel (a mixture of diesel with 2% biodiesel) [12]. Due to compulsory use of B100 (pure biodiesel) for B2 biodiesel production and increased B5 biodiesel demand, B100 production increased in 2009 and 2010.

Figure 3: Ethanol and biodiesel production in Thailand and 15 year Alternative Energy Development Plan (AEDP) target [8,14].



Note: The data for 2012 is an estimate [14].

Although, it is mandatory to regular diesel with biodiesel, the production has fallen short of the targeted production of 3 million liters/day in 2011 (Figure 3), as the actual production in 2011 was only around 1.72 million liters/day, mainly due to under-targeted planting of palm oil trees and unpredictable weather patterns [14]. However, biodiesel production is expected to grow significantly, due to the mandatory B5 rule (a mixture of diesel with 5% biodiesel) that came into force in January 2012 and growing diesel consumption.

The production trend for ethanol and biodiesel in Thailand has been increasing over the years. The number of registered biofuel plants (Table 3) has increased and so has their production efficiency. However, it is not clear whether the current trend is likely to meet the government's long-term target. Both ethanol and biodiesel production fell short of achieving their targeted production in 2011, and future compliance to the target not only depends on climatic conditions for crop yield, but also to a greater extent on the government's incentives, which affect the price difference, blending rates and consumption preference. According to Preechajarn and Prasertsri [14]:

- Although the production of ethanol is likely to increase with the operation of new ethanol plants, the consumption level of ethanol depends on whether the government is able to completely suspend all Octane 91 regular sales as planned.
- Five out of the total six refineries are not ready to shift from Octane 91 regular gasoline production to gasohol production by October 2012 and have been negotiating with the government to delay the plan until 2014 or else the government will have to subsidize the additional costs of imported petroleum products for gasohol production during their production restructuring process.
- In the case of biodiesel, although the number of biodiesel plants has remained constant since 2010, increased production of biodiesel is likely due to the compulsory mandate of B5 that came into force in January 2012.

- However, the productivity of fresh fruit bunches of crude palm oil is estimated to drop in 2012 as a result of dry conditions and a natural reduction in productivity a year after palm plantations reaped record yields in 2011.

2.2. Estimated Potential and Production of Second Generation Biofuel from Agricultural Residues

Thailand with its agriculture-based economy employs agricultural wastes and by-products for the generation of biofuels using commercially viable technologies. According to the Department of Alternate Energy Development and Efficiency (DEDE), the potential of electricity generation through biomass resources in Thailand is 4,400 MW and that for ethanol and biodiesel are estimated at 6–10 million liters/day and 4–5 million liters/day, respectively [18]. Although the study by DEDE does not specify which particular agricultural residues and by-products are utilized to estimate the potential, other studies indicate that bagasse (a by-product of sugar production) and rice husk (the remains from rice milling), with a total energy content between 560–620 PJ, are the major biomass used for energy production in Thailand [19,20]. We have estimated that by using 20% of available agricultural residues alone, there exists the potential to produce between 3.1–8.6 million liters/day of ethanol and 2.1–5.7 million liters/day of biomass to Fischer-Tropsch (F-T) diesel (Table 4). These values were derived by assuming a 365 day/year operation for biofuel (bioethanol and biomass to F-T diesel) production amounts in Table 4

Table 3: Number of registered biofuel plants in Thailand since 2006 [14].

Year	No. of approved/registered ethanol plants			No. of approved/registered biodiesel plants		
	No. of bio-refineries	Combined production capacity (million liters/day)	Capacity in use (%)	No. of bio-refineries	Combined production capacity (million liters/day)	Capacity in use (%)
2006	5	0.78	48	3	0.6	1
2007	7	0.96	54	5	1.3	14
2008	11	1.6	58	9	2.3	53
2009	11	1.7	65	14	5.4	31
2010	19	2.9	40	13	5.4	34
2011	19	2.9	50	13	5.4	32
2012	21	3.7	51	13	5.4	44

