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Global Assessments and Guidelines for Sustainable Liquid Biofuel Production in Developing Countries

FINAL REPORT

A GEF Targeted Research Project

Organized by

Heidelberg/Paris/Utrecht/Darmstadt
29 February 2012

GLOBAL ENVIRONMENT FACILITY
INVESTING IN OUR PLANET

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Report overview

This report consists of a main report, appendices and databases. The authorship of chapters and databases is shown in the following table.

Component	Description	Authorship/ Responsibility
Chapter 1	Introduction	IFEU, UU, OEKO
Chapter 2	Biofuel settings	IFEU, UU, OEKO
Chapter 3	Life cycle energy and greenhouse gas (GHG) assessment	IFEU
Chapter 4	Economic viability of the production of liquid biofuels	UU
Chapter 5	Global non-GHG environmental impacts of	OKEO
Chapter 6	Social impacts of liquid biofuel production	OEKO
Chapter 7	Next generation of liquid biofuel production	UU
Chapter 8	Fuel and vehicle compatibility	UNEP-DTIE
Chapter 9	Stationary applications	OEKO
Chapter 10	Scale up and integration	UU
Chapter 11	Recommendations	IFEU, UU, OEKO
Appendix A	Elements of a GEF project screening tool	IFEU, UU, OEKO
Appendix B	Life cycle energy and greenhouse gas assessment	IFEU
Appendix C	Evaluation of GHG calculation in certification systems in the context of GEF	IFEU
Appendix D	Assessment of next generation biofuel production in the Xinjiang Uyghur Autonomous Region, PR China	Xinjiang Academy of Environmental Protection Science, Urumqi/China
Appendix E	Background data for economic analysis	UU
Appendix F	Background data for next generation biofuels	UU
Appendix G	Water footprints of biofuel cropping systems in Mexico	Red Mexicana de Bioenergía (*REMBIO*), Morelia/Mexico
Appendix H	Background data for global non-GHG environmental impacts of biofuels	OEKO
Appendix I	Biofuels and employment effects	Thailand partners/ OEKO
Appendix J	Social and socio-economic impacts of cassava and sugarcane ethanol production in Thailand	OEKO
Database 1	GEF Biofuel Greenhouse Gas Calculator (MS Excel format)	IFEU
Database 2	Data on air, water and waste (GEMIS format)	OEKO

Steering committee

The following persons served as steering committee members:

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The first project steering committee meeting was held via teleconference on September 30, 2009 where a detailed *Project Work Plan* was discussed and endorsed by the members. A second steering committee meeting took place on July 20, 2010 in Paris. The steering committee members reviewed and commented on the draft final report prepared on September 15, 2011.

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Abbreviations

AEZ	Agro-Ecological Zones
AFREPREN	Energy Environment and Development Network for Africa
ASTM	American Society for Testing and Materials
AZE	Alliance for Zero Extinction
BAU	Business As Usual
BC	Black Carbon
BEFSCI	Bioenergy and Food Security Criteria and Indicators (FAO project)
BEI	BEI International, LLC, American harvester producer
BioNachV	Biomassenachhaltigkeitsverordnung (Biomass Sustainability Ordinance; in Germany)
BLCAO	Biofuels Life Cycle Assessment Ordinance
BOD	Biological Oxygen Demand
BSI	British Standards Institution
BTL	Biomass-to-Liquid
BTRR2	Soybean breed
CaO	Calcium oxide
CAPRI	Common Agricultural Policy Regionalized Impact analysis
CARB	California Air Resources Board
CBD	UN Convention on Biological Diversity
CEC	Council of the European Communities
CEN	European Committee for Standardization
CEPAGRI	Centre for the Promotion of Agriculture
CENIPALMA	Investigación e Innovación Tecnológica en Palma de Aceite
CFB	Circulating Fluidised Bed (gasification)
CGE	Computable General Equilibrium
CGEE	Centro de Gestão e estudios estratégicos, Brasilia
CGP	Central Gathering Point
CH_4	Methane
CIFOR	Centre for International Forestry Research
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2 eq	Carbon dioxide equivalents
CPO	Crude Palm Oil
CRL	Composite Residue Log (biomass bundle)
dLUC	Direct Land Use Change
DTIE	Division of Technology, Industry and Economics
EC	European Community
EPA	Environmental Protection Agency (USA)
EtOH	Ethanol
EU	European Union
FAME	Fatty Acid Methyl Ester (biodiesel)
FAO	Food and Agriculture Organisation of the United Nations
FASOM	Forest and Agricultural Sector Optimisation Model
FFB	Fresh Fruit Bunches
FFV	Flex-Fuel-Vehicles
FT	Fischer Tropsch
GAP	Good Agricultural Practices

GBEP	Global Bioenergy Partnership
GDP	Gross Domestic Product
GEB	Global Environmental Benefits
GEF	Global Environment Facility
GEMIS	Global Emissions Model for Integrated Systems
GGL	Green Gold Label
GHG	Greenhouse Gas(es)
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für internationale Zusammenarbeit (German Society for International Cooperation)
GJ	GigaJoule(s) (10^9 J)
GWh	GigaWatt-hour(s)
GP	Gathering Point
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
GTAP	Global Trade Analysis Project
GWP	Global Warming Potential
HC	Hydrocarbons
HLPE	High Level Panel of Experts on Food Security and Nutrition
IA	Implementing Agencies
IBA	Important Bird Area
IBAT	Integrated Biodiversity Assessment Tool
ID	Indonesia
IDB	Inter-American Development Bank
IEA	International Energy Agency
IFEU	Institute for Energy and Environmental Research, Heidelberg/Germany
IFPRI	International Food Policy Research Institute
IIAM	Mozambique National Institute of Agronomic Research
IIASA	International Institute for Applied Systems Analysis
IIED	International Institute for Environment and Development
ILO	International Labour Organization
iLUC	Indirect Land Use Change
IPA	Important Plant Area
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainable and Carbon Certification
ISO	International Standardization Organization
JME	Jatropha Oil Methyl Ester (Jatropha biodiesel)
KBA	Key Biodiversity Area
K_2O	Potassium oxide
l	Litre
LCA	Life Cycle Assessment
LCFS	Low Carbon Fuel Standard (California)
LHV	Lower Heating Value
LPG	Liquefied Petroleum Gas
LUC	Land Use Change(s)
MAI	Mean Annual Increase
ML	Mali
MWel	MegaWatt (electric)
MY	Malaysia

MZ	Mozambique
MZM	Mozambique Metical (Mozambique currency)
NBER	National Bureau of Economic Research
NH_3	Ammonia
NH_4	Ammonium
N_2O	Laughing Gas
NO_x	Nitrogen oxides
NPV	Net Present Value
NTA	Dutch Technical Agreement
OAE	Office of Agricultural Economics
OECD	Organisation for Economic Cooperation and Development
OEKO	Oeko-Institut - Institute for Applied Ecology, Darmstadt/Germany
OEM	Original Equipment Manufacturer
PA	Protected Area
PE	Partial Equilibrium
PIF	Project Identification Forms
PM_{10}	Particles on the order of ~10 micrometers or less
P_2O_5	Phosphorus pentoxide
POME	Palm Oil Mill Effluent
RED	Renewable Energies Directive (of the EU)
REMBIO	Red Mexicana de Bioenergía
RFS2	Renewable Fuel Standard (USA)
RSB	Round Table on Sustainable Biofuel
RSPO	Roundtable on Sustainable Palm Oil
RTRS	Round Table on Sustainable Soy
SBA	Sustainable Biodiesel Alliance
SEKAB	Swedish Ethanol Chemistry AB
SO_2	Sulphur dioxide
SO_2 eq	Sulphur dioxide equivalents
SOC	Soil Organic Carbon
SRC	Short Rotation Coppice
SRWC	Short Rotation Woody Crops
SRF	Short Rotation Forest
STAP	Scientific and Technical Advisory Panel to the GEF
SVO	Straight Vegetable Oil
t	Metric Tonne
THB	Thailand Baht
TOPs	Torrefied and Pelletised Biomass
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
UNIDO	United Nations Industrial Development Organization
USAID	United States Agency for International Development
UA	Ukraine
UU	Utrecht University, Utrecht/The Netherlands
VOC’s	Volatile Organic Compounds
WB	The World Bank
WCMC	World Conservation Monitoring Centre (UNEP-WCMC)

WGCB	GBEP Working Group on Capacity Building for Sustainable Bioenergy
WWF	World Wide Fund for Nature
WTO	World Trade Organization
XJAEPS	Xinjiang Academy of Environmental Protection Science

SI system

T	=	tera-	=	10^{12}	= 1,000,000,000,000
G	=	giga-	=	10^{9}	= 1,000,000,000
M	=	mega-	=	10^{6}	= 1,000,000
k	=	kilo-	=	10^{3}	= 1,000
m	=	milli-	=	10^{-3}	= 0.001
µ (u)	=	micro-	=	10^{-6}	= 0.000 001
n	=	nano-	=	10^{-9}	= 0.000 000 001
p	=	pico-	=	10^{-12}	= 0.000 000 000 001
f	=	femto-	=	10^{-15}	= 0.000 000 000 000 001
a	=	atto-	=	10^{-18}	= 0.000 000 000 000 000 001

Executive Summary

An integrated global project

The *Global Environment Facility (GEF)* needs to set clear policies and priorities for future work and investments in biofuel related projects while providing guidance to countries that are keen to engage themselves in this sector. UN agencies in collaboration with scientific institutions worldwide address issues such as life-cycle energy and greenhouse gas assessments, economics, social/food security, pricing and overall environmental impacts, fuel and vehicle compatibility plus stationary applications, scale-up impacts and next generation biofuels. The results of this *GEF Targeted Research Project* are summarised in this report and its associated databases. The overall goal was to identify and assess sustainable systems in developing countries worldwide for the production of liquid biofuels for both transport and stationary applications.

The settings

Nearly all steps within bioenergy fuel-cycles vary with location and time, and each step can be realised with different processes, intensity and efficiency, emission characteristics, land use patterns, etc. as well as under very different social and economic circumstances. To allow for a conceptual framing of the broad variety of cases, the so-called “setting” approach has been developed. “Setting” is defined as a generic representation created by combining fuel chains (“life-cycles”) with socioeconomic (e.g. ownership structure, intensity and scale of production) and environmental (geo- and biophysical, climatic) categories.

A total number of 74 representative, though partially overlapping, settings were selected for analysis. These include **all liquid biofuels with a reasonably large market share**: straight vegetable oil (SVO) as well as biodiesel and ethanol, both for 1st and 2nd generation technology. The **feedstocks** are sugarcane, cassava, palm, energy grass, soy, short rotation coppice, Jatropha and organic residues. The **geographical coverage** includes 12 countries in Africa, Americas, Asia and Eastern Europe; three crop management settings were analysed. For representative settings, **seven environmental** and **six social impact categories** are analysed in various depths. For the entire set of 74 settings, greenhouse gas balances are determined in the GEF Biofuel Greenhouse Gas Calculator, allowing the option to provide user-defined input data.

Life cycle energy and greenhouse gas (GHG) assessment

A thorough life cycle energy and greenhouse gas assessment is a major step in determining the sustainability of biofuels. This report gives an overview on how energy and greenhouse gas balances are calculated and on the key parameters influencing the results. It presents GHG emission results for 74 biofuel pathways and gives an overview on GHG calculation methodologies implemented in certification schemes. The main work task was the development of an Excel-based spread sheet tool, the so called ‘GEF Biofuel Greenhouse Gas Calculator’ that is publicly available for free. The tool contains pre-calculated GHG results for 74 biofuel settings covering the full life cycles up to their provision (“from cradle to tank”). The focus was put on developing a tool that is simplified and justified but still complex enough to assure accuracy. The ready-to-use result values can serve as basic references for biofuel projects in the respective countries. Beside the pre-calculated biofuel pathways, the calculation tool allows operators, stakeholders or decision makers to adopt the determined settings to actual case situations or to calculate own pathways by using user specific input data[1]. Such adoptions require some relevant pathway information like fertiliser consumption, harvest levels, energy input and efficiency factors. In many cases these types of information are not easily available. However this data is essential if a biofuel project intends to improve its performance.

The calculation of the 74 biofuel settings showed that all biofuels emit less GHG than the replaced fossil fuels, provided that direct and indirect land use changes are avoided. In cases where direct land use change is given, emissions depend on the actual change in carbon stock between the previous status and the implemented farming system. Within the pathways, high yielding crops such as sugarcane or palm oil show best results on a per hectare basis. Also certain second generation biofuels from perennial woody crops show high potentials of reducing GHG emissions. Besides yields, results are strongly influenced by the co-product use (best is an energetic use) and the production management. For example in palm oil production, the capture of methane from the oil mill's effluent (POME) has a much larger influence on results than yields. In contrast, transports and the type of management system have minor influences.

When it comes to GHG calculations within sustainability schemes, there still is a low degree of standardization despite the long-term and widespread experiences and practices of GHG assessments for biofuels. Different approaches are in place that lead to quite different GHG results depending on scope, methodic settings and applied background data. Unfortunately biofuel pathways tend to be rather complex. Essentially GHG figures need a maximum of transparency to be acceptable for policy purposes. With regard to the complexity of supporting calculation tools it will be inevitable to foster both: applying GHG assessments at large and making it transparent and reproducible.

Economic viability of the production of liquid biofuels

Net present value (NPV) and life cycle cost calculations are made for the 1st generation feedstock settings (setting 1-54). A positive NPV indicates profitability. Two timeframes are included, 2010 and 2020; cost of inputs for 2020 has been considered a constant. Yields are expected to increase due to better management and improved varieties.

High NPVs are calculated for cassava and palm. But cassava can also have a negative NPV which indicates that the project investment is not robust. The calculated NPVs for jatropha also range from negative to positive, while for sugarcane and soy the NPV is more robust (always positive). Total life cycle cost in 2010 is estimated to vary between below 10 $/GJ to above 40$/GJ for 1st generation feedstocks in the chosen settings and from below 10 to above 20 $/GJ in 2020, see specifics per crop below;

- *Soy* - Costs for soy SVO and biodiesel are calculated to be the lowest with 6.4-10.1 $/GJ, only 20% of the production costs are allocated to soy biodiesel since the crop is used mainly for animal feed. The NPV is positive in all cases, ranging from 180 $/ha/year to above 2,900 $/ha/year in 2020 assuming a yield of 5 ton/ha/yr.

- *Sugarcane* - Sugarcane ethanol (incl. 2nd generation next ethanol) can be produced for 21-26 $/GJ in 2010 and 20-23 $/GJ in 2020 in our study. The NPV for

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[1] Please note: as the tool includes a limited number of biofuel pathways (raw material and conversion to 1st or 2nd generation biofuel) a user can calculate only such biofuel pathways with user specific data.

farmers in Mozambique is positive, however only if the installation costs of an irrigation system do not have to be paid for by the farmers.

- *Palm oil* - Palm oil can be produced between 12-22 $/GJ in 2010 and between 8.5-12 $/GJ in 2020 in our study. The NPV is positive, although for Malaysia and Colombia more specific data is required to calculate NPVs.
- *Jatropha* - Jatropha can be produced for 20-42 $/GJ in 2010 and 13-25 $/GJ in 2020. The wage rate has a large influence on the costs. Yields are currently quite low since this is a relatively new commercial crop, but there is quite a lot of room for improvement. The NPV is high when low amounts of inputs are used, high amounts of expensive fertilizer decreases profitability up to a point where farmers can make a loss. With low wage rates (e.g. family labour) profitability is reasonable.
- *Cassava* - Cassava ethanol can be produced in our study between 22-46 $/GJ in 2010 and between 15-21 $/GJ in 2020. Except for the 2010 settings with low yields in Mozambique, all NPVs are positive.

Data quality is crucial, local conditions can have a major influence. Main factors that influence the outcome of the NPV calculations are; yield, labour requirements, labour costs, costs of other inputs (land costs etc.) and the value of the by-products that are produced. More local data is required to be able to make more detailed calculations and to take site specific conditions into account. The ranges in this report can be used as benchmark if there is a lack of sufficient data, life cycle costs of the same feedstocks and/or in the same region can be compared.

Global environmental impacts -other than GHG emissions

The “traffic light” thresholds suggested in this study were derived from life-cycle and material flow analyses for the settings selected, and are subject to significant uncertainty and variation, especially for the feedstock cultivation. There is a lack of empirical evidence and representative data for some of the life-cycles and settings, so that future GEF activities should concern compiling more comprehensive data on non-GHG emissions, and especially address regionalized water use.

A key requirement to successfully meet the environmental challenges on the project level is the availability of adequate **spatially explicit** data on land use and biodiversity, especially high resolution maps. In that regard, enabling activities are crucial to consider for future GEF funding.