Note: The data for 2012 is an estimate [14]

Bioenergy from agricultural residues is acknowledged as possessing favorable sustainability benefits, notably greenhouse gas emissions (direct and indirect), net energy balances, water consumption and usage, food security and biodiversity [21–24]. Sustainable extraction rates of agricultural residues are influenced by edaphic factors (*i.e.*, soil type, soil fertility), land slope, tillage, cutting height, crop yield, weather and wind patterns [25–27]. For example, findings from a Canadian study show that the sustainable extraction rate of agricultural residues could range from 44% to 64% [28]. The actual amount of residues that could be sustainably extracted in Thailand would require further analysis to be determined by edapho-climatic studies. However, for this study, we assume a more

conservative extraction rate of 20% for bioenergy applications, requiring balance for maintaining soil health and function and other utilizations in some sectors, such as animal fodder, *etc.*

In this study, we estimated the potential availability of sustainably-derived agricultural residues based on the information [29] to contribute to transportation fuels in Thailand from the following major crops—maize (*Zea mays*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), sugarcane (*Saccharum officinarum*), wheat (*Triticum aestivum*), cocoa (*Theobroma cacao*), coconut (*Cocos nucifera*) and coffee (*Coffea arabica*) (Table 4). Herein, we have quantified the technical potential for biofuel production via biochemical ethanol (enzymatic hydrolysis and fermentation) conversion, as well as diesel production (thermochemical syngas to Fischer-Tropsch diesel) (Table 4)

Our analysis shows that approximately 10.4×10^6 (10.4 million) bone-dry tons per year of agricultural residues to be potentially available for biofuel production (based on a 20% residue extraction rate).

Using the conversion factors [30], our estimation indicates that the potential for ethanol production per year from agricultural residues is in the range of 1.14–3.12 billion liters. This would be sufficient to offset 25.1%–68.5% of Thailand's (year 2011) national consumption of gasoline as transportation fuel (Tables 4 and 5). Alternatively, 0.8–2.1 billion liters per year diesel (biomass to F-T diesel) could be technically produced from agricultural residues to displace 5.7%–15.1% of its transportation diesel utilization in the year 2011 (Tables 4 and 5). Our estimated values are comparable to and consistent with a potential of 6–10 million liters/day of ethanol and 4–5 million liters/day of biodiesel calculated by the Department of Alternative Energy Development and Efficiency (DEDE) [18]. However, the likely growth and development of the cellulosic ethanol sector based on agricultural residue feedstock could result in increased competition over resources from other utilization, such as for animal fodder and cooking fuel. Previous work [31] recommends that targeted policies would be required to help achieve sustained access to available cheap feedstock, thereby ensuring long-term sustainably of the biofuel industry.

The government of Thailand is also promoting research and pilot projects for the development of second generation biofuels, generated from non-food feedstock, such as ligno cellulosic biomass from agricultural residues and waste. According to the Energy Policy and Planning Office and the Department of Alternate Energy Development and Efficiency, the total amount of crop and wood residues in Thailand in the year 2002–2003 was about 47.8 Mt, which would have been enough to replace 130% of the then gasoline consumption and 17% of Thailand's crude oil imports through biofuel production [32]. A facility using a molasses-based ethanol plant has opened a second production line using second-generation biofuels in the form of cane bagasse as a pilot project with the production of 10,000 liters/day bioethanol, which will be increased to its full capacity of 120,000 liters/day once fully developed [14].

However, full commercialization of second generation biofuels will be years away without significant additional government support. Unprofitable large-scale production due to relatively high production costs, the need for technological breakthroughs to make the processes more cost-and energy-efficient and additional development of a whole new infrastructure for harvesting, transporting, storing and refining biomass are some of the challenges for second generation biofuel production in Thailand [33]. The development and monitoring of large-scale demonstration projects and more

investment in research, development, demonstration and deployment is needed to move forward to second generation biofuel production and to ensure it can be undertaken sustainably [33].