Priority for GEF project portfolios should further acknowledge that in the coming decades, conventional agricultural practices are not adequate to meet climate change challenges, and food security needs especially in rural areas. Thus, GHG mitigation measures and adequate biodiversity safeguards should be considered as “standard” requirements for GEF-finances projects, and **best practices** for biofuel projects should be demonstrated by project developers

Social standards, criteria and indicators

The “traffic light” approach developed in this study to address social issues of biofuel developments should be tested (and possibly refined). Both for food security and employment effects, key requirements on the project level is the availability of adequate data, and analytical skills and access to modeling. Usually, this goes beyond capacities and resources available to project developers or the GEF staff reviewing projects. Therefore, GEF is dependent on the responsibility of countries and governments to analyse the characteristic of their own country and provide the necessary data sets. Here, **collaboration should be sought with the GBEP activities** on implementing sustainability indicators for bioenergy on the national level for which a new Working Group on Capacity Building for Sustainable Bioenergy (WGCB) was created in the GBEP. A key focus for this should be on the food security indicators, and employment effects.

With regard to strategic issues, priority for GEF project portfolios should consider countries which already analysed biofuel production impacts on prices and food security. Potential GEF projects must further pay attention to land tenure, labor conditions and gender issues. These impact categories influence human welfare and can avoid poverty and hunger. Due to increasing population, increasing demand for food, and the growing needs for modern energy services, biofuel production and use – also for stationary applications – should focus on projects which deliver on all those issues without major negative tradeoffs. Here, the sustainable use of biogenic residues and wastes and of sustainably using marginal and degraded land for biofuel feedstock cultivation should receive priority in project funding strategies.

Evaluation of potential future (next generation) types of biofuels

Next generation biofuels can be produced in developing countries at costs that range from 10 to 30 $/GJ for next ethanol and synfuel derived fuels. Feedstocks considered in this study include eucalyptus, poplar, switchgrass wheat straw and rice straw. Key to the competitive production of next generation fuels is the optimisation of the conversion process, which dominates overall production costs (conversion costs range from 35-65% of total supply chain costs). Also important is the efficient organisation of supply chain logistics, especially for the low energy density feedstocks such as wheat straw – the handling, storage and transportation of bulky agricultural residues requires densification of the feedstock early in the chain to reduce subsequent step costs. For wheat and rice straw, storage costs account for up to 20% while their truck transportation accounts for up to 35% of the total supply chain costs. Feedstock production costs are also important – for the selected energy crops, feedstock costs account for 20% of total costs for eucalyptus and poplar, and 16% for switchgrass.

The estimated biomass feedstock production from eucalyptus in Mozambique is 3.96 $/GJ in 2020 and 3.27 $/GJ in 2030 at the farm gate. For eucalyptus in Brazil, the estimated biomass feedstock production on marginal soils is 3.3 $/GJ in 2020 and 2.9 $/GJ in 2030 at the farm gate. For the more suitable land quality, eucalyptus production is estimated to be about 2.44 $/GJ in 2020, decreasing to 2.22 $/GJ in 2030. In Ukraine, poplar production costs are estimated to be 3.5 $/GJ on marginal soils in 2020, decreasing to about 3 $/GJ in 2030. On good quality land, poplar can be produced at a cost of 2.26 $/GJ in 2020 and at 2.02 $/GJ in 2030. Switchgrass production costs in Argentina are estimated to be 3.22 $/GJ in 2020 and 2.97 $/GJ by 2030, in all cases on marginal land. The production cost of wheat straw in Ukraine is estimated to be 2.88 $/GJ in 2020 and 1.89 $/GJ in 2030. In China rice straw is estimated to cost 2.24 $/GJ in 2020 and 1.47 $/GJ in 2030 at the farm gate. It is important to note that these costs are estimated based on current market prices and the projected technological and socio-economic dynamics in the respective countries.

Given the status of the technology and investment requirements to establish processing plants, it is unlikely that second generation biofuels production can be achieved in developing countries in the coming decade. However, developing countries can already develop a biofuel feedstock production industry, which could be the basis for a strong biofuel industry when the technology matures. Investment in feedstock production could offer an option for developing countries to profit from the growing biomass market for second-generation biofuel production outside their borders, provided that transport infrastructure is suitably developed and key socio-economic and environmental sustainability frameworks are institutionalised. As a next step, cooperation on R&D at a scientific level, skills development and adaptation of technology would be needed in developing countries to build capacity for second-generation biofuel production. Similarly, investment strategies need to be developed and piggybacking on existing industries could be one route to overcoming the project finance barriers.

Fostering fuel and vehicle compatibility

For countries creating biofuel mandates and/or targets, analysing whether or not certain biofuel blends will be compatible in vehicle fleets is a critical part of a national planning process. However, identifying the appropriate biofuel blend level (i.e. one that will not affect the durability and operability of a fleet) will depend on a range of different factors. If a country is not equipped with either (1) a compatible fleet, or (2) compatible infrastructure for distribution/storage, then compatibility issues might impact the implementation of a mandate. Therefore, it is imperative to develop mandates that are compatible with a majority of the fleet or create innovative policies that structure appropriate conditions to turn over old fleets in order to make new generations of fleets more compatible.

For developing countries that are interested in developing a bioethanol blending mandate, a safe level of blending is below E10 (assuming there is not a high prevalence of FFVs pre-existing). This would assume that a blend level of E5 is suitable as an “entry” blend level, as bioethanol blends move incrementally from E5 to E10 to E15, etc. For countries without prior blending mandate for bioethanol, the recommendation is to directly implement an E5 blending level.

Biodiesel mandates also have blend walls and constraints in terms of fleet compatibility. For countries that are considering the introduction of biodiesel, research has shown that lower blends from B5 to B7 would be suitable even in older vehicles. There is even some evidence that shows that in developed markets, all levels under B20 would be suitable. For countries without prior blending mandates for biodiesel, the recommendation is to gradually implement B3 and then increase to B5 blending levels.

Other issues besides vehicle/fuel compatibility influence the successful implementation of a national biofuel blending mandate. Many of these issues can be seen as external constraints and, if considered before the development of mandates and targets, might prevent future economic losses. Decision makers should consider alongside physical compatibility: the availability of sustainably sourced and produced biofuels, fuel quality concerns, consumer awareness and use of biofuels, and industry engagement to name a few.

Innovative policies and strategies can be undertaken to move a country towards compatibility. Some of these policies include: tax incentives to retrofit existing distribution infrastructure and vehicle fleets to become compatible to a higher blend; policies that help a country turn over their legacy fleet faster; and even policies that help maintain a protection grade (regular gasoline for older cars) while introducing new biofuel blends. To help guide decision making, a fuel/compatibility decision framework should be followed that outlines critical questions. Through addressing these questions and defining key barriers, developing country governments can better understand how to effectively resolve certain challenges and how to identify what an appropriate blend level is for their current light-duty passenger vehicle fleet.

Liquid biofuels in non-transport applications

The exemplary analysis of stationary applications of liquid biofuels indicates that village-based, decentralised rural electrification can be more effective than transport applications in reducing GHG and non-GHG emissions, without negative cost and employment impacts. Therefore, stationary biofuel options should be explored further and possibly implemented where energy access is a key issue of sustainable development. In this, applications such as EtOH-based gelfuels for cooking and conversion of biogenic residues and bioenergy crops into biogas could offer additional options for clean cooking, and electricity generation, and biogas production could be integrated in many biofuel production systems which would help reducing CH_4 leakage (e.g. in palmoil mills).

It is recommended to consider alternative uses of liquid biofuels during the evaluation of GEF project proposals, and to extend the available information on decentralised stationary uses of biofuels to more settings.

Furthermore, there might be opportunities to “modernise” provision of biomass-based energy services – especially traditional use in stoves – using liquid biofuels to replace firewood and charcoal, which could reduce pressure of forests, and respective negative impacts. These options should be explored in more detail, taking into account the cost and investment implications, and potential benefits on health, including effects on black carbon emissions.

Integrated scenario-based analysis of biofuels production impacts: case studies Mozambique, Ukraine and Argentina

The research for this chapter is still on-going and will be finalised in July 2012.

Recommendations

Recommendations for future GEF policies and priorities for future biofuel related investments are provided in Chapter 11.

1 Introduction

Based on a recommendation of the Scientific and Technical Advisory Panel of the Global Environment Facility (GEF STAP) in the 2006 Workshop on Liquid Biofuels, UNEP/DTIE agreed to collaborate with FAO, UNIDO and the IEA in the joint execution of a *GEF Targeted Research Project* that aims to identify and assess sustainable systems in developing countries for the production of liquid biofuels both for transport and stationary applications worldwide.

The outcome of this study should enable the GEF to set clear policies and priorities for future work and investments in biofuel related projects while providing guidance to countries that are keen to engage themselves in this sector. UN agencies in intimate collaboration with scientific institutions worldwide address issues such as life-cycle energy and greenhouse gas assessments, economics, social/food security and pricing and overall environmental impacts, fuel and vehicle compatibility plus stationary applications, scale-up impacts and next generation biofuels in order to arrive at a set of concise and comprehensive recommendations for future use in GEF and beyond.

After approval by the GEF, the project team at IFEU, UNEP, UU and OEKO were contracted in December 2009 to carry out the project. The work was defined in a work and management plan including specification of settings that are considered in the analysis that was developed and agreed on by the members of the project team and endorsed by the steering committee. The set of environmental and social impacts and indicators covered was determined during the inception phase of the project. All 7 main executing partners (DTIE, FAO, UNIDO, IFEU, OEKO, UU and IEA), plus STAP, were actively involved in this exercise through the preparation and participation to the Project Inception Workshop and follow-up discussions.

1.1 Report structure

Nearly all steps within bioenergy fuel-cycles vary with location and time, and each step can be realised with different processes, intensity and efficiency, emission characteristics, land use patterns, etc. and under very different social and economic circumstances. To allow for a conceptual framing of these broad varieties of cases, the so-called setting approach has been developed. “Setting” is defined as a generic representation created by combining fuel chains (“life-cycles”) with socioeconomic (e.g. ownership structure, intensity and scale of production) and environmental (geo- and biophysical, climatic) categories. The concept is explained in more detail in **Chapter 2**.

A thorough life cycle energy and greenhouse gas (GHG) assessment is a major step in determining the sustainability of biofuel development. **Chapter 3** consists of a report about guidance and information for future GEF policies and interventions on GHG and energy balances, certification systems concerning GHG savings and provides an introduction to the Excel-based spread sheet tool, the *GEF Biofuel Greenhouse Gas Calculator*.

The economic viability of the production of liquid biofuels is addressed in **Chapter 4**, allowing the GEF, and others, to identify current and future economically viable biofuels options, and identify GEF interventions that can help achieve economic viability for otherwise promising (i.e. low GHG, resource efficient, environmentally sustainable) options.

The global environmental impacts -other than GHG emissions balance- of the production of liquid biofuels such as biodiversity and land degradation are the focus of **Chapter 5**, to ensure that besides climate change benefits, projects would not bring global environment "*dis*-benefits". This includes a description of a GEMIS-based database.

Chapter 6 contains a report on social standards, criteria and indicators for biofuels to guide GEF project development, including methods for their determination as well as food security impacts and direct and indirect employment effects of biofuel production.

The evaluation of potential future (next generation) types of biofuels is provided in **Chapter 7**. Perennial cropping systems, waste and residue collection systems, pre-treatment technologies and supply systems and two next generation liquid biofuels production technologies are analysed.

In setting mandates and targets, issues of fuel/vehicle compatibility need to be assessed and addressed to ensure feasibility, acceptability and cost-efficiency. The challenge of fostering sustainable transport solutions globally as well as fuel and vehicle compatibility is assessed in **Chapter 8**.

Liquid biofuels used can be used in non-transport applications in the developing world, such as grid or off-grid electricity generation, household cooking and heating. The advantages and disadvantages of biofuels used in stationary applications with regard to cost and environmental effects are analysed in **Chapter 9**.

An integrated scenario-based analysis of the potential and the environmental and socio-economic impacts of biofuel production in Mozambique, Ukraine and Argentina is presented in **Chapter 10.** As Chapter 10 draws on information from the other chapters, and the complex modelling techniques involved, the work on this chapter will be finalized in July 2012.

Recommendations for future GEF policies and priorities for future biofuel related investments are provided in **Chapter 11**.

Supporting documents and special studies are provided in the **Appendices:**

Appendix A contains a description of the proposed elements for a project screening tool that uses a traffic light system for biofuel project applications to the GEF. Details about the life cycle energy and greenhouse gas assessment are found in **Appendix B**. A detailed evaluation of GHG calculations in certification systems in the context of GEF is summarised in **Appendix C**. An important case study *Assessment of next generation biofuel production in the Xinjiang Uyghur Autonomous Region* is provided in **Appendix D** and was prepared by the Xinjiang Academy of Environmental Protection Science (*XJAEPS*), Urumqi/PR China. Data for the economic analysis of settings is summarised in **Appendix E**; for the assessment of next generation biofuels, the data is summarised in **Appendix F**. A report with field data on biofuels from sugarcane in Mexico was prepared by *Red Mexicana de Bioenergía* (*REMBIO*), Morelia/Mexico and is found in **Appendix G**. Background data for global non-GHG environmental impacts of biofuels are provided in **Appendix H**. An assessment of the employment and social effects of biofuels are provided in **Appendix I** and **Appendix J**, respectively.

1.2 Databases

As part of the project, an Excel-based spread sheet tool, the ***GEF Biofuel Greenhouse Gas Calculator*** was developed. This tool has three functions (a) to increase awareness on GHG emission results for biofuel pathways relevant for GEF eligible countries, (b) to make GHG results transparent and replicable and (c) to customise GHG calculations.

A second database, the ***GEF Non-GHG Environment Database*** is GEMIS-based and contains data on water use, selected air emissions and water effluents as well as solid wastes from biofuel supply chains for selected settings.

1.3 Elements of a GEF project screening tool

The proposed screening tool uses a traffic light system for biofuel project applications submitted to the *Global Environmental Facility* (GEF) under the GEF-5 programme (i.e. fifth replenishment of resources of the GEF Trust Fund). The objective of the project screening tool is to enable the GEF and its *Implementing Agencies* (IA) to assess on the bases of the *Project Identification Forms* (PIF) if a biofuel project brings adequate *Global Environmental Benefits* (GEB) and any other additional benefits. Furthermore, it can be used by applicants in GEF eligible countries to improve their applications. The screening tool covers two sectors of environmental issues: those identified as *Global Environmental Benefits* (GEBs) and additional benefits, i.e. social benefits and economic viability. More details about the proposed elements for a GEF project screening tool were developed by the team and are provided in Appendix A.

2 Biofuel settings

2.1 The settings concept

Nearly all steps within bioenergy fuel-cycles vary with location and time, and each step can be realised with different processes, intensity and efficiency, emission characteristics, land use patterns, etc. and under very different social and economic circumstances. Among the variables are the type of fuel produced, the feedstock used, the soil characteristics and climate conditions where production occurs, the type of cultivation, socio-economic conditions (e.g. price of labour and fuels, (un)employment rate, availability of land for energy crop production, ownership of land), among other factors. There is a multitude of farming and forestry systems, residue extraction or waste collection systems, downstream conversion routes, and waste treatment options as well as their respective links to auxiliary energy, as well as fuel and material inputs and associated transports.

To allow for a conceptual framing of this broad variety of cases, the so-called setting approach has been developed. “Setting” is defined as a generic representation created by combining fuel chains (“life-cycles”) with socioeconomic (e.g. ownership structure, intensity and scale of production) and environmental (geo- and biophysical, climatic) categories. All settings form a multidimensional matrix with dimensions describing the full multitude of combinations. In practical terms, this can be represented by a sequence of matrices (e.g. spread sheets) which is valid for a specific sub-set. A schematic overview is shown in Figure 2-1.