Table 4. Estimated technical potential of second generation biofuel production from agricultural residues in Thailand (Source: Authors).

Agricultural Residues[a]	Production (tons/year)	Residue Type	Residue to Product Ratio (RPR)[b]	Moisture Content (%)[c]	Residue (wet tons/year)	Residue (dry tons/year)	Residue, 20% Sustainable Extraction (dry tons/year)	[d]Biochemical Ethanol (million liters/year)		[e]Biomass to Fischer-Tropsch Diesel (million liters/year)	
								Low	High	Low	High
Maize	4.45×10^6	Stalk	1.5	15	6.68×10^6	5.68×10^6	1.14×10^6	125	341	85.2	227
Rice	3.16×10^7	Straw	1.5	15	4.74×10^7	4.03×10^7	8.06×10^6	886	2,420	604	1610
Sorghum	5.40×10^4	Stalk	2.62	15	1.42×10^5	1.20×10^5	2.41×10^4	2.65	7.22	1.8	4.81
Sugarcane	6.88×10^7	Bagasse	0.3	75	2.06×10^7	5.16×10^6	1.03×10^6	114	310	77.4	206
Wheat	1.10×10^3	Straw	1.2	15	1.32×10^3	1.12×10^3	2.24×10^2	0.0247	0.0673	0.0168	0.0449
Cocoa	7.63×10^2	Pods,Husk	1	15	7.63×10^2	6.49×10^2	1.30×10^2	0.0143	0.0389	0.0097	0.0259
Coconut	1.30×10^6	Shell	0.6	10	7.79×10^5	7.01×10^5	1.40×10^5	15.4	42.1	10.5	28
Coffee	4.90×10^4	Husk	2.1	15	1.03×10^5	8.74×10^4	1.75×10^4	1.92	5.24	1.13	3.5
Total							**1.04×10^7**	**1,140**	**3,120**	**781**	**2,080**

Note: [a]agricultural crop production based on year 2010 statistics information [34]; [b]RPR based on information in [35]; [c]moisture content based on information in [35]; [d]low biochemical enzymatic hydrolysis ethanol based on a conversion factor of 110 l/dry t; high biochemical enzymatic hydrolysis ethanol based on conversion a factor of 300 l/dry t [30]; [e]low thermochemical syngas-to-diesel using the Fischer-Tropsch process and based on a conversion factor of 75 l/dry t; high thermochemical syngas-to-diesel using the Fischer-Tropsch process and based on a conversion factor of 200 l/dry t [30].

Table 5. Estimated biofuel potential in relation to Thailand's transportation fuel consumption. F-T, Fischer-Tropsch (Source: authors).

	Potential feedstock sustainably extracted (dry million tons/year)[a]	Estimated bioethanol production (billion liters/year)	Percentage of national (year 2011) gasoline consumption it could potentially displace	Estimated biomass to F-T diesel production (billion liters/year)	Percentage of national (year 2011) diesel consumption it could potentially displace
Agricultural residues (year 2010 data)[a]	10.4	1.14–3.12	25.1–68.5%[b]	0.8–2.1	5.7–15.1%[c]

Note: [a]in order to maintain soil health and minimize any potential competition for the resource from other sectors, only 20% of available agricultural residues is used in this estimation; [b]ethanol production amount was compared with gasoline on an energetic basis. The year 2011 national gasoline consumption in the transportation sector of 2.27×10^6 t (Table 1) was used for comparison; [c]the year 2011 national diesel consumption in the transportation sector of 11.2×10^6 t (Table 1) was used for comparison.

3. Biofuel Policy in Thailand

The main policy for promotion and development of renewable energy sources was given by the Alternative Energy Development Plan (AEDP) (2008–2012). The plan set an ambitious 15-year target to increase the share of the alternative energy mix to be 20% of the country's total energy demand by 2022 and the share of biofuel in it to be around 4.1%. Based on the AEDP, the 15-year Ethanol Development Plan set production targets of bioethanol at 3.0, 6.2 and 9.0 million liters/day for the short-term (by 2011), medium-term (by 2016) and long-term (by 2022), respectively. Similarly, the 15-year Biodiesel Development Plan (2008–2022) set production targets of biodiesel at 3.0, 3.6 and 4.5 million liters/day for the short-term (by 2011), medium-term (by 2016) and long-term (by 2022), respectively [8]. In December 2011, the government modified its old 15-year AEDP (2008–2022) with the current 10-year AEDP (2012–2021), which is set to increase the share of renewable and alternative energy from 20% to 25% by 2021. The driving force behind the AEDP was to reduce oil imports, strengthen energy security, enhance the development of alternative energy industries and conduct research and develop renewable energy technologies [8].

The new 10-year AEDP (2012–2021) is set to increase ethanol consumption to 9.0 million liters/day by 2021, unchanged from the old 15-year plan (2008–2022). To make the new plan operational, the government devised strategies and incentives at both the supply and demand sides, as follows [8]:

(1) On the production side, the plan focuses on increasing the national average production of cassava and sugarcane and promotes other alternative feedstock commercially.

(2) On the demand side, the government plans to:

- Terminate using Octane 91 regular gasoline by October 2012;
- Subsidize E20 gasohol from the State Oil Fund at 3.0 Baht/liter (36 US cents/gallon) cheaper than Octane 95 gasohol and encourage the extension of E20 service stations;

- Support the manufacturing of eco-cars and E85 cars in general, by reducing the excise tax to car makers by 50,000 Baht per each E85 car (about US$ 1,600/vehicle) and 30,000 Baht (about US$ 950/vehicle) for each eco-car;
- Support the manufacture of eco-cars (E20 vehicles) and flex-fuel vehicles (FFV), which are compatible with E85 gasohol, by reducing the excise tax for automobile manufacturers by 50,000 Baht/vehicle (about US$ 1,600/vehicle) for FFV and 30,000 Baht/vehicle (about US$ 950/vehicle) for eco-cars;
- Support research and development; encourage gasohol usage through public campaigns.

The new 10-year Biodiesel Development Plan revised its target for biodiesel consumption from the previous 4.5 million liters/day to 5.97 million liters/day by 2012. The government's strategies and incentives at both the supply and demand sides are [8]:

- Expansion of the oil palm area and increasing the production capacity of crude palm oil above 3.05 million tons/year;
- Compulsory biodiesel blending requirements (currently, B5) and managing the proportion of biodiesel blend relevant to the domestic palm oil production and plan to increase the blending share up to 7% in diesel.

Table 6: Price structure of petroleum products in Bangkok (as of November 5, 2012) [36].

Unit: Baht/liter	Premium Gasoline (Octane 95)	Regular Gasoline (Octane 91)	Gasohol			B3 Biodiesel
			E10 (Octane 95)	E20 (Octane 95)	E85 (Octane 95)	
Ex-refinery Factory Price	23.1596	22.7253	23.0134	22.7818	20.4314	25.1665
Excise Tax	7.0	7.0	6.3	5.6	1.050	0.0050
Municipal Tax	0.7	0.7	0.63	0.56	0.1050	0.0005
State Oil Fund	8.0	6.7	2.3	- 2.3	- 11.80	0.70
Conservation Fund	0.25	0.25	0.25	0.25	0.25	0.25
VAT and Market Margin	8.3904	5.2747	4.2366	4.3881	11.0436	3.6679
Retail Price	47.50	42.65	36.73	31.28	21.08	29.79

Note: Exchange rate 30.87 Baht/ US Dollars. VAT, value added tax.

Table 6 shows the current price structure of petroleum products in Thailand, showing the preferential tax to promote biofuels in Thailand. Both excise and municipal tax for biodiesel and gasohol is lower compared to that of conventional gasoline, with further reduction for increased blending types. Moreover, the contribution to the state oil fund from conventional gasoline subsidizes biofuels, particularly E20 and E85 blends. These set of incentives make the retail price (Baht per liter) of both ethanol and biodiesel less than that of conventional gasoline.