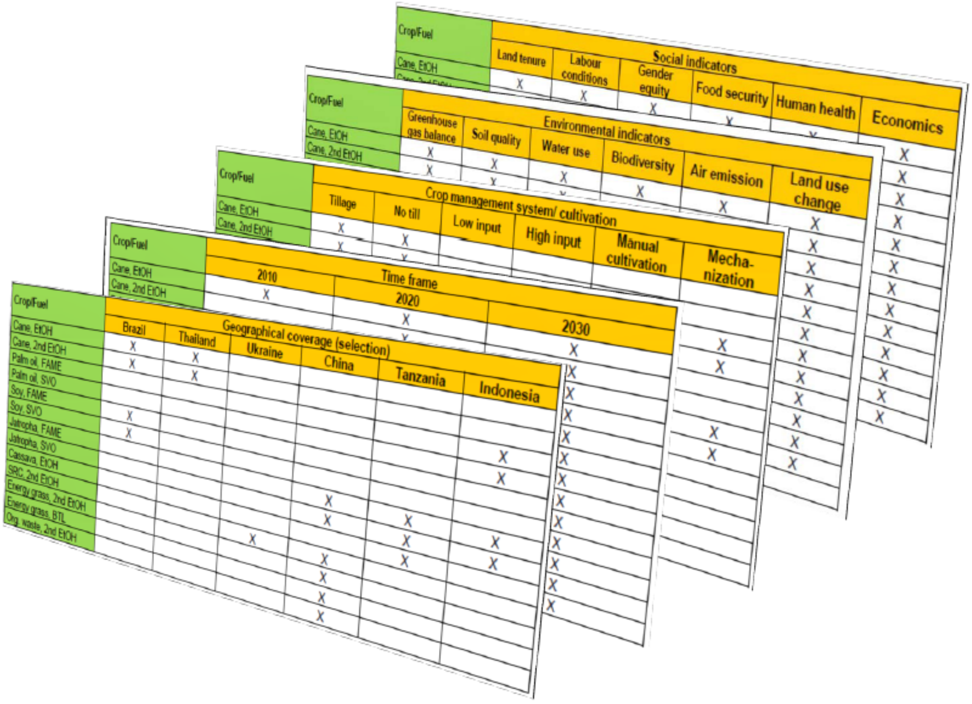

Figure 2-1 Multi-dimensional settings scheme

2.2 Overview on settings used in this report

Environmental impacts, the scale of production, social and economic impacts can be either regarded as separate setting dimensions or as sub-components of the analysis. In order to keep the structure of the settings approach manageable, the number of settings has been kept small and they have been analysed on the impact side. Consequently, the following dimensions are being considered:

- Fuel output
- Feedstock input
- Geographical scope
    - Soil and climatic conditions (within geographical scope)
    - Socio-economic conditions (within geographical scope)
- Crop management system / cultivation
- Time frame

2.2.1 Fuel output

All liquid fuels that have reasonably large market shares are considered:

- SVO (Straight Vegetable Oil)
- Biodiesel, 1st generation FAME (Fatty-acid methyl ester)
- Biodiesel, 2nd generation BTL (Biomass-to-Liquid)
- Ethanol, 1st generation
- Ethanol, 2nd generation (enzyme-enhanced lignocellulose conversion)

There are further fuels such as bio-butanol, bio-methane and bio-electricity for transport, but they are outside of the scope of the study.

2.2.2 Feedstock input

The list of potential feedstocks is long. The selection of feedstocks that are considered for analysis is the result of discussions at the inception meeting in Paris, April 15-16, 2009. It reflects a compromise between the goals of a representative list that applies to many geographical regions and a manageable list given the resources available. The following feedstocks (with reference – between parenthesis – to the liquid fuels they are converted to) were selected:

- Sugarcane (1st and 2nd generation EtOH)
- Cassava (EtOH)
- Oil palm (FAME, SVO)
- Energy grass (2nd generation EtOH, BTL)
- Soy (FAME, SVO)
- SRC: short rotation coppice (BTL, EtOH)
- Jatropha (FAME, SVO)
- Organic residues such as rice straw (2nd generation EtOH)

Some other feedstocks are worth mentioning, such as maize, rapeseed, sweet sorghum, pongamia, castor, cotton, sunflower, and algae, but those were not selected at this time for the purpose of this *targeted* research project.

2.2.3 Geographical coverage

The combinations of feedstocks and geographical coverage that have been selected for the project are listed in Table 2-1. Often several AEZ (agro-ecological zones) exist in a given country. These are considered as a sub-component in the analysis. The selection of feedstocks and geographical areas is believed to provide a representative selection from the multitude of potential settings. The settings that are included in Component 9 are shown in **bold**. These settings are also used to exemplify methodological issues of energy and greenhouse gas assessments in chapter 3.1. In that chapter Jatropha from Tanzania is used as an additional example.

Table 2-1 Combinations of feedstocks and geographical coverage

	Soy	**Sugar cane**	**Oil palm**	**Jatropha**	**Cassava**	**Energy grass**	**SRC**	**Residues**
Africa								
Mali				X				
Mozambique		***X***			***X***		***X*** a)	
Tanzania				X	X			
Americas								
Argentina	***X***					***X*** *b)*		
Brazil		X					X a)	
Columbia			X					
Asia								
China								X d)
India				X				
Indonesia			X					
Malaysia			X					
Thailand					X			
Europe								
Ukraine							***X*** *c)*	***X*** *d)*

a) eucalyptus, b) switchgrass, c) poplar d) cereal straw

2.2.4 Crop management system

The management systems are described per feedstock. Three differences of management systems are taken into account:

- Tillage / no tillage
- Low inputs / intermediate inputs / high inputs
- Low level of mechanisation / high level of mechanisation / no mechanisation

Tillage/no tillage

Tillage practices affect various aspects of agricultural systems, such as soil functions and other soil characteristics. Soil characteristics have impacts on the amount of residues that can be removed from the fields and water retention, and thus affect crop yields. Also the amount of chemical fertilisers and herbicides applied depends on the type of tillage practice.

Low inputs/intermediate inputs/high inputs

The level of inputs influences the labour requirements for feedstock production, affecting the expenses and the yields. Table 2-2 provides a detailed overview of the different activities that are included per level of inputs. Also the quantities of fertilisers and pesticides vary between the levels.

Table 2-2 Activities included in the different input systems

	Field clearing	Filed preparation	Planting	Weed control	Pruning	Fertilisation	Pest and disease control	Irrigation	Harvesting	Post-harvest activities
Low inputs	●	●	●	●					●	●
Intermediate inputs	●	●	●	●	●	●	●		●	●
High inputs	●	●	●	●●	●	●●	●●	●	●	●

Low level of mechanisation / high level of mechanisation / no mechanisation

The level of mechanisation has an influence on production expenses (field clearing, field preparation, planting, weed control, fertilisation etc.) and potentially on the socio-economic impacts. There is a ‘normal’ or most common level of mechanisation (referred to as ‘low level’) and a level of mechanisation that can be realised in the future (referred to as ‘high level’) including quantities per level of input, and related changes in, e.g. labour requirements, yields etc..

2.2.5 Time frame

Two timeframes are included; 2010 and 2020 (for 2nd generation biofuels: 2020 and 2030). For 2020/2030 estimations were made from yield and cost developments.

2.2.6 Impact categories

For a given setting (i.e. combination of dimensions), an array of impact categories are considered. The following **environmental impact categories** are addressed:

- Greenhouse gas emissions
- Soil quality and erosion
- Water use
- Biodiversity
- Land use change
- Solid and liquid waste products
- Air emissions

The following **social impact categories** are addressed**:**

- Economics

- Land tenure
- Labour conditions
- Social (including gender) equity impacts
- Food security
- Human health impacts

2.2.7 Selection of settings for analysis

The theoretical matrix of 5 fuel types, 8 feedstock types, 12 geographical areas, 8 combinations of crop management/cultivation systems and 3 time frames would result in 11,520 different settings. The combinations were limited as described in chapters 2.3 and 2.4. A total number of 74 representative, though partially overlapping, settings for further analysis were selected and are shown in Table 2-3. A detailed description of all settings is presented in Annex E-1.

Table 2-3 Selection of representative settings for analysis

Feedstock	**Fuel**	**Time frames**	**Geographical areas**	**Crop management systems**	**Number of settings**
Sugar cane	EtOH	2	2	2	8
	next EtOH	2	1	1	2
Palm oil	FAME	2	3	2	6
	SVO	1	1	1	1
Soy	FAME	2	1	3	6
	SVO	1	1	1	1
Jatropha	FAME	2	3	13	16
	SVO	1	1	1	1
Cassava	EtOH	2	3	3	15
Short rotation crop	next EtOH	2	2	1	6
	BTL	2	1	1	4
Energy grass	next EtOH	2	1	1	2
	BTL	2	1	1	2
Organic residues	next EtOH	2	2	1	4
Total					**74**

The settings are the basis for the environmental, economic, social and technical assessments in the following chapters. In each chapter, the settings' impacts are evaluated in a way that is adapted to the availability of data, the required depth of the analysis and need to generate results for the GEF decision making process. For certain impacts (e.g. social impacts), an aggregate of settings or selected representative settings are considered. The medium-term impact from climate change (i.e. impact resulting from increased climate variability) on settings characteristics is acknowledged to the extent possible.

3 Life cycle energy and greenhouse gas (GHG) assessment

The following sections deal with different aspects of life cycle energy and greenhouse gas assessments of liquid biofuels. Chapter 3.1 gives some general notes on how energy and greenhouse gas balances are calculated and on the key parameters influencing the results. Chapter 3.2 presents the GEF GHG calculator that calculates GHG balances for all 74 biofuel settings that were identified in chapter 2. Chapter 3.3 provides an overview on greenhouse gas calculation methodologies as they are applied in certification schemes, i.e. in a more political context.

3.1 Energy and greenhouse gas (GHG) calculation of liquid biofuels

Biofuels for transport have been promoted for their environmental virtues since they are said to save non-renewable energy resources and to mitigate greenhouse gas (GHG) emissions as the raw material (i.e. biomass) is renewable. However, when looking at the entire life cycle of biofuels – from biomass cultivation (including the input of fuels, fertilisers and pesticides) through conversion into liquid biofuels and combustion – considerable amounts of (mostly non-renewable) energy resources are used which are associated with greenhouse gas emissions. In addition, changes in organic carbon stocks (due to land use changes) and the resulting GHG emissions have to be taken into account. The question is whether liquid biofuels generate fewer emissions than the fossil fuels that they replace i.e. whether their use is beneficial for the climate. Life cycle assessment is a tool used to answer this question.

This section explains the methodology of life cycle assessments and key methodological issues that influence the results of life cycle energy and GHG balances (chapter 3.1.1). Subsequently, compliance of life cycle GHG calculations with the EU Renewable Energy directive (EC 2009) and United Nations Framework Convention on Climate Change (UNFCCC 2009) is reviewed (chapters 3.1.2 and 3.1.3).

3.1.1 Life cycle energy and greenhouse gas balances of liquid biofuels

Numerous publications on life cycle energy and greenhouse gas balances of biofuels can be found (see reviews by Quirin et al., 2004, Larson, 2006, Menichetti & Otto, 2009). Interestingly, their results sometimes differ quite substantially, even for the same biofuel pathway. Most often, differences in goal and scope definition and/or methodological choices are responsible for this (Gnansounou et al., 2009, Cherubini et al., 2009). The objective of this chapter is to highlight key methodological issues associated with the calculation of life cycle energy and greenhouse gas balances which are two constituent parts of a life cycle assessment (LCA). Further (global) environmental impacts are discussed in chapter 5.

3.1.1.1 A brief introduction to life cycle assessment

The environmental impacts of a product are typically quantified by performing a so-called life cycle assessment (LCA) which looks into primary energy consumption and greenhouse gas emissions associated with the product. LCA is a structured, comprehensive and internationally standardized method (ISO, 2006) and considers:

- **The entire life cycle of the product** from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (a so-called “cradle-to-grave” or “well-to-wheels” approach). Moreover, all co-products are accounted for.
- **All inputs and outputs** such as biomass and other raw materials, ancillary inputs and energy carriers as well as all co-products and emissions.
- **Potential environmental impacts**, e.g. the use of non-renewable primary energy carriers and environmental consequences of releases such as climate change induced by greenhouse gas emissions.

Taking a life cycle perspective, i.e. considering the entire life cycle including all co-products and land use changes, is essential for avoiding a shift of environmental burdens from one stage of the life cycle to another, from one geographic region to another or from one impact category to another. The ISO 14040 and 14044 standards (ISO, 2006) provide an indispensable framework for LCA, however, they leave the individual practitioner with a range of choices, which can affect the results of an LCA study. This flexibility is essential in responding to the large variety of questions addressed, but complicates the comparison of studies.

There are four iterative phases in a LCA study: (1) goal and scope definition, (2) inventory analysis, (3) impact assessment, and (4) interpretation. The first phase (goal and scope definition) is most important. It determines the intended application of the study, identifies the targeted audience and defines the object of the study, i.e. the question(s) to be answered. These parameters already pre-determine or at least influence the choice of applicable methodologies. As a consequence, the large variety of questions potentially addressed inevitably leads to different choices and results. In the inventory analysis phase, all inputs and outputs are collected, e.g. the emission of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4) or laughing gas (N_2O). To account for differences in global warming potential (GWP), all GHG are converted into so-called CO_2 equivalents in the following impact assessment phase. Per definition, the GWP of CO_2 is 1 and the conversion factors are 25 for CH_4 and 298 for N_2O (IPCC, 2007a).

3.1.1.2 Key methodological issues

In the following section, the most important methodological issues in the context of biofuels are described and discussed. In Figure 3-1, these issues are marked with red numbers.

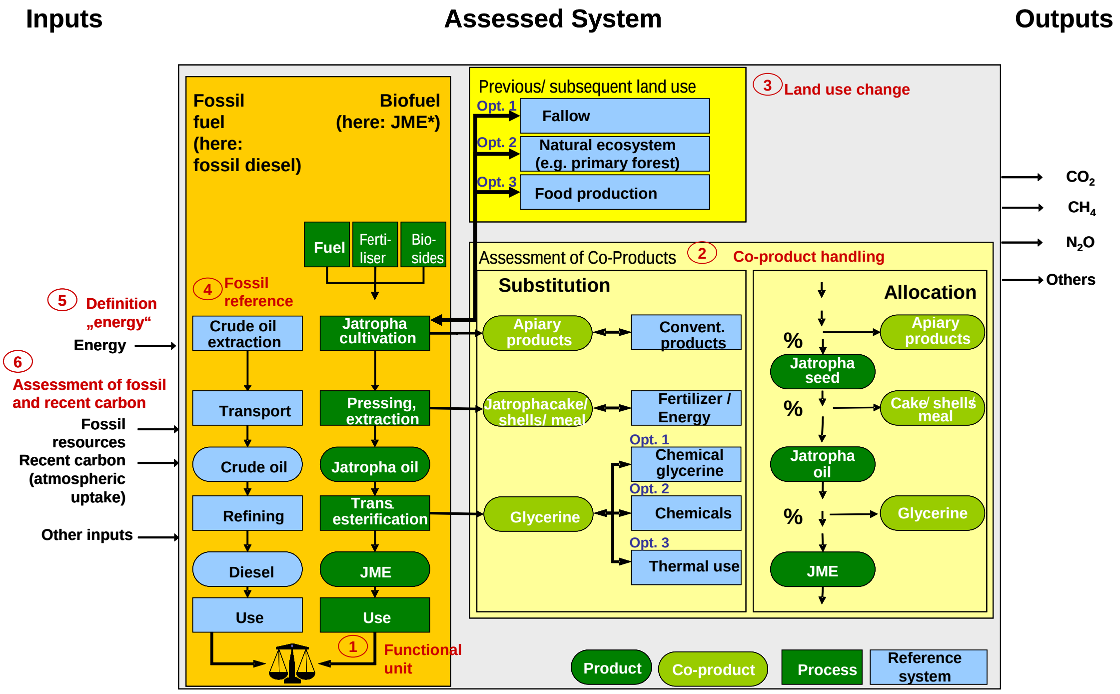

Figure 3-1 Life cycle comparison between Jatropha biodiesel (Jatropha oil methyl ester, JME) and conventional diesel. Key methodological issues are marked with red numbers.

Subsequently, the effects of methodological choices on LCA results are exemplified for selected GEF case studies. Further details and examples are given in appendix B. Very often, a so-called comparative LCA is performed, in which the product’s environmental impacts are compared to the impacts of a superseded conventional product. Figure 3-1 depicts a life cycle comparison between a biofuel and a conventional fuel.

① Functional unit

An LCA is always anchored in a precise, quantitative description of the function(s) provided by the analysed system, the so-called functional unit. The functional unit is supposed to reflect the goal and scope definition. The results of energy and greenhouse gas balances of biofuels are often related to functional units such as:

- 1 MJ of biofuel (absolute results, product basis)
- 1 hectare of cultivated land (absolute results, area basis)
- percentage of energy / greenhouse gas (GHG) emission saving (relative results).

Due to the large variety of questions addressed in LCA studies, there is no universal ‘best choice’. It is impossible to directly compare the results of studies with different functional units as the chosen functional unit affects the interpretation of results.

② Co-product handling

Biofuel production typically entails multiple output products (i.e. main product and co-products) with different functions, e.g. biodiesel, press cake and glycerine. For each process, it is necessary to account for the energy consumption and GHG emissions associated with each of the obtained products (functions). There are two different approaches to solve this multifunctionality:

- *Substitution*: A co-product is substituted with an alternative way of providing it, i.e. the process that the co-product supersedes. This means that the avoided environmental burden of another system is subtracted from the analysed system.
- Allocation: The amounts of the individual inputs and outputs are partitioned between all output products according to some allocation criterion. Allocation can be performed in accordance with underlying causal physical relationships (mass, volume etc.) or with another relationship (energy content, market price etc.).

According to the ISO standards for LCA, allocation should be avoided wherever possible. However, for the purpose of regulation, e.g. legal acts stipulating the compliance with GHG emission saving thresholds, the substitution method is considered less suitable. As a consequence, allocation based on energy content is often chosen as it is easy to apply, predictable over time and indisputable. What is not reflected, however, is the fact that the specific use of co-products actually does affect the results considerably (cf. Figure 3-3).

③ Land use change

The cultivation of dedicated crops for biofuels requires land which, in consequence, cannot be used for other purposes such as food, feed production or nature conservation. Land-use changes comprise any change in land use which is directly or indirectly induced by the cultivation of dedicated crops. Two types of land use change are distinguished (Fehrenbach et al., 2008):

- *Direct land use change (dLUC):* Cultivation of dedicated crops on existing agricultural land which formerly was not used for crop production (e.g. replacing fallow / set-aside land or grassland) or on new cropland resulting from the conversion of (semi)natural ecosystems such as grassland, forest land or wetland.
- *Indirect land use change (iLUC)*: Cultivation of dedicated crops on agricultural land which so far was used for food and feed production. Provided that the demand for food and feed is constant, food and feed production is displaced to another area where again unfavourable land-use changes might occur.

Land use changes affect the carbon stock of above- and below-ground biomass, soil organic carbon, litter and dead wood. The resulting release (or sequestration) of carbon – mainly in form of CO_2 – has to be accounted for in GHG balances.

Regarding dLUC, two issues are debated: (1) the magnitude of the carbon stock change and (2) the annualisation of emissions resulting from singular events, i.e. a partitioning over a certain period of time. The magnitude of change depends on the previous land use, the type of dedicated crop (annual or perennial) and the subsequent land use, the latter being omitted in many studies. In terms of annualisation, the ISO standards do not specify any time span.

Both above mentioned issues significantly affect the results. Regarding iLUC, however, there is no commonly accepted method on how to quantify its effects, let alone how to integrate iLUC into LCA studies (Rettenmaier et al., 2010).

④ Fossil reference product

The so-called fossil reference product (or fossil fuel comparator) is the conventional product which is replaced by the biofuel. The fossil reference product must be clearly defined in the goal and scope definition phase. Depending on this, the results may vary because of:

- Differences in definitions, e.g. average vs. marginal fuel (or fuel mix). In the EU for example, the emissions of the fossil fuel comparator are defined as the 'latest available actual average emissions from the fossil part of petrol and diesel consumed' (CEC, 2009c).
- Quantitative differences in emissions related to fuel (or fuel mix) production due to regional fuel origin (e.g. Brent, WTI etc.) and utilised refinery technology.

The choice of reference product considerably affects LCA results (for further details cf. annex B).

⑤ Accounting for primary energy consumption (only relevant for energy balances)

The life cycle energy consumption of biofuels is usually expressed in terms of primary energy[1]. However, it must be further specified which type of primary energy is considered and how the primary energy content of biomass is calculated:

- *Non-renewable vs. total primary energy:* The majority of LCA practitioners choose non-renewable primary energy demand, however, studies reporting total primary energy demand can be found.
- *Primary energy content of biomass:* Although most commonly defined as the lower heating value (LHV) of the harvested biomass, deviating definitions can be found.

LCA results differ significantly depending on these definitions (cf. annex B)

⑥ Accounting for fossil and biogenic carbon (only relevant for GHG balances)

Carbon dioxide (CO_2) emissions can originate from either (recent) biogenic or fossil carbon stocks. In the case of biofuels, the amount of CO_2 released into the atmosphere from direct biofuel combustion equals the amount of CO_2 that recently has been taken up by the plants. This release of biogenic CO_2 is considered carbon neutral, i.e. it does not fuel climate change. There are two approaches to handle recent and fossil carbon stocks:

- Distinguishing between biogenic and fossil CO_2 and accounting only for the latter
- Considering all CO_2 emissions as well as all CO_2 uptakes.

In this context, fatty acid methyl ester (FAME, biodiesel) is an interesting example as the FAME molecule consists of biogenic (fatty acids) and fossil carbon (methanol) (cf. annex B for more information).

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[1] Primary energy is defined as the energy content of primary energy carriers (e.g. fossil fuels, uranium ore, biomass) and primary energy flows (e.g. wind, solar radiation) which have not been subjected to any transformation.

3.1.1.3 Results exemplified for selected GEF case studies

The key methodological issues described above significantly affect the results of the energy and greenhouse gas balances. Figure 3-2 to Figure 3-4 show selected results for the GEF case studies “Jatropha oil Fatty Acid Methyl Ester (FAME)” and “Eucalyptus next generation ethanol”. More results can be found in annex B. In the following, a few findings are highlighted:

- The choice of functional unit may lead to diametrically opposed results and interpretations: Jatropha FAME from marginal land performs better than next generation ethanol (next EtOH) from eucalyptus if GHG emissions are related to the unit product (GJ biofuel) but vice versa if related to the unit area (hectare).
- The specific use of co-products has a considerable impact on the results: if the substitution method is applied in the example chosen, the results differ up to a factor of two. The range of results is narrower if the allocation method is used.
- Both the magnitude of the carbon stock change and the annualisation of GHG emissions significantly affect the results and may even lead to a change of sign: in case of converting savannah to arable land for Jatropha cultivation, annualisation over 25 years would result in additional GHG emissions, whereas annualisation over 100+ years would result in GHG emission savings.

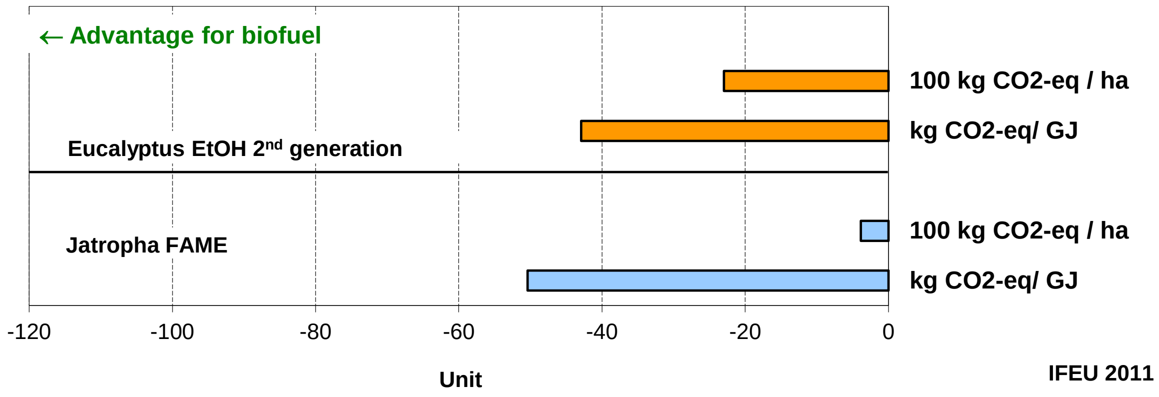


Figure 3-2 Results of the GHG balance for Jatropha FAME (Tanzania, smallholder, low input, marginal land) and Eucalyptus next EtOH (2nd generation, Mozambique, less suitable land).

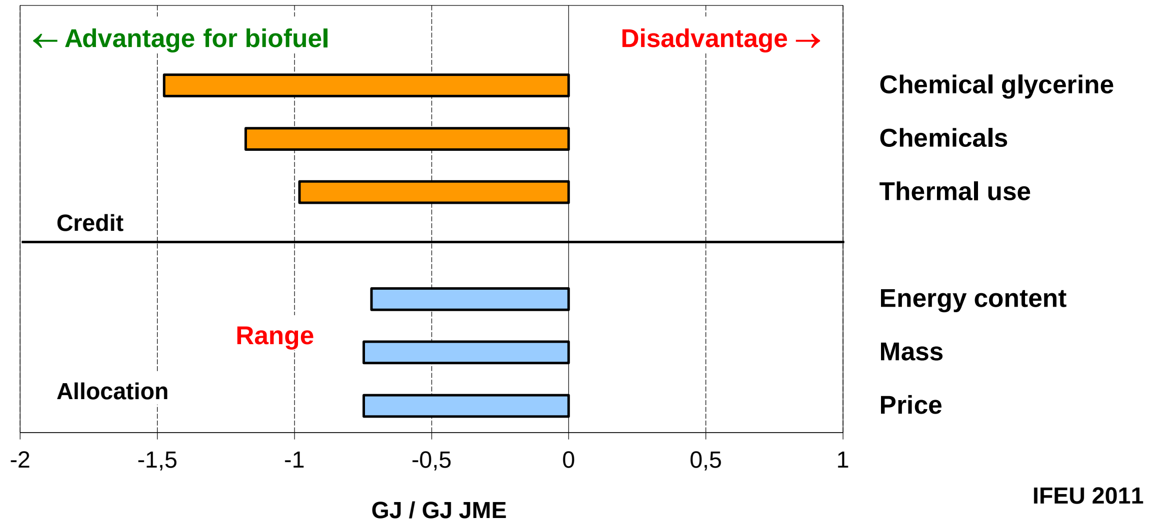


Figure 3-3 Results of the energy balance for Jatropha FAME for different options in terms of co-product (glycerine) handling.

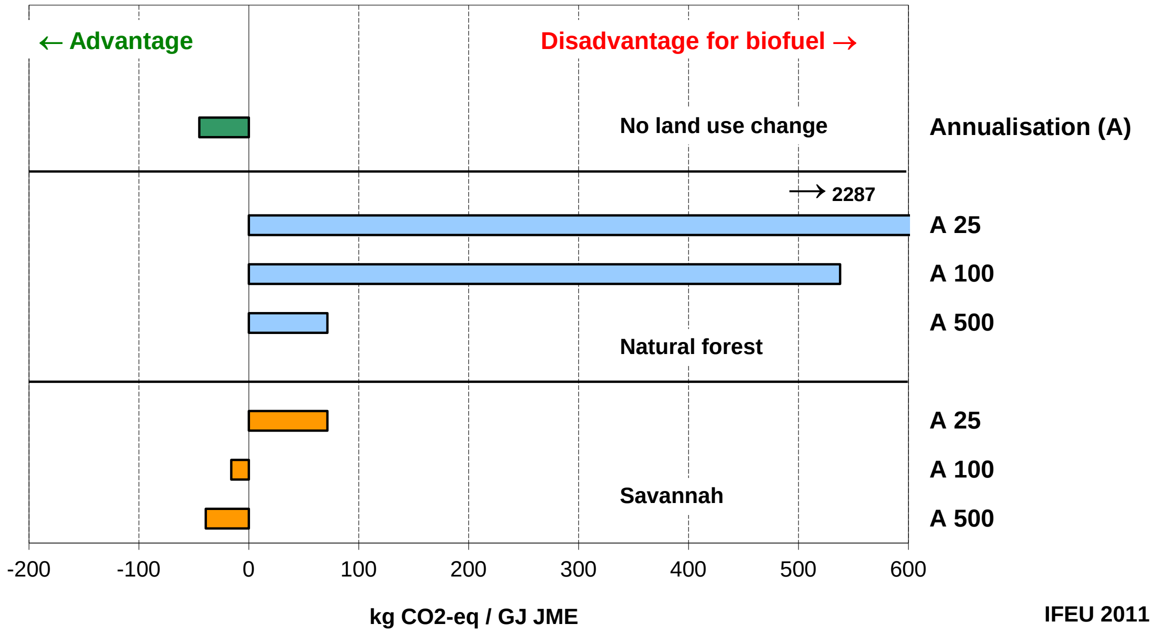


Figure 3-4 Results of the GHG balance for Jatropha FAME for different options in terms of land use change and annualisation

3.1.1.4 Recommendations

Life cycle energy and greenhouse gas balances using life cycle assessment (LCA) methodology are a suitable tool to assess important aspects of the environmental impact of biofuels, despite well-known (but mostly explicable) differences in results. However, as methodological choices may lead to major deviations in results, it is important to apply a tailor-made GEF calculation tool providing comparable and reliable results. Most importantly, the underlying methodology, assumptions and data should be clearly documented. When evaluating a proposed GEF project, it is crucial to identify the goal and scope of that project, in order to select the most suitable options in the GEF calculation tool.

3.1.2 Compliance with EU Renewable Energy Directive

The EU Renewable Energy Directive (RED) sets a mandatory target for the share of renewable energy in the transport sector (10% by 2020), most of which is expected to be met by biofuels. Increased environmental awareness has led to a number of safeguards in the form of sustainability criteria, which biofuels have to meet to be able to be accounted towards the target. One of these sustainability criteria is to achieve certain greenhouse gas emission savings.

The RED contains rules for calculating the greenhouse gas impact of biofuels as well as default values for some of the most common biofuels. Further information on RED calculation rules are given in chapter 3.2.5 and annex C. The GEF tool for GHG balances can also be used to calculate balances in accordance with EU RED (cf. chapter 3.5). Regarding the GEF case studies, only 5 out of the 12 biofuel pathways can be found in the current list of default values (Table 3-1). Currently, biofuels from crops such as jatropha, cassava and energy grass are not included in the list.

Table 3-1 Biofuel pathways covered by the GEF project and availability of RED default values

No	Feedstock	Origin	Liquid biofuel	RED default value
1	Soy	Argentina	FAME, SVO	FAME
2	Sugar Cane	Mozambique	1st and 2nd EtOH	1st EtOH
3	Jatropha	Mozambique	FAME, SVO	-
4	Cassava	Mozambique	EtOH	-
5	Energy grass	Argentina	2nd EtOH, BTL	-
6	SRC (eucalyptus)	Mozambique	BTL	BTL
7	SRC (poplar)	Ukraine	BTL	BTL
8	Residue (straw)	Ukraine	2nd EtOH, BTL	2nd EtOH

3.1.3 Compliance with UNFCCC

The UNFCCC provides methodologies for calculating GHG emission savings tradable within the international emission trading system based on the Kyoto protocol. For emission savings from the production and use of biofuels, there is currently only one approved methodology available: Methodology ACM0017 “Production from biodiesel for use as a fuel”. The applicability of this methodology is very limited. The development of new methodologies stalled because of the status of international negotiations on climate change. Therefore, certification under UNFCCC is currently not helpful within the GEF context.

Table 3-2 Main characteristics of UNFCCC ACM0017 methodology: Production from biodiesel for use as a fuel (UNFCCC, 2009)

Coverage	Biodiesel from seed oil grown on degraded or degrading land or within afforestation and reforestation projects
Land use change	DLUC addressed (baseline definition, but only soil carbon) ILUC considered not relevant (as only on degraded land)
Co-product handling	Four options: allocation by market price, substitution, allocation by energy content or attribution of all emissions to the main products
Uncertainty assessment	Detailed, parameter specific assessment needed
Data and defaults	Default values available for cultivation of Jatropha and oil palm. Individual data needed for all other plants and processes.

3.2 Setup of a spread sheet-based calculation tool for GHG balances

3.2.1 What is the purpose of the tool?

As part of the GEF project, the Excel-based ‘GEF Biofuel Greenhouse Gas Calculator’ was developed. This tool has different purposes:

1. **Increasing awareness on GHG emissions of biofuel pathways relevant for GEF eligible countries:** the tool generates life-cycle GHG emission results for all 74 biofuel settings defined in chapter 2. Therewith it gives a comprehensive overview of GHG emissions related to biofuel production and use in developing countries. The results are summarised in a lookup table in chapter 3.2.4.2. They can be used during biofuel project preparation phases (i.e. PIF submission) to gain an overview of the impact of that project in terms of GHG savings. Results can also be used indicatively for estimating the impacts of biofuel projects that are carried out in similar settings to those covered by the tool.
2. **Making GHG results transparent and replicable:** for users with a deeper interest in greenhouse gas balancing, the tool provides transparency with respect to the 74 greenhouse gas calculations. It lists all relevant input data for each life cycle step, emission and conversion factors as well as actual emission calculations. Thus results become replicable and the calculation methodology can be transferred to pathways not yet included in the tool.
3. **Customise GHG calculations:** the user can customise the pre-defined settings to his/her needs by using own input data (e.g. different yields). For this purpose every

calculation sheet (covering a certain feedstock / biofuel combination) contains a so-called ‘user-defined’ column where own input data can be entered. In the GEF context, user-defined calculations can be used to determine the exact GHG emissions or reductions of a specific project – either beforehand or in the context of an ex-post evaluation. The tool thus can supplement the ‘Manuals for calculating GHG benefits of GEF project’.

It has to be noted that all 74 GHG balances which are pre-calculated within the tool – and thus all ready-to-use results – only apply to the pre-defined settings. Furthermore, the given results do not present averages of the countries but are to be viewed as case study results that only apply to the specific circumstances listed for each setting. Thus, a transfer of results can only be done indicatively to feedstocks and biofuels that are produced under similar conditions. For a given feedstock / biofuel combination, results can be adjusted in the user-defined column by using own input data and select country-specific electricity and fuel mixes. However, if there is a need for new feedstock and / or biofuel pathways, new calculation sheets have to be set up in the tool.