4. Sustainability of First Generation Biofuel Production in Thailand

Biofuels are an important alternate source of energy, but their impact on society and the environment, besides its oil import reduction capability, must be assessed carefully if they are to be considered as a sustainable resource. In line with the World Commission on Environment and

Development definition of sustainable development, which is to meet the needs of present without compromising that of future generations [37], the sustainability dimension of biofuels should consider potential tradeoffs between food production and fuels, as well as the need to apply a broad systems perspective [38]. Measuring the sustainability of biofuel is equally difficult and depends on factors, such as the definition of system boundary, the reference scenario and any assumptions taken regarding the impact of the results [39].

The sustainability of biofuels, *i.e.*, the environmental, social and economic impacts, are usually assessed using suitable criteria and indicators. At the international level, initiatives, such as The Roundtable on Sustainable Biofuels (RSB), The Roundtable on Sustainable Palm Oil (RSPO), Global Bioenergy Partnership (BGEP) and EU Renewable Energy Directive, *etc.*, have developed standards and criteria that focus on environmental impacts, such as greenhouse gas (GHG) emissions, land use change, social impacts, such as food security, and economic impacts, such as economic viability for sustainable biofuel production [40], to assess the sustainability of biofuels.

At the national level, only a few countries have implemented sustainability components into the production requirement and lifecycle standards. The USA, Brazil and some European countries (Germany, the UK and the Netherlands) have also developed and implemented standards, policies and initiatives that deal with the sustainability aspect of biofuel production and consumption. For example, the Renewable Fuel Standard (RFS) of the United States, amongst others, deals with GHG sustainability and has specific provisions on the GHG reduction target and GHG savings, which biofuel production should meet [27,41]. Similarly, the Social Fuel Seal program of Brazil deals with social sustainability by providing incentives for the producers to purchase (10% to 30%) of their feedstock from small holder farmers [42].

When standards and regulations directly assessing biofuel sustainability are non-existent, policies and plans through incentives set constraints to ensure that some elements of biofuel sustainability are addressed. For example, the AEDP plan of Thailand mentions that to promote biodiesel production from the supply side, palm trees will be grown in appropriate areas not competing with any food crops and priority will be given to promote new fuel (e.g., from jatropha, microalgae) for future diesel substitution [8]. The following section thus discusses the sustainability issues on Thailand's biofuel development efforts in terms of environmental sustainability, socio-economic sustainability and food security.

4.1. Environmental Sustainability

On a positive note, biofuels are an alternative to fossil fuels. Generally, sustainably-derived biofuels are considered carbon neutral, as the carbon released from burning it is removed from the atmosphere by growing the plant. The advantage of biofuels over fossil fuels is the possibility of making them carbon negative, and only carbon-negative fuel can reduce the build-up of carbon in the atmosphere and its greenhouse effect [43]. According to Quadrelli and Petersons [44], the greenhouse gas reduction of ethanol with respect to conventional gasoline, on a well to wheel basis, is about 13% when ethanol is derived from grain and up to 90% for sugarcane-based ethanol. Similarly, when compared to conventional petroleum diesel on a well to wheel basis, oil seed-derived biodiesel leads to greenhouse gas emission reductions of 40% to 60%. Therefore, use of biofuels as an alternative energy

source in the transport sector is a positive step towards reduction of GHG emission to address the global warming issue.

However, the emissions generated from indirect land use change due to biofuel production can counteract the greenhouse emissions savings achieved from biofuel use. A study by Reijnders and Huijbregts [45] on the lifecycle emission of greenhouse gases associated with rapeseed-based biodiesel showed that biodiesel performs worse than conventional diesel (as the biogenic emissions exceeded the 1.2 kg CO_2 equivalent of kg^{-1} biodiesel) when one considers not only fossil fuel inputs, but also N_2O emissions and changes in carbon stocks of agro-ecosystems linked to cultivation of biofuel crops.