In the user-defined columns of the tool, customisation possibilities are restricted to keep it simple and thus make it applicable to the widest possible group of users. It is possible to enter own input data while the transformation into greenhouse gas emissions is done automatically. The formulas cannot be changed by the user. However, a skilled user still could use the tool to make more elaborate calculations. For example, a detailed description is included in the tool on how to make the results conform to EU-RED, i.e. to prove compliance with the GHG reduction thresholds stipulated in the EU-RED (see chapter 3.1.2 for explanations). The information on material and energy inputs could be used as a basis to add on alternative calculations. For example, references for co-product allocation could be changed or the substitution method could be added (see chapter 3.1.1.2 for explanations on co-product handling).

3.2.2 A short introduction to the tool’s structure

How is the tool structured?

The tool includes several sheets:

- The ‘Directory’ sheet lists all pathways and settings and includes links to each pathway.
- The ‘About’ sheet explains abbreviations and the general mode of operation of the tool.
- The ‘Background data’ sheet lists all CO_2 emission and other conversion factors (e.g. heating values, densities) that are necessary for calculating the GHG balances.
- The ‘Lookup table’ sheet summarises the GHG emission and savings results of all 74 biofuels in a condensed way.
- The ‘Diagrams’ sheet contains ready-to-use diagrams for all results. Results in the graphs are presented for two functional units: per MJ fuel and per hectare
- The ‘References’ sheet includes all references used in the tool.

The introductory sheets are followed by pathway calculation sheets where the GHG calculations of the 74 settings are presented in a most transparent way.

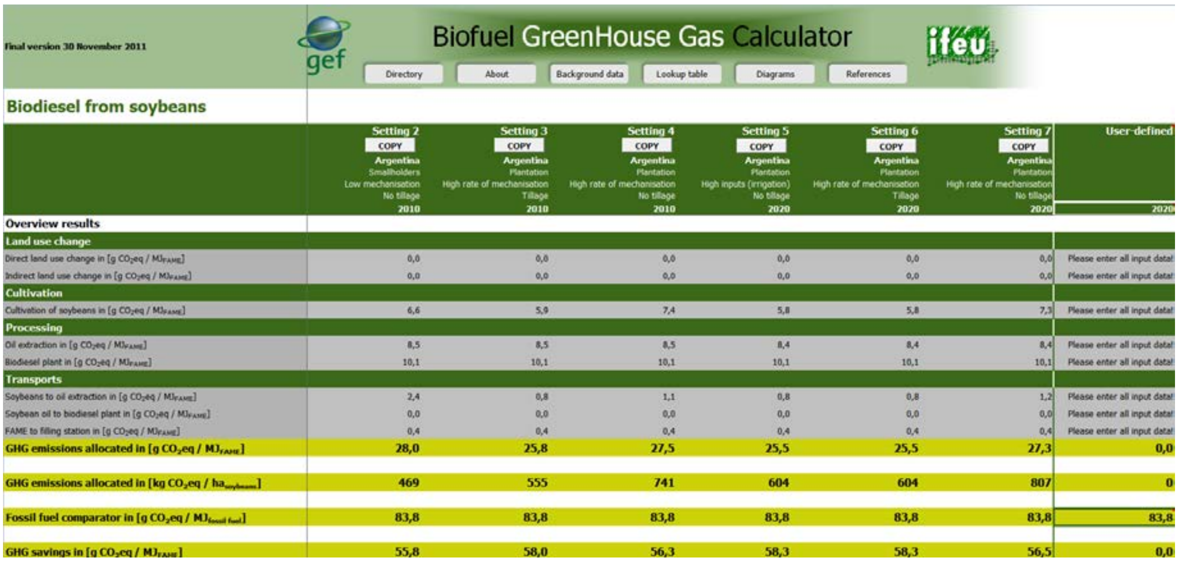
How are the pathway calculation sheets structured?

The pathway calculation sheets cover specific feedstock / fuel combinations (e.g. biodiesel from oil palm). Within the sheets calculations are made for several settings covering different countries and different cultivation conditions (e.g. plantations and smallholders, low input and high input; see chapter 2). The key specifications of each setting are described at the top of the sheets. In addition to the pre-defined settings, every sheet includes a ‘user-defined’ column that allows customising the pre-calculated scenarios by entering one’s own input data.

Each pathway calculation sheet is split vertically into three sections:

1. Overview results

The first part of the first section presents the GHG emissions that result from the individual life cycle steps, following the ‘well-to-wheel’ approach and presented per MJ fuel (see Figure 3-5). At the end of the section, overall results are presented for each setting: first, the total GHG emissions are presented, second the GHG savings that result from balancing the emissions with the fossil fuel comparator. The GHG savings refer to different functional units (per hectare, per MJ fuel, in %).



Biodiesel from soybeans

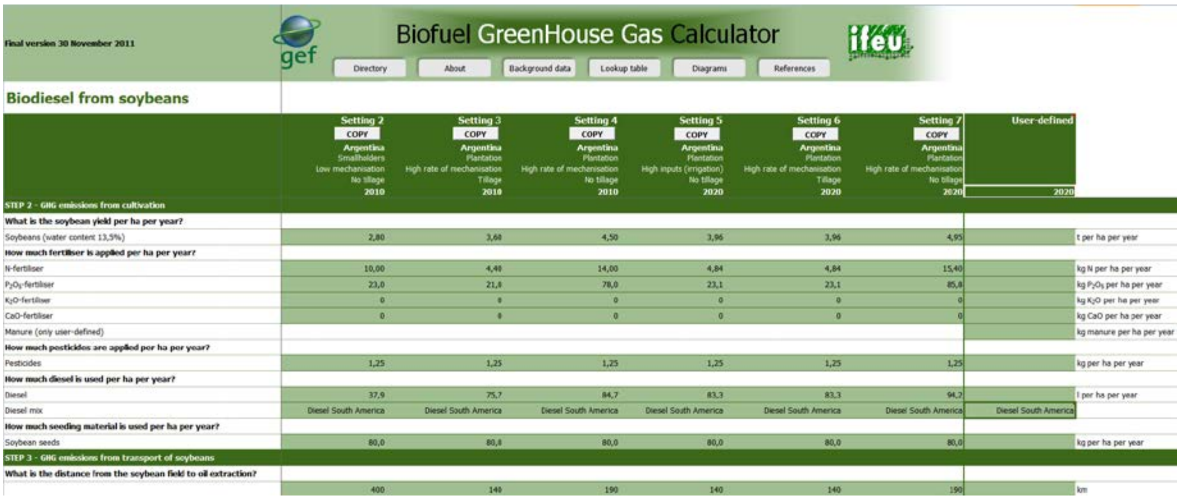
	Setting 2 COPY Argentina Smallholders Low mechanisation No tillage 2010	Setting 3 COPY Argentina Plantation High rate of mechanisation Tillage 2010	Setting 4 COPY Argentina Plantation High rate of mechanisation No tillage 2010	Setting 5 COPY Argentina Plantation High inputs (irrigation) No tillage 2020	Setting 6 COPY Argentina Plantation High rate of mechanisation Tillage 2020	Setting 7 COPY Argentina Plantation High rate of mechanisation No tillage 2020	User-defined 2020
Overview results							
Land use change							
Direct land use change in [g CO_2eq / MJ_{FAME}]	0,0	0,0	0,0	0,0	0,0	0,0	Please enter all input data
Indirect land use change in [g CO_2eq / MJ_{FAME}]	0,0	0,0	0,0	0,0	0,0	0,0	Please enter all input data
Cultivation							
Cultivation of soybeans in [g CO_2eq / MJ_{FAME}]	6,6	5,9	7,4	5,8	5,8	7,3	Please enter all input data
Processing							
Oil extraction in [g CO_2eq / MJ_{FAME}]	8,5	8,5	8,5	8,4	8,4	8,4	Please enter all input data
Biodiesel plant in [g CO_2eq / MJ_{FAME}]	10,1	10,1	10,1	10,1	10,1	10,1	Please enter all input data
Transports							
Soybeans to oil extraction in [g CO_2eq / MJ_{FAME}]	2,4	0,8	1,1	0,8	0,8	1,2	Please enter all input data
Soybean oil to biodiesel plant in [g CO_2eq / MJ_{FAME}]	0,0	0,0	0,0	0,0	0,0	0,0	Please enter all input data
FAME to filling station in [g CO_2eq / MJ_{FAME}]	0,4	0,4	0,4	0,4	0,4	0,4	Please enter all input data
GHG emissions allocated in [g CO_2eq / MJ_{FAME}]	**28,0**	**25,8**	**27,5**	**25,5**	**25,5**	**27,3**	**0,0**
GHG emissions allocated in [kg CO_2eq / $ha_{soybeans}$]	**469**	**555**	**741**	**604**	**604**	**807**	**0**
Fossil fuel comparator in [g CO_2eq / $MJ_{fossil\ fuel}$]	**83,8**	**83,8**	**83,8**	**83,8**	**83,8**	**83,8**	**83,8**
GHG savings in [g CO_2eq / MJ_{FAME}]	**55,8**	**58,0**	**56,3**	**58,3**	**58,3**	**56,5**	**0,0**

Figure 3-5 GEF biofuel greenhouse gas calculator: overview results

2. Input data per step

The second section presents all input data along the pathways on a step by step basis (see Figure 3-6). The first columns contain the pre-defined settings with default data, the last column (‘user-defined’) allows for entering one’s own values. All default data used in the settings are referenced in the sheets.

For each life cycle step the following information is given: yields of the main products and co-products, energy inputs (e.g. steam or electricity) and other material inputs (e.g. fertiliser, chemicals, etc.).



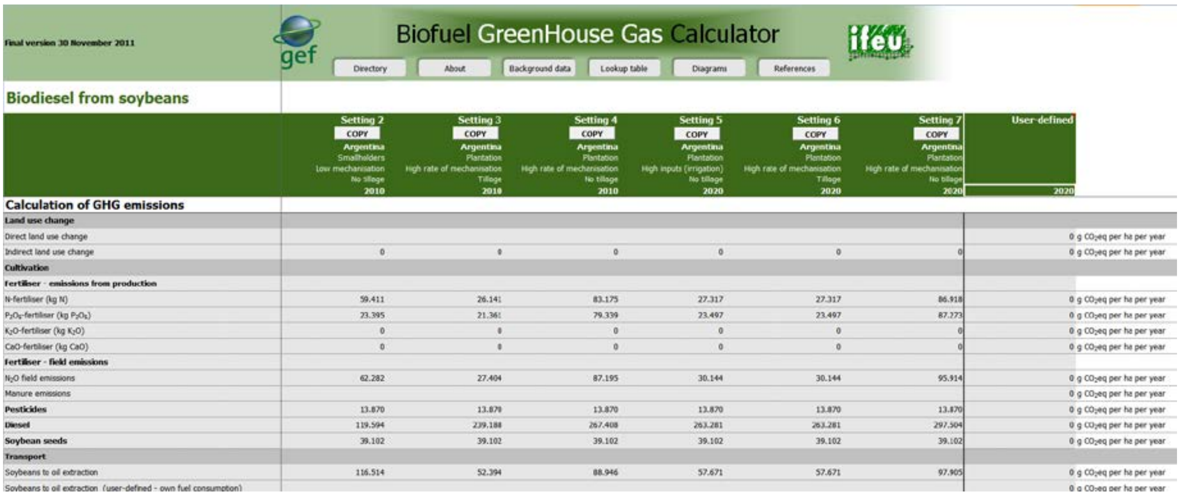
Biodiesel from soybeans

	Setting 2 Argentina Smallholders Low mechanisation No tillage	Setting 3 Argentina Plantation High rate of mechanisation Tillage	Setting 4 Argentina Plantation High rate of mechanisation No tillage	Setting 5 Argentina Plantation High inputs (irrigation) No tillage	Setting 6 Argentina Plantation High rate of mechanisation Tillage	Setting 7 Argentina Plantation High rate of mechanisation No tillage	User-defined	
	2010	2010	2010	2020	2020	2020	2020	
STEP 2 - GHG emissions from cultivation								
What is the soybean yield per ha per year?								
Soybeans (water content 13,5%)	2,80	3,60	4,50	3,96	3,96	4,95		t per ha per year
How much fertiliser is applied per ha per year?								
N-fertiliser	10,00	4,40	14,00	4,84	4,84	15,40		kg N per ha per year
P_2O_5-fertiliser	23,0	21,0	78,0	23,1	23,1	85,8		kg P_2O_5 per ha per year
K_2O-fertiliser	0	0	0	0	0	0		kg K_2O per ha per year
CaO-fertiliser	0	0	0	0	0	0		kg CaO per ha per year
Manure (only user-defined)								kg manure per ha per year
How much pesticides are applied per ha per year?								
Pesticides	1,25	1,25	1,25	1,25	1,25	1,25		kg per ha per year
How much diesel is used per ha per year?								
Diesel	37,9	75,7	84,7	83,3	83,3	94,2		l per ha per year
Diesel mix	Diesel South America	Diesel South America	Diesel South America	Diesel South America	Diesel South America	Diesel South America	Diesel South America	
How much seeding material is used per ha per year?								
Soybean seeds	80,0	80,0	80,0	80,0	80,0	80,0		kg per ha per year
STEP 3 - GHG emissions from transport of soybeans								
What is the distance from the soybean field to oil extraction?								
	400	140	190	140	140	190		km

Figure 3-6 GEF biofuel greenhouse gas calculator: input data

3. Calculation of GHG emissions

The last section contains the actual conversion of input data into GHG emissions, again stepwise (see Figure 3-7). The calculation uses all input data from the second section as well as conversion and emission factors listed in the 'Background data' sheet. Also 'user-defined' column contains fixed formulas which calculate emissions automatically. It is not possible to change any formula here.



Biodiesel from soybeans

	Setting 2 Argentina Smallholders Low mechanisation No tillage	Setting 3 Argentina Plantation High rate of mechanisation Tillage	Setting 4 Argentina Plantation High rate of mechanisation No tillage	Setting 5 Argentina Plantation High inputs (irrigation) No tillage	Setting 6 Argentina Plantation High rate of mechanisation Tillage	Setting 7 Argentina Plantation High rate of mechanisation No tillage	User-defined	
	2010	2010	2010	2020	2020	2020	2020	
Calculation of GHG emissions								
Land use change								
Direct land use change							0	g CO_2eq per ha per year
Indirect land use change	0	0	0	0	0	0	0	g CO_2eq per ha per year
Cultivation								
Fertiliser - emissions from production								
N-fertiliser (kg N)	59.411	26.141	83.175	27.317	27.317	86.918	0	g CO_2eq per ha per year
P_2O_5-fertiliser (kg P_2O_5)	23.395	21.361	79.339	23.497	23.497	87.273	0	g CO_2eq per ha per year
K_2O-fertiliser (kg K_2O)	0	0	0	0	0	0	0	g CO_2eq per ha per year
CaO-fertiliser (kg CaO)	0	0	0	0	0	0	0	g CO_2eq per ha per year
Fertiliser - field emissions								
N_2O field emissions	62.282	27.404	87.195	30.144	30.144	95.914	0	g CO_2eq per ha per year
Manure emissions							0	g CO_2eq per ha per year
Pesticides	13.870	13.870	13.870	13.870	13.870	13.870	0	g CO_2eq per ha per year
Diesel	119.594	239.188	267.408	263.281	263.281	297.504	0	g CO_2eq per ha per year
Soybean seeds	39.102	39.102	39.102	39.102	39.102	39.102	0	g CO_2eq per ha per year
Transport								
Soybeans to oil extraction	116.514	52.394	88.946	57.671	57.671	97.905	0	g CO_2eq per ha per year
Soybeans to oil extraction (user-defined - own fuel consumption)							0	g CO_2eq per ha per year

Figure 3-7 GEF biofuel greenhouse gas calculator: calculation of GHG emissions

Which data sources are used for the background data?

All greenhouse gas emission factors and conversion data (e.g. lower heating values, densities etc.) required for the calculations are listed in the 'Background data' sheet. A large part of this data has been compiled in the course of the BioGrace project[2]. One objective of this EU-funded project is to harmonise data necessary for greenhouse gas balancing on a European level. Where necessary, data has been complemented with data compiled and evaluated by IFEU. All data is referenced.

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[2] http://www.biograce.net/

3.2.3 How GHG calculations are done within the tool

What are the specifications?

As chapter 3.1 has shown, certain parameters have a strong impact on the greenhouse gas emission results. Therefore, it is crucial to clearly specify and define such parameters. The following specifications apply in the tool:

- **Overall system boundaries:** the calculations in the tool follow a “well-to-wheel” approach, i.e. the whole life cycle of the biofuels is included starting from cultivation (including both direct and indirect land use changes), covering biofuel processing and including transports and distribution. All inputs into and outputs from the system are taken into account such as fertilisers, fuels, co-products and emissions. Infrastructure, i.e. emissions from the manufacturing of buildings and machinery, is not included**.** The use phase GHG emissions of biofuels are set to zero since the CO_2 emitted is biogenic.
- **Functional unit:** different functional units may be subject to different goal and scope definitions. The results in the tool are given for different functional units to meet the needs of different users:
  - kg CO_2 eq per hectare
  - g CO_2 eq per MJ fuel
  - Percent of GHG emissions saved (relative to fossil fuel comparator)

  For the input data along the life cycles, different units are used to increase practicality and data transparency.
- **Co-product handling:** along the biofuels’ life cycles several co-products are obtained which can be dealt with in different ways (see chapter 3.1). In the tool, allocation is applied on the basis of the energy content (lower heating values).
- **Fossil reference product:** the fossil reference product (in the tool referred to as ‘fossil fuel comparator’) is the product that is replaced by the biofuel. In the tool, a default fossil fuel comparator is included (83.8 g CO_2 eq / MJ). It can be replaced by another value in the user defined column.
- **Land use change:** the tool offers the possibility to include GHG emissions from direct and indirect land use changes (see chapter 3.1 and appendix B-1.2.2 for definitions). Emissions from direct land use changes are not included in the calculations from the outset since it strongly depends on the specific project settings whether land use changes occur or not. If necessary, emissions can be calculated on an extra sheet and included in the user-defined column. For indirect effects, a clear and straightforward quantification is not possible (see appendix B-1.2.2). There is a worldwide debate on the extent of such GHG emissions and on how to deal with this issue. Many studies focus on the quantification of indirect land use change effects, generally using two approaches: global agro-economic equilibrium models are used that predict market responses and related changes in land allocation to additional biofuel demand (CARB, 2009; EPA, 2010; Al-Riffai et al., 2010; Fonseca et al., 2010, Hiederer et al., 2010). Others use a simpler causal-descriptive approach (Overmars et al., 2011; Bowyer, 2010; Nassar et al., 2010; Arima et al., 2011; Bauen et al., 2010). Regardless of the approach used, very dif-

ferent results are obtained from the studies (see Dehue et al., 2011; DG Energy, 2010 and Edwards et al., 2010; for an overview). Among the many studies, however, only Fritsche et al., 2010a made an attempt to develop a concept on how to include indirect land use changes into regulatory policies for biofuels. He used a deterministic approach to develop a so-called ‘iLUC factor’ which is also included in the GEF calculator. The factor is the same for all feedstocks, namely 3.4 t CO_2 eq per ha for 2010 and 3.6 t CO_2 eq per ha for 2020 and 2030.

The GEF tool and the RED

In the recent past, many greenhouse gas calculation tools were developed – among others tools that enable calculations that prove compliance with the RED GHG emission thresholds. The GEF tool, however, is not intended to perform such calculations, i.e. in its standard configuration it is not suitable to prove whether a certain biofuel will meet the RED thresholds. However, in the user-defined column calculations can be adjusted in a way that they are in line with the RED methodology. It has to be noted, however, that compliance can only be indicatively checked but not proven with the tool. This has to be done via a third party certification scheme that has been approved by the European Commission.

One main principle of RED compliant calculation is already included in the tool: co-product allocation is done based on the lower heating values of the products. Also the default fossil fuel comparator is the same as is used in the RED. To make the calculation even more in line with RED, the following major changes have to be applied:

- **Co-product allocation:** in the tool, all co-products (excluding wastes) are allocated whereas the RED excludes certain co-products from allocation: agricultural crop residues (including straw, bagasse, husks, cobs and nut shells) and process residues (including crude glycerine) shall not been taken into account for allocation (Annex V C(18)) in (CEC, 2009c). To some co-products the special allocation rule for refineries may apply (for definitions, see Annex II in (CEC, 2009c). To check RED conformity, the amounts of co-products to which these definitions apply must be set to zero.
- **Indirect land use changes:** in the RED only GHG emissions from direct land use changes have to be included. Regarding indirect land use changes, there is no agreement so far on which method should be applied. Therefore, emissions from indirect land use changes should be excluded by choosing ‘No’ for 'Indirect land use changes'.
- **Straw:** In the RED approach, agricultural residues that are used for biofuel production are counted with 'zero' life cycle emissions. In the pre-defined rice and wheat straw settings, however, fertilisers are included, as they compensate for the nutrient losses resulting from the straw's removal. Change these inputs to 'zero' in order to check RED-conformity.

How is the actual calculation done?

For each input value from section 2 (e.g. fertiliser, diesel fuel, electricity etc.), the emissions of the three main greenhouse gases for liquid biofuels (CO_2, N_2O, CH_4) are calculated. The gases are transferred into CO_2 equivalents (CO_2 eq) based on their global warming potentials (GWPs, included in the ‘Background data’ sheet). All CO_2 emission factors required are listed in the ‘Background data’ sheet. These values cannot be changed by users. Details on the calculation formula applied can be seen by clicking on the respective cells in the third section of each sheet. Please note that formula cannot be changed!

For transparency reasons, the calculation of GHG emissions is done individually for each life cycle step. The emissions are summed up to total GHG emissions per hectare and transferred into different functional units. Energy-based allocation between main products and co-products is applied at each life cycle step where a relevant co-product is obtained. For doing so, all emissions that occur up to this separation point are summed up and divided between the products based on their lower heating values. The lower heating values are listed in the ‘Background data’ sheet.

3.2.4 Overview on GHG results from the tool

The following sections depict selected results from the GHG calculation tool. First, some greenhouse gas emission results are visualised with diagrams, and second, a lookup table is included in section 3.2.4.2 that contains the GHG results of all 74 biofuel settings.

3.2.4.1 Selected diagrams

The diagrams presented in the following section aim at giving an overview on the diversity of biofuel GHG results covered by the GEF calculator. Some meaningful settings were chosen to show the possibilities of how to compare and interpret results. Diagrams for all settings that refer to different functional units are included in the GHG calculator.

Greenhouse gas emissions from direct land use changes can have a major effect on the results (see also section 3.1.1.2). Despite their large influence, they are not included in the calculations from the outset. It strongly depends on the specific project circumstances whether land use changes occur and how large emissions are. Therefore, there is no valid reason for generally adding land use change emissions to, for example, Indonesian palm oil. If necessary, emissions from land use changes can be calculated on an extra sheet and added in the user-defined columns.

The same applies to greenhouse gas emissions from indirect land use changes (iLUC) (for a definition of indirect land use change, see section 3.1.1 and appendix B-1.2.2). The relevance of indirect land use changes (iLUC) is still strongly issued at expert level. As explained in chapter 3.1.1 a number of assessments conclude that iLUC is likely to have a strong effect on the GHG performance of 1st generation biofuel. The tool allows to express the specific iLUC results applying the approach of Fritsche et al. 2010. However, since this is not a commonly agreed methodology the standard configuration of the tool excludes iLUC. Also in the lookup Table 2 3 emissions from iLUC are not included.

Having said that, emissions from indirect effects are displayed in all of the following diagrams in order to show their potential impact on the overall results. They are added as grey bars at the outer right hand side so that they can be deducted easily from overall emissions. All diagrams display GHG emissions per MJ fuel. The fossil fuel comparator (83.8 g CO_2 eq / MJ_{fuel}) is plotted with a vertical red line in every diagram.

Biodiesel (FAME) from palm oil

Figure 3-8 shows the GHG emissions of all palm oil biodiesel (FAME) settings.

- All settings emit far less greenhouse gases than the fossil fuel comparator provided that there are no indirect land use change effects. If such effects occur, setting 20 emits almost exactly the same amount of greenhouse gases as fossil fuel, meaning that there are no net GHG savings from using palm oil biodiesel.
- Differences between settings are due to different cultivation practices (e.g. smallholders with intermediate inputs vs. plantations with high inputs in settings 19 and 20) and due to different production conditions in individual countries (e.g. Indonesia in setting 20 and Colombia in setting 21).
- The large emission reduction in 2020 compared to 2010 is due to improvements in the oil mill's production process: whereas in 2010 oil mill effluents are assumed to be stored in open ponds, in 2020 these ponds are supposed to be covered. In open ponds very high methane emissions arise which can be avoided by covering the ponds. Additionally, the captured methane can be used for biogas production and thus for allocation. Emissions in 2020 are further reduced by increases in oil yields.

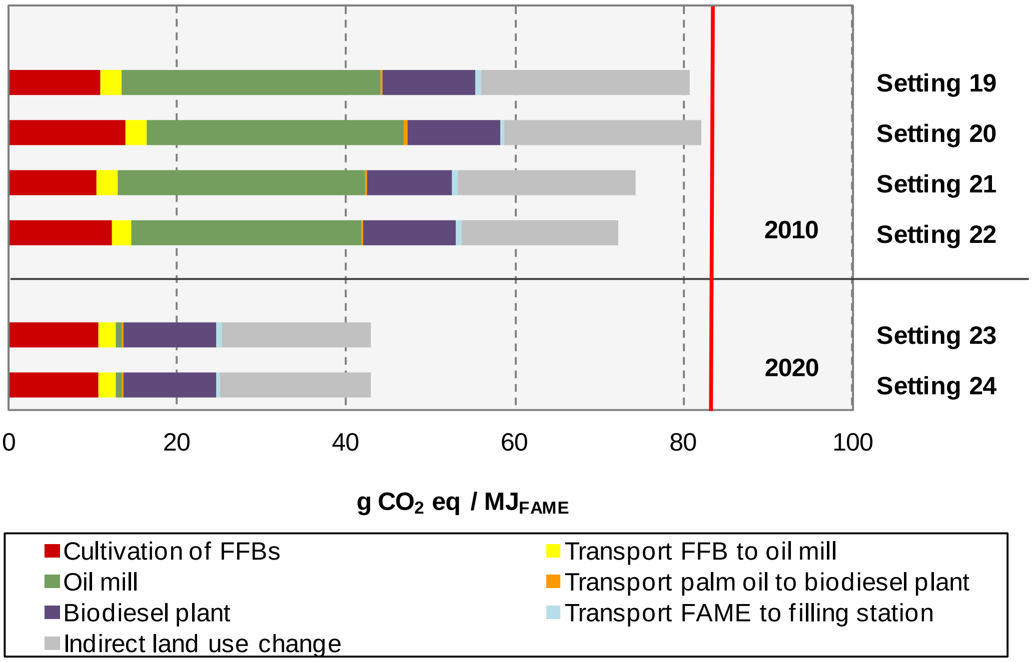

Figure 3-8 GHG emissions for biodiesel (FAME) from palm oil; vertical red line marks fossil fuel comparator; right-most bars display emissions from indirect land use changes

Biodiesel (FAME) from jatropha

Figure 3-9 shows the GHG emissions of biodiesel (FAME) produced from jatropha.

- Differences between the settings are caused in the cultivation phase and are due to differences in cultivation practices and logistics. In settings 28 to 31 (34 to 39 for 2020), husks remain at the field to be used as fertiliser resulting in a reduced need for mineral fertiliser. In the two smallholder settings (28, 30), it is assumed that no fertiliser at all is applied. In contrast, in setting 26 and 27 husks are used in the oil extraction plant for process energy generation thus higher amounts of mineral fertiliser are needed. Additionally, in these scenarios high amounts of diesel fuel are used for field work.

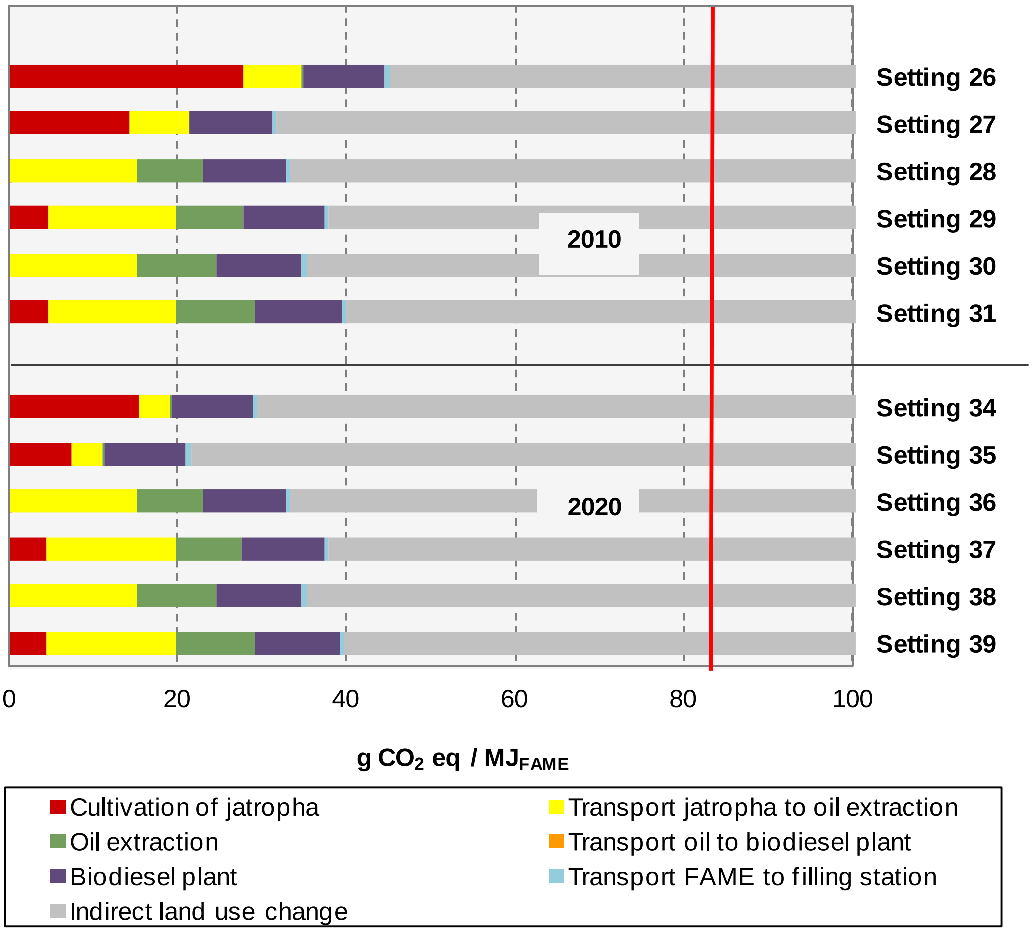

Figure 3-9 GHG emissions for FAME from jatropha; vertical red line marks fossil fuel comparator; overall emissions are up to 491 g CO_2 eq / MJ_{FAME}; right-most bars display emissions from indirect land use changes

- The four settings 26 / 27 and 34 / 35 visualise the great influence co-product allocation has on the overall results (for explanation, see chapter 3.1.1.2 and appendix B-1.2). Whereas all other scenarios hardly show any difference between 2010 and 2020, settings 34 and 35 clearly emit less than their counterparts 26 and 27. In the four settings, husks are combusted in the oil extraction plant for process energy generation. But only in the 2020 settings is surplus electricity fed into the grid which means that the corresponding amount of husks can be used for allocation. As a result, a considerable share of the greenhouse gas emissions is allocated to the husks leading to an emission reduction for the biofuel.

First generation ethanol from sugarcane and cassava

Figure 3-10 shows the impact feedstock choices can have on the GHG performance of a biofuel. First generation ethanol from sugarcane and cassava is used as an example.

- The great influence of the feedstock chosen is obvious – sugarcane ethanol production causes far less GHG emissions than cassava ethanol production leading to higher savings compared to the fossil fuel. There are two reasons.
- First, the cassava pathway includes an additional, energy consuming, processing step as well as an additional transport step: cassava roots are chipped and dried before being transported to the ethanol plant.