Biofuel production is also controversial for its potential to negatively affect land use, natural habitat and biodiversity and to displace valuable food production. Studies indicate that depending on the method of conversion, it could take between 75 to 93 years for the carbon emissions saved through the use of biofuel to compensate for the carbon lost through forest clearing. If the original habitat was peatland, the carbon balance would take more than 600 years and planting oil palms on grassland would lead to removal of carbon within 10 years [46].

A study by Silalertruksa and Gheewala [47] on the GHG performance of bioethanol in Thailand observed that there are wide ranges of GHG emissions depending on the production environment, such as types of fuel used in ethanol plants, crop productivity and approaches to manage the crop residues and, especially, if direct land use change (LUC) is included in the system boundary. According to them, if the changes of tropical forest land (FL) and/or grassland (GL) to cropland (CL) are included in the analyses, GHG emissions can possibly increase from 1 to 10 times as compared to cases where LUC is excluded. The conversion of tropical forest to cropland results in the highest GHG emissions, due to the CO_2 emissions from the loss of carbon stock in above-and below-ground biomass and non-CO_2 emissions from burning biomass as part of the first clearance of land.

Even more important and controversial is the issue of indirect land use change (ILUC), which occurs when the diversion of crops to produce biofuels causes farmers to respond by clearing non-agricultural lands to replace the displaced crops [48]. The indirect land use impact of ethanol production in Thailand analyzed through the displacement of the cultivated area of other crops (sugarcane) in the country and reduced sugar production showed that ILUC could result in a larger impact on the emission of GHGs, mainly due to the change of above-ground and below-ground biomass and the soil carbon stock [49].

The production of biofuels can also significantly impact water resources as a result of land use change, which can affect water runoff, ground water recharges, water availability and the local climate by altering the levels of evapotranspiration from the land [50]. In a study to evaluate a potential impact of biofuel production on the hydrology of a small watershed, Khlong Phlo in Thailand, through a water footprint revealed that although oil palm expansion has a negligible alteration in evapotranspiration (0.5 to 1.6%) and water yield (−0.5% to −1.1%), nitrate loading (1.3% to 51.7%) to the surface water can increase and the expansion of cassava and sugarcane can decrease evapotranspiration (0.8 to 11.8%) and increase water yield (1.6 to 18.0%), thereby increasing sediment (10.9 to 91.5%), nitrate (1.9 to 44.5%) and total phosphorus (15.0 to 165.0%) [51]. Thus, the land use change for biodiesel production had the potential to affect both the water quality and water balance components.

4.2. Socio-Economic Sustainability

Another key element of biofuel is the impact of biofuel production in the social-economic conditions, including the employment generation potential and the effect on GDP and trade balance. The impact of biofuel development in socio-economic development of Thailand based on the 15-years AEDP target for 2022 showed that employment generation would be around 238,700–382,400 person-years and 150 million dollars in additional GDP, imported goods worth 1,583 million dollars with 2,547 million dollars of imports would be saved compared to petroleum fuels (Table 7) [52].

Table 7: Socio-economic impact of biofuel production in Thailand [52].

Biofuels	Employed Persons (Person-years) of Biofuels Production (per TJ of biofuels)			GDP Effects of Biofuels (k$ TJ^{-1} of biofuels)			Import Effects of Biofuels (k$ TJ^{-1} of biofuels)			
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Difference (import of biofuel -import of gasoline/diesel)
Cassava Ethanol	3.3	2.2	5.5	12	11	23	8	21	29	- 31
Molasses Ethanol	0.5	4.8	5.3	11	8	19	5	13	18	- 41
Sugarcane Ethanol	4.0	1.7	5.7	13	16	28	18	32	49	- 10
Palm Biodiesel	2.0	1.5	3.5	13	5	17	5	9	15	- 46

Although the Thai government has been promoting the use of biofuels to reduce the consumption of fossil fuel, there are, however, concerns over promoting biofuels because of the high costs involved in its production and the need for the government to provide subsidies to make the fuel affordable. Thailand also has a lower unit of production costs, which could be further lowered with increases in yields and technology improvements. For example, the production cost of sugar-based ethanol in Thailand is approximately 0.27 US$/liter (2005 price), whereas the cost of wheat/sugar beet ethanol in EU ranges between 0.44–0.51 US$/liter (2005 price) [53]. This is mainly due to the relatively lower cost of feedstock production (as feedstock costs account from 58% to 65%) and cheap skilled and abundant labor [53].