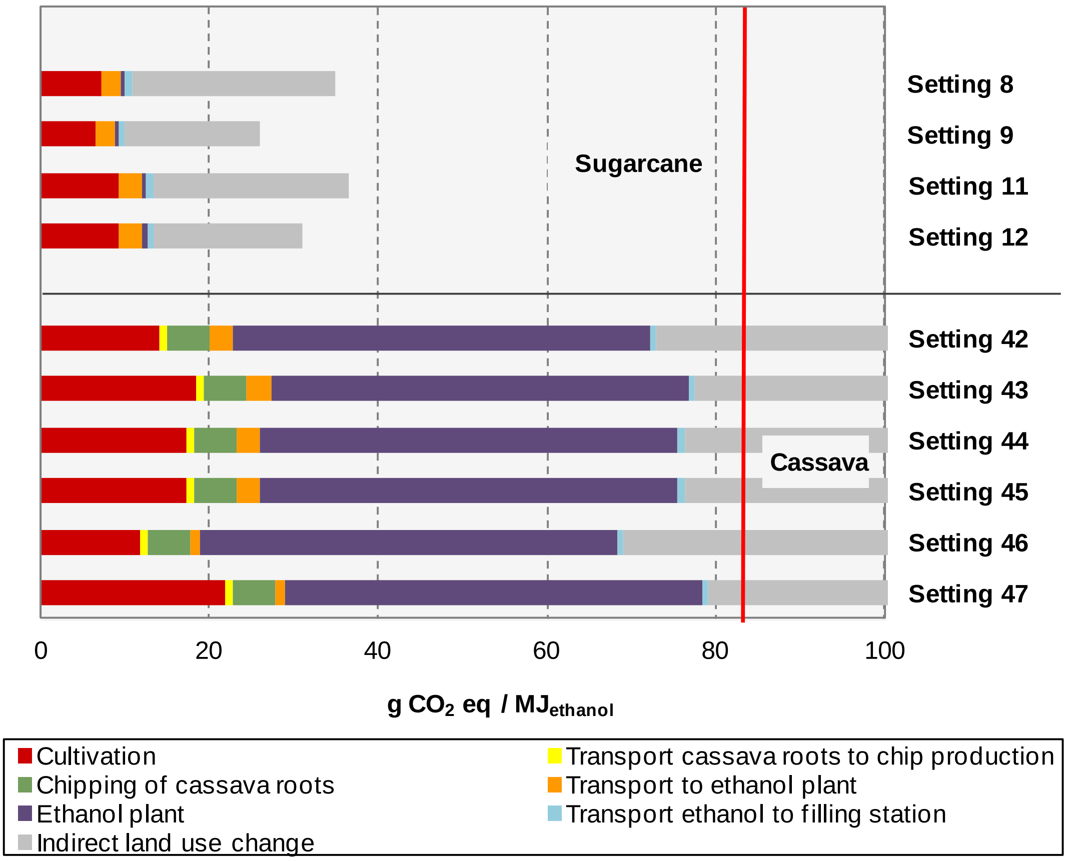

Figure 3-10 GHG emissions for ethanol from sugarcane and cassava (for 2010 only); vertical red line marks fossil fuel comparator; for cassava, overall emissions are up to 341 g CO_2 eq / $MJ_{ethanol}$; right-most bars display emissions from indirect land use changes

- The largest difference between both feedstocks, however, is due to the fact that ethanol production itself requires much more energy for cassava than for sugarcane. Whereas sugarcane contains an easily fermentable juice, cassava chips need some further preparation before fermentation.

First generation ethanol from sugarcane

Figure 3-11 again displays the GHG emissions from sugarcane ethanol, however, this time referring to two different functional units: results are shown per MJ fuel and per hectare sugarcane.

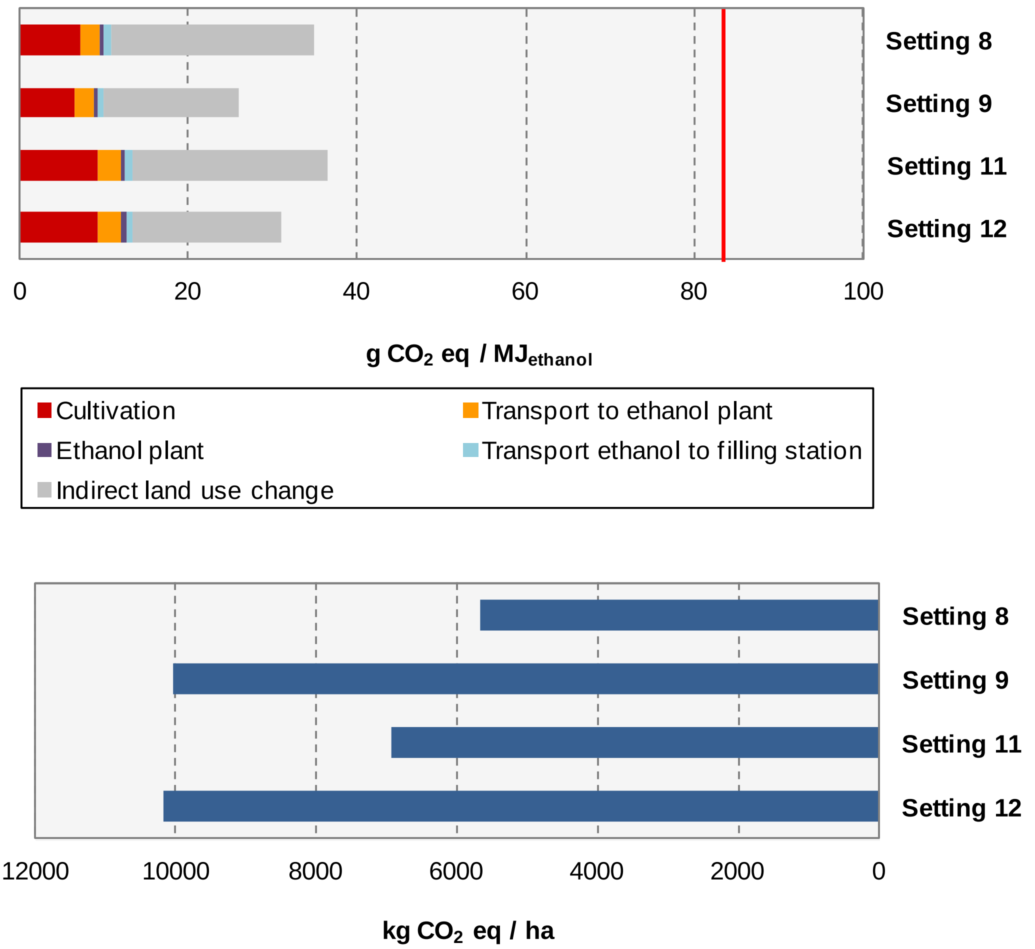

Figure 3-11 GHG emissions for ethanol from sugarcane and cassava (for 2010 only); vertical red line marks fossil fuel comparator; right-most bars in the upper diagram display emissions from indirect land use changes

- The diagram clearly shows that the choice of the functional unit influences the outcomes of results and their interpretation. In the upper graph, there are only small differences between the settings, especially if effects from land use changes are ignored. However, in the lower graph differences become clearly visible. The reason is that differences between settings are only during the cultivation phase. Since most inputs depend on the yield, the respective emissions change proportionally to the yield results refer to MJ_{fuel}. If results refer to one hectare, effects from yield changes have a much stronger impact. Please also refer to chapter 3.1 for some more examples on the influence of the functional unit.

Second generation ethanol and BtL from switchgrass

Figure 3-12 shows the GHG emissions of two different fuels that can be produced from a feedstock, namely second generation ethanol and BtL from switchgrass.

- Since the same feedstock is used, all emissions that occur up to the fuel processing plant (i.e. from cultivation and switchgrass transport) are equal. Emissions occurring during fuel production, however, are very different. Both processes run energy autonomously with process energy being gained from co-product combustion. Thus, variations are due to different chemical inputs. Ethanol production requires a much higher material input compared to BtL resulting in higher greenhouse gas emissions.
- The diagram displays settings for 2020 and 2030 which are equal both for ethanol and BtL. The reason is that during this period no profound improvements in production processes are assumed to occur. Since no external energy carriers are used in the process, also changes in electricity mixes do not influence the results. Differences only occur from differences in transport fuel emissions. However, influences are marginal as transports contribute only little to overall emissions.

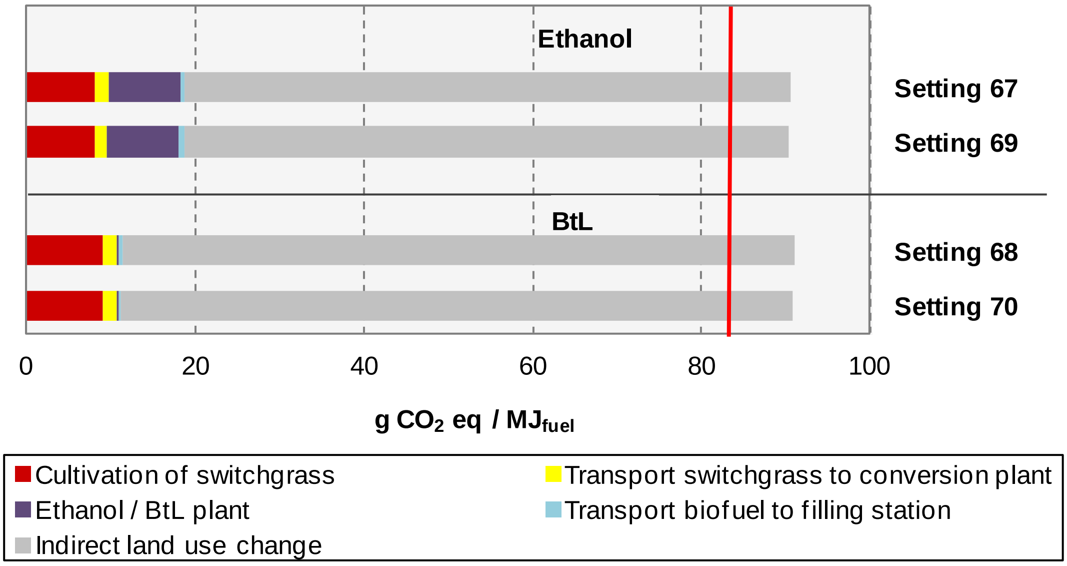

Figure 3-12 GHG emissions for second generation ethanol and BtL from switchgrass; vertical red line marks fossil fuel comparator; right-most bars display emissions from indirect land use changes

3.2.4.2 Lookup table

Table 3-3 lists the greenhouse gas results of all 74 biofuel settings. Results are given as disaggregated greenhouse gas emissions per life cycle step as well as overall savings referring to two functional units. Emissions from direct and indirect land use changes (LUC) are not included in the table. However, they can be added in the calculator.

Table 3-3 Lookup table with greenhouse gas emissions and savings for all 74 biofuel settings; results without direct and indirect land use change (LUC) effects; for abbreviations see 'Abbreviation' section

Pathway	**N°**	**g CO_2eq per MJ fuel**						**kg CO_2eq per ha**
		LUC	**Culti-vation**	**Pro-cess-ing**	**Trans-port**	**Fossil fuel compara-tor**	**Overall savings**	**Overall savings**
Soybean SVO	1	0.0	6.8	9.6	2.9	83.8	64.5	1123
Soybean FAME	2	0.0	6.6	18.6	2.8	83.8	55.8	933
	3	0.0	5.9	18.6	1.3	83.8	58.0	1248
	4	0.0	7.4	18.6	1.6	83.8	56.3	1513
	5	0.0	5.8	18.4	1.3	83.8	58.3	1380
	6	0.0	5.8	18.4	1.3	83.8	58.3	1380
	7	0.0	7.3	18.4	1.6	83.8	56.5	1672
Sugarcane EtOH1	8	0.0	7.3	0.5	3.0	83.8	73.0	8457
	9	0.0	6.5	0.5	3.0	83.8	73.8	12824
	11	0.0	9.2	0.6	3.5	83.8	70.5	10339
	12	0.0	9.3	0.6	3.5	83.8	70.4	13583
	13	0.0	7.2	0.5	3.0	83.8	73.2	8894
	14	0.0	7.2	0.5	3.0	83.8	73.1	13330
	16	0.0	7.5	0.5	3.0	83.8	72.7	8422
	17	0.0	7.2	0.5	3.0	83.8	73.1	14809
Sugarcane EtOH1 & 2	10	0.0	7.6	1.7	3.1	83.8	71.4	14577
	15	0.0	7.5	1.7	3.1	83.8	71.5	15332
Oil palm SVO	18	0.0	11.3	32.7	1.1	83.8	38.7	4543
Oil palm FAME	19	0.0	10.9	41.7	3.4	83.8	27.8	3117
	20	0.0	13.8	41.7	3.4	83.8	24.9	2964
	21	0.0	10.4	39.5	3.3	83.8	30.7	4034
	22	0.0	12.2	38.2	3.1	83.8	30.2	4190
	23	0.0	10.7	11.7	2.9	83.8	58.5	8687
	24	0.0	10.7	11.5	2.9	83.8	58.7	8713
Jatropha SVO	25	0.0	0.0	9.3	17.2	83.8	57.3	440

Pathway	N°	g CO_2eq per MJ fuel						kg CO_2eq per ha
		LUC	Cultivation	Processing	Transport	Fossil fuel comparator	Overall savings	Overall savings
Jatropha FAME	26	0.0	27.8	9.9	7.5	83.8	38.7	811
	27	0.0	14.3	9.9	7.5	83.8	52.1	925
	28	0.0	0.0	17.6	15.7	83.8	50.5	387
	29	0.0	4.7	17.6	15.7	83.8	45.8	629
	30	0.0	0.0	19.5	15.7	83.8	48.5	337
	31	0.0	4.7	19.5	15.7	83.8	43.9	461
	32	0.0	0.0	21.2	15.7	83.8	46.9	530
	33	0.0	4.7	21.2	15.7	83.8	42.3	717
	34	0.0	15.3	9.9	4.3	83.8	54.3	1311
	35	0.0	7.3	9.9	4.3	83.8	62.3	1272
	36	0.0	0.0	17.6	15.7	83.8	50.5	445
	37	0.0	4.6	17.6	15.7	83.8	45.9	725
	38	0.0	0.0	19.5	15.7	83.8	48.5	387
	39	0.0	4.6	19.5	15.7	83.8	44.0	531
	40	0.0	0.0	21.2	15.7	83.8	46.9	610
	41	0.0	4.6	21.2	15.7	83.8	42.4	826
Cassava EtOH1	42	0.0	19.0	49.5	4.5	83.8	10.8	137
	43	0.0	23.5	49.5	4.5	83.8	6.3	120
	44	0.0	22.3	49.5	4.5	83.8	7.5	142
	45	0.0	22.2	49.5	4.5	83.8	7.6	288
	46	0.0	16.8	49.5	2.8	83.8	14.7	935
	47	0.0	26.8	49.5	2.8	83.8	4.7	329
	48	0.0	22.0	49.5	4.5	83.8	7.8	149
	49	0.0	21.9	49.5	4.5	83.8	7.9	301
	50	0.0	28.9	49.5	3.9	83.8	1.5	74
	51	0.0	14.0	49.5	4.5	83.8	15.8	1002
	52	0.0	21.3	49.5	4.5	83.8	8.5	592
	53	0.0	28.4	49.5	3.9	83.8	2.0	175
	54	0.0	16.1	49.5	2.8	83.8	15.4	1560
	55	0.0	26.2	49.5	2.8	83.8	5.3	570
	56	0.0	28.2	49.5	3.9	83.8	2.2	308
Eucalyptus EtOH2	57	0.0	24.6	8.5	4.3	83.8	46.4	2482
	58	0.0	24.0	8.5	4.9	83.8	46.4	3653
	59	0.0	23.5	8.5	4.9	83.8	46.9	8126

Pathway	N°	g CO_2eq per MJ fuel						kg CO_2eq per ha
		LUC	Culti-vation	Pro-cess-ing	Trans-port	Fossil fuel compara-tor	Overall savings	Overall savings
Eucalyptus EtOH2	60	0.0	23.9	8.5	4.3	83.8	47.1	3856
	61	0.0	23.6	8.5	4.9	83.8	46.8	4416
	62	0.0	23.1	8.5	4.9	83.8	47.3	8927
Poplar BtL	63	0.0	16.4	0.2	1.7	83.8	65.6	143
	64	0.0	7.0	0.2	1.7	83.8	74.9	8379
	65	0.0	16.4	0.2	1.7	83.8	65.6	3143
	66	0.0	7.0	0.2	1.7	83.8	74.9	8379
Switchgrass EtOH2	67	0.0	8.2	8.5	2.0	83.8	65.1	2562
	69	0.0	8.1	8.5	2.0	83.8	65.2	2566
Switchgrass BtL	68	0.0	9.1	0.2	2.0	83.8	72.5	2694
	70	0.0	9.0	0.2	2.0	83.8	72.6	2698
Rice straw EtOH2	71	0.0	12.3	8.5	2.2	83.8	60.7	406
	73	0.0	12.1	8.5	2.2	83.8	60.9	408
Wheat straw EtOH2	72	0.0	11.7	8.5	1.6	83.8	62.1	415
	74	0.0	11.5	8.5	1.6	83.8	62.2	416

3.2.5 Conclusions

The Excel-based GHG calculation tool offers two general ways to get informed on the GHG performance of a specific biofuel. First, a readily calculated value can be selected from the 74 settings representing a wide range of possible pathways. If none of the settings should match with the respective case, the user can define settings alternatively.

The results show that all 74 biofuel settings are connected with lower GHG emission than the replaced fossil fuel, supposed no land use change is given, neither direct nor indirect.

In cases where direct land use change (dLUC) is given, the actual change in carbon stock between the previous status and the implemented farming system is the crucial factor. Particularly where forested area is replaced by cropland an overall saving of GHG emissions will not be realised anymore. Replacing fragmented wooded areas or grasslands by permanent croplands might still allow a net saving. After all, the result is depending on actual conditions which have to be assessed case by case. The tool offers a separate worksheet to figure single cases out.

Regarding the crop types it can be concluded that there are some crops with generally better results than other crops. Best results show ethanol from sugar cane, and 2nd generation ethanol or BtL from poplar and switchgrass, given that the energy demand of the processing steps are fuelled with non fossil fuels.

Medial results are provided by FAME from soybean and jatropha. Smallholders on marginal land and plantations on good land with higher input do not differ strongly within the overall balance. As for jatropha the efficiency of the use of co-products (residues) is a key factor. Agricultural options like no-till render some improvement but not very significantly. As for FAME from palm oil the use of POME is the key factor. Uncaptured methane emissions lead to a low final saving rate while methane capture and use as biogas will enhance the benefit of this type of biofuel significantly.