Biofuel production can also undermine land tenure and labor rights, where these are not respected. For example, forest areas might be exploited for plantations without consideration for its rightful owners. However, independent smallholder oil palm growers constitute the vast majority of growers in Thailand, and large estates of oil palm plantations are rather rare, in comparison to neighboring Malaysia and Indonesia. Therefore, Thai oil mills strongly depend on purchasing fresh fruit bunch (FFB) from independent oil palm growers, mostly smallholder farmers, leaving the farmers in a good bargaining position with fewer chances of land rights and security issues [54].

4.3. Food Security

The expansion of the biofuel market has created many trade-offs, new linkages and also competition between the different economic sectors, such as agriculture and energy [55]. Biofuels may help to avoid the risk to energy security, but at the same time, introduce risks to food security. Over 93% of palm plantations are situated in southern Thailand, and these rice plantations are likely to be reduced as a result of oil palm plantations [56].

According to the study by Salvatore and Damen [57], the effect of implementing the AEDP biofuel targets of Thailand will result in an increase in the price of these crops and food crops in general. Analysis of the impact of biofuel development on households (especially the poor), due to a general rise in the price of agriculture goods (especially food crops) showed that, following a rise in food prices, the incidence of poverty increases in all regions of Thailand under the vast majority of scenarios tested, the rice-only growing farmers being hit the hardest, as poorer households would need to spend a large proportion of their (slightly greater) income on more expensive food.

However, at a macro level, increased food prices could affect the Thai economy in many ways. On the one hand, domestic prices of food could be pushed upwards as domestically produced food products progressively substitute for imports. On the other hand, the higher price could provide incentives for supporting industries to increase the output of products and services, such as fertilizer, energy, transportation, retail services, *etc.* This increase in output among agricultural and supporting sectors could flow on to the broader economy and increase national income [57].

To evaluate the security of the feedstocks supply for long-term bio-ethanol production in Thailand, Silalertruksa and Gheewala [58] conducted an assessment based on the policy targets set by the government, *i.e.*, 3.0, 6.2 and 9.0 million liters/day by year 2011, 2016 and 2022, respectively, for bio-ethanol production. Feedstock supply potentials were analyzed based on three scenarios of yield improvement, such as low yield improvement, moderate yield improvement and high yield improvement. The results showed that based on surplus availabilities and the net feedstock balances, the total capacity of bio-ethanol production in Thailand in 2022 could vary from 3.6 to 17.6 million liters of ethanol/day. Only the high yields improvement scenario would result in a reliable and sufficient supply of molasses, cassava and sugarcane to satisfy the long-term demands for bio-ethanol and other related industries.

Therefore, to enhance the long-term security of feedstock supply for sustainable biofuel production in Thailand, improved yields of existing feedstocks and promoting production of biofuel derived from agricultural residues are critical. Since Thailand is among the world's largest producers and exporters of many food products (rice, sugar, corn, *etc.*), the issue of food security not only impacts domestic supply, but also the global food supply chain [59]. Therefore, it becomes imperative for the government to identify the risks of changes of food price and carefully weigh the real costs and benefits of biofuel production. Many of the problems associated with the risks posed to food security by biofuel crops can be addressed by the production of biofuels through agricultural residues and non-food crops. Significant research, development, investment and pilot demonstration projects are required to further commercialize the deployment of such second generation biofuels.

4.4. Sustainability Assessment

In order to determine the net cost and benefit of the biofuels, a lifecycle assessment (LCA) can be used to assess the sustainability of fuel products [22]. It can assess the impacts in the complete lifecycle of the fuel product, from raw material production and extraction, processing, transportation, manufacturing, storage, distribution, use and disposal and, hence, is a valuable tool in assessing the sustainability of the fuel products [39]. In the context of biofuel, the system boundary is determined as "well to tank", "tank to wheel" or "well to wheel", and the results of the assessment are usually compared with fossil fuel or alternative biofuel product [39]. A LCA study of palm biodiesel production in Thailand indicates that although biodiesel can lead to a GHG reduction of about 46%–73% as compared to conventional diesel, the production and utilization of biodiesel also leads to emissions of other products and contaminants, which affect the environment in terms of photochemical oxidation, toxicity, acidification, eutrophication, global warming, *etc.* [60].

In spite of the above mentioned environmental impacts, another important aspect to be considered while evaluating the lifecycle cost of biofuel production is the externalities that are internalized through biofuel compared to conventional fuel. Silalertruksa *et al.* [61] evaluated the influence of externalities on the cost performance of various palm oil biodiesel blends (B5, B10 and B100) when internalized into their respective production cost for the case of Thailand through the lifecycle costing approach. The key environmental burdens considered included land use, fossil energy resources depletion and air pollutants emissions, *i.e.*, CO_2, CH_4, N_2O, CO, NO_x, SO_2, VOC and PM10, and the results showed that environmental costs contributed to 34% of the total costs of conventional diesels. In comparison to diesel and for the same performance, the total environmental cost of biodiesel-based palm methyl ester (PME) was about 3%–76% lower, depending on the blending levels. Therefore, an important benefit of biofuel production is the lower environmental externalities it causes in comparison to regular gasoline.

5. Conclusion

Biofuels can potentially provide several benefits to Thailand, particularly in energy diversification, energy independence, rural development, income generation opportunities for farmers and poverty alleviation. Due to concerns mainly related to energy security, the Thai government has promoted the production and utilization of biofuels through various policies, plans and initiatives. Ambitious short-term, medium-term, long-term targets have been put in place, blending mandates have been enforced and several financial and non-financial incentives have been devised to producers and consumers. As a result, ethanol and biodiesel production have increased over the years, albeit not to the targeted level, and Thailand is undoubtedly one of the regional leaders in the biofuel market.

However, biofuel development in Thailand is unlikely to remain non-contentious. Although initially promoted to address energy security, first generation biofuel has now been increasingly linked to other social and environmental issues, like food security and land use change impacts. On the one hand, many studies have demonstrated tangible benefits of biofuel to Thailand in terms of GHG reduction, increased job creation, reduction of imports, increased GDP contribution, *etc.* On the other hand,

impacts due to land use change and vulnerability to food security, particularly to the poor, are worrying.

Following the increased trajectory of biofuel production and the government's interest and support for biofuel, the production and consumption of biofuels in Thailand is likely to increase in the future. There is reason for concern for whether the fast development of first generation biofuel industry causes an increase in already scarce resources. In the absence of biofuel-specific sustainability standards and initiatives, the government needs to carefully examine the tradeoffs concerning food security and environmental repercussion of biofuel development. The second generation of biofuels using agricultural residues and wastes presents an opportunity to deal with the existing issue of food insecurity and environmental damage. This study has shown that an annual availability of 10.4 million bone dry tons of agricultural residues could potentially yield 1.14–3.12 billion liters per annum of cellulosic ethanol or, alternatively, 0.8–2.1 billion liters per year of diesel (biomass to Fischer-Tropsch diesel) in Thailand. This could potentially displace 25%–69% or 6–15% of Thailand's transportation fuel consumption of gasoline and diesel, respectively. This will require dealing with existing barriers of second generation biofuel and considerably more investment in research, development, demonstration and deployment.

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Conflict of Interest

The authors declare no conflict of interest.

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