Within the analysed pathways ethanol from cassava turns out to provide the highest GHG emission rates which are marginally lower than fossil fuel comparators. The major reason is the high demand of process energy (steam) which is based on the use of fossil fuels according to the settings here. These scenarios might improve in case biogas should be used in future as the study by Nguyen and Gheewala, 2008 can show.

Analysing these 74 settings can support the choice of a crop beneficial for the GHG balance. Perennial crops tend to provide higher saving potentials than annual crops. Good practice in process efficiency and use of co-products and residues will always help to improve the overall performance.

3.3 Evaluation of GHG calculation in certification schemes in the context of GEF activities

3.3.1 Goal and scope

In recent years, greenhouse gas balancing has found its way into the political context as a means to assess the environmental sustainability of bioenergy. Many certification schemes introduced GHG emission thresholds and require the performance of greenhouse gas calculations for proving compliance with those thresholds. This chapter provides guidance on these methodologies. Although the focus is on certification schemes, a broader context is provided by including international agreements such as the Global Bioenergy Partnership (GBEP) and regulatory frameworks such as the European Renewable Energy Directive (RED). Especially the latter significantly influences the design of GHG calculation methodologies in certification schemes.

From the many existing certification schemes the only ones assessed are those that operate in the field of biofuels and include a clear methodology for greenhouse gas calculations.

3.3.2 Overview on GHG calculation in the systems

The following sections provide a summary of the most relevant features of included GHG calculation methods and the differences between the systems. Table 3-4 lists the selected systems and their scope of applications. A more extended table can be found in appendix C. Also in the appendix are detailed descriptions of all systems, of the role of GHG calculation within the systems as well as characterisation tables describing the most important elements of GHG calculation.

Table 3-4 System selected for assessment

Name	**Website**	**Scope**
International agreements and standards		
UNFCCC - United Nations Framework Convention on Climate Change	http://cdm.unfccc.int/methodologies/DB/Z6UFHXTRQJ2PSZ1EOD21IT8FEF4AE7	Only biodiesel[3]
GBEP – Global Bioenergy Partnership	http://www.globalbioenergy.org	All biomass for energy
ISO 13065 Sustainability criteria for bioenergy	http://www.iso.org/iso/iso_technical_committee.html?commid=598379	All biomass for energy
EU standard prEN 16214-4: Sustainability criteria for the production of biofuels and bioliquids for energy applications	http://www.cen.eu/cen/Sectors/Sectors/UtilitiesAndEnergy/Fuels/Pages/Sustainability.aspx	Biofuels and other bioliquids
Regulatory frameworks		
LCFS – Low Carbon Fuel Standard (California)	http://www.energy.ca.gov/low_carbon_fuel_standard/index.html	Most common biofuels in California
RFS2 – Renewable Fuel Standard (USA)	http://www.epa.gov/otaq/fuels/renewablefuels/index.htm	Most common biofuels in US
RED – European Renewable Energy Directive	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF	All liquid biofuels / bioliquids
Voluntary certification schemes		
BioGrace (GHG calculation tool)[4]	http://www.biograce.net/	25 biofuel / bioliquid pathways
BSI – Bonsucro	http://www.bonsucro.com/welcome.html	Sugarcane
GGL – Green Gold Label	http://www.greengoldcertified.org/index.php?id=5	All biomass for fuel, power and material use
ISCC – International Sustainable and Carbon Certification	http://www.iscc-system.org/index_eng.html	All biomass for energy uses (material use under development)
NTA 8080	http://www.sustainable-biomass.org/publicaties/3892	All biomass for energy uses
RSB – Roundtable on Sustainable Biofuel	http://rsb.epfl.ch/	All liquid biofuels
RTRS – Roundtable on Sustainable Soy	http://www.responsiblesoy.org/	Soy

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[3] CDM provides guidelines on various project scopes. However, with respect to biofuels, there is only one methodology that applies to biodiesel from waste oils and oil seeds produced on degraded land.

[4] BioGrace is a GHG calculation tool currently under development for performing calculations that conform to RED. As soon as it is finalised, the application as a certification scheme will follow.

The systems are assessed with respect to two aspects:

1. The detail level of greenhouse gas calculations within the systems
2. Methodological differences between the systems with regard to greenhouse gas calculation

3.3.2.1 Level of detail

International agreements and standards

Subject to their different scopes and fields of application, greenhouse gas calculation within the systems differs with regard to its level of detail. The GBEP framework and the standards (ISO 13065 and prEN 16214-4, both in process) are guidelines that have been agreed (or are assumed to be agreed) upon on an international level. All three do not describe specific GHG calculation methodologies but rather give guidance on how to perform such calculations. GBEP has been initiated by governments and international organisations and therefore takes a policymaker's perspective. The framework in the form of a checklist shall enable decision makers to identify the character and completeness of specific GHG calculation methodologies. Within the ISO standardisation process industry is strongly represented and therefore, the ISO 13065 (under development) will address the market actors viewpoint. The standard shall define good GHG calculation practice in compliance with other standards but will not determine a specific methodology.

The European standards prEN 16214 (draft standard) strongly follows the principles and rules stipulated in the EU-RED (see below). The purpose of the standard is to give appropriate clarifications, explanations and further elaborations concerning the rules given in the RED and any additional interpretation of the legislative text published by the EU Commission.

Regulatory frameworks

Two fundamentally different approaches can be distinguished: under the US laws LCFS and RFS2 ex ante greenhouse gas calculations are performed. These calculations are done for most common biofuels in order to a) assess whether they meet certain GHG emission thresholds and thus are allowed to be counted towards a biofuel goal (RFS2) or b) in order to generate default greenhouse gas emission values (LCFS). Under both laws, individual calculations by market operators are not required. Since the calculations are performed by scientific institutions within a larger time frame, they can be realised in great scientific depth. The calculations are model-based and include global direct and indirect land use change effects.

In contrast, the European Renewable Energy Directive (RED) sets a greenhouse gas emission threshold for biofuels that has to be met by every economic operator on the European market. Compliance with the threshold has to be proven individually. Although default emission values are provided for many biofuel pathways, ones own calculations are often necessary. These calculations have to generate transparent, replicable and clear results. Therefore, the RED provides a clear methodology with energy-based allocation of co-products as the most important feature.

Voluntary certification schemes

Many voluntary certification schemes introduced GHG emission thresholds that have to be met by parties that want to get certified. Individual greenhouse gas calculations are also here required to prove compliance with the thresholds. The respective calculation methodology is provided by the certification schemes focusing again on generating results that are as clear and unambiguous as possible.

3.3.2.2 Methodological differences

International agreements

As explained above neither the GBEP framework nor the ISO standard determines specific methodological rules. The European standard prEN 16214-4 recaptures the RED rules which are analysed below.

Regulatory frameworks

The two US laws and the RED use profoundly different calculation methodologies subject to their different fields of application. Under the RFS2 and the LCFS biofuel GHG emissions are modelled. RFS2 uses a partial equilibrium model covering the whole agricultural sector. It determines the overall response of economic sectors to a certain volume change of biofuels. The responses are expressed as changes in total GHG emissions. Two separate partial equilibrium models (FASOM and CAPRI) are added to assess effects from global direct and indirect land use changes.

LCFS uses a simpler approach with the multi-dimensional spread-sheet based GREET model covering more than 100 fuel pathways (fossil and biogenic). It was adapted to Californian conditions and a partial equilibrium model (GTAP) was added to include land use change effects.

In contrast, the RED provides a simpler methodology that can be used for individual greenhouse gas calculations. The verification of compliance with the GHG emission thresholds is realised by third-party certification schemes that also have to put into practice the GHG calculation methodology. As a result, the RED influenced the worldwide design of certification schemes in the field of biofuels. Existing certification schemes created add-on standards to enable EU market access. Other recently developed schemes adopted the RED calculation methodology from the onset.

Voluntary certification schemes

Among the certification schemes assessed, only RSB and BSI require GHG calculations independently from the RED and therefore provide their own methodologies. Both schemes, together with RTRS which did not require GHG calculation, developed add-on standards to prove RED compliance. GGL, NTA, ISCC and the BioGrace tool included the RED methodology from the onset. This strong influence of the RED results in a low variability of greenhouse gas methodologies in certification schemes.

Differences between methodologies are due to two facts: first, GHG calculation is part of the main scheme independently from the RED (only in RSB and BSI). Second, there are differences between RED-compliant schemes and add-on standards since the RED leaves certain room for interpretation and does not always give exact guidance.

Table 3-5 lists the certification schemes and the RED for comparison. All schemes including add-on standards are differentiated – the original one for global application is referred to as ‘main’ and the add-on standard for granting an EU compliant certificate is referred to as ‘EU’. The table lists only those methodological specifications that are known to have a major influence on GHG calculation results (see also chapter 3.1). For exact details on all schemes, please refer to the characterisation tables in appendix C. Generally, all schemes follow a “well-to wheel” calculation approach with the same functional unit (results are referred to MJ fuel).

In the ‘main’ standards of RSB and BSI and in NTA, additional major deviations from the RED methodology can be found. In order to not overload the table they are listed separately:

GHG thresholds (RSB), GWPs and greenhouse gases taken into account (RSB), infrastructure (RSB), LUC methodology (RSB), cut-off date for land use change (NTA), emissions from sugarcane trash burning (RSB, BSI), indirect field N_2O emissions (RSB), surplus electricity (RSB, BSI).

Besides methodological specifications, the database used is a further reason for deviations between the schemes. Even the RED does not give any obligatory guidance on background data to be used such as emission or conversion factors. As a result, the certification schemes refer to existing data bases such as ecoinvent[5] or GEMIS[6] or include reference values from different sources in their appendices. The tool developed in the BioGrace project includes a separate sheet with all relevant background data.

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[5] www.ecoinvent.ch

[6] http://www.oeko.de/service/gemis/

Table 3-5 Overview on greenhouse gas balancing in certification systems

Name	Overall methodology	Data used	Land use change	Co-products	Fossil reference system
RED	Well-to-Wheel calculation	Default values provided; operator-specific values can be used	Direct LUC according to Decision 2010/335/EU based on IPCC 2006 Tier 1	Allocation based on LHV except agricultural residues	Default provided
RSB – main	Same as RED; some minor variations	Operator-specific values shall be used	Same as RED with some additional features	Economic allocation, all co-products	Different from RED
RSB – EU	Same as RED	Same as RED	Same as RED	Same as RED	Same as RED
BSI – main	Well-to-Wheel	Only operator-specific values can be used	Same as RED	Substitution and allocation (different references), all co-products	Different from RED
BSI – EU	Same as RED	Only default values can be used	Same as RED	Same as RED	Same as RED
GGL	Same as RED	Operator-specific values should be used	Same as RED	Same as RED	Same as RED
ISCC	Same as RED	Same as RED	Same as RED	Same as RED	Same as RED
NTA	Same as RED	Same as RED		Same as RED	Same as RED
RTRS – main	No GHG balancing				
RTRS – EU	Same as RED	Same as RED	Same as RED	Same as RED	Same as RED
BioGrace tool	Same as RED	Default values provided; operator-specific values can be included	Same as RED	Same as RED	Same as RED

3.3.3 Conclusions

Different scopes and fields of application for the systems assessed lead to differences regarding levels of detail and methodological aspects in greenhouse gas calculation methodologies. GBEP and the international and European standards only want to guide greenhouse gas calculation and thus do not provide exact methodologies. RFS2 and LCFS perform ex ante GHG calculations in great scientific depth. Only the RED and the voluntary certification schemes provide calculation methodologies for individual market players. Since most certification schemes included such methodologies only after the adoption of the RED, they do not show great diversity. In addition, when methodologies are provided independently, methodological deviations are rather marginal. The need for a clear, transparent methodology that leads to unambiguous results limits eligible specifications.

If a respective scheme or methodology is to be introduced in the GEF context, the certification schemes presented in this section can serve as appropriate examples since they focus on clearness and an easy application of greenhouse gas calculation. It should be noted, though, that no matter how detailed guidance may be, it can still leave space for interpretation and thus could lead to differences in results. Furthermore, if background data is not predefined, the same methodology could still lead to diverging results.

Regarding aspects such as applicability and accurateness of the presented schemes, in-depth experiences are still missing. Greenhouse gas calculation in the context of regulatory frameworks is a rather new topic compared to life cycle assessments in general which have been applied since the 1990’s. Certification of biofuels is only about to start and is therefore still subject to changes and adaptations.

The same applies to experiences regarding the effectiveness of such systems when it comes to their contribution to greenhouse gas savings. It is already obvious that, among the three regulatory frameworks, the RED provides most possibilities to introduce further incentives to reduce greenhouse gas emissions. Since each economic operator is asked to calculate his/her emissions, savings that go beyond the thresholds could easily be linked to financial incentives. In contrast, under the US laws no results on actual greenhouse gas emissions from single economic operators are available. Furthermore, the inclusion of GHG calculations for new pathways is quite time-consuming which could slow down the implementation of new solutions.

4 Economic viability of the production of liquid biofuels

The economic viability of the 1st generation bioenergy crops: soy, sugarcane, palm, jatropha and cassava will be presented in US-$ per GJ. The cost figures have been collected or reviewed by local experts to make sure they represent realistic values. The economic viability varies greatly with the agricultural intensity of the cultivating stage, therefore the management settings will be described together with more background information on the specific settings in section 4.2.

4.1 Methodology

Feedstock costs are calculated by taking an economic lifetime of 24 or 25 years (depending on the crop cycle), and discounting all expenses (labour and other inputs) over the years. The NPV is calculated to show the profitability of the crop for the farmers. The revenues for a farmer are a multiplication of the yield and the market price for the fresh product, see Appendix D with all data input. The NPV is calculated using the following formula (I):

$$NPV = \sum_{i=0}^{n} \frac{B_i - C_i}{(1+r)^i} \qquad \text{(I)}$$

where

NPV	Net Present Value [US-$]
Bi	benefits in year i [US-$]
Ci	costs in year i [US-$]
r	discount rate [%]
n	lifetime of project [years]

If yields are increased or costs reduced, the NPV will increase. In the following results section, figures with stacked columns also show the breakdown of the largest contributors to costs (for example labour expenses or fertilisers). To be able to compare the different end products of the feedstocks, the final costs are given in US-$$_{2010}$/GJ. The final costs represents: feedstock costs (including labour, fertilizers etc.), transport costs (from field to conversion plant), conversion costs (in $/l), if applicable transesterification or further refining costs and finally distribution to the end consumer (filling station). The transport expenses are linked to the GHG balance data by using the same transport distances, also the yields are equal. The final cost is calculated by dividing the total discounted costs by the total discounted yields, using the following formula (II):

$$C = \frac{\sum_{i=1}^{i_t} \left(ecc_i \sum_{y=1}^{n} \frac{f_i(y)}{(1+r)^y} \right)}{yld \sum_{y=1}^{n} \frac{f_{yld}(y)}{(1+r)^y}} \qquad \text{(II)}$$

where

C	Cost of biomass [$ kg^{-1} or $ t^{-1} or $ m^{-3}]
i_t	number of cost items with different time pattern
ecc_i	cost of energy crop cost item [$ ha^{-1}]
n	number of years of plantation lifetime [yr]

$f_i(y)$	number of times that cost item i is applied on the plantation in year y [dimensionless]
r	discount rate [dimensionless]
yld	yield of the energy crop [kg ha^{-1} yr^{-1} or t ha^{-1} yr^{-1} or m^3 ha^{-1} yr^{-1}]
$f_{yld}(y)$	binary number, harvest (1) or not (0) in year y [dimensionless]

All \$ are US\$ $_{2010}$, the lifetime is 24 or 25 years for all crops (perennial and annual crops) and the discount factor is 8.2 (van Eijck et al. 2011). This rate, which applies to Tanzania, Mozambique, Mali and Thailand, is assumed to be equal for the other regions in our settings.

First the input data that is used in the calculations is described and in the second section the results are given that show the total prices per GJ and the NPV or agricultural input breakdown. Finally, the cost ranges of the liquid biofuels per region and per feedstock are given.

4.2 Description of input data

The different feedstocks are described separately, the most important input parameters are given and a discussion on the sensitivity of some of the data. Tables with all input data are available in Appendix E.

4.3 Soy

All 7 settings that concern soy are situated in Argentina. The management systems that are varied are the rate of mechanisation and the practice of tillage. Furthermore smallholders and plantations are incorporated as well as two timeframes: 2010 and 2020, see Table 4-1.

Table 4-1 Seven settings for soy taken into account in the cost calculations

Setting No	Smallholder/ plantation	Management system	End product	Timeframe
1	smallholders	low mechanisation, no tillage	SVO	2010
2	smallholders	no mechanisation, no tillage	FAME	2010
3	plantation	high rate of mechanisation, tillage	FAME	2010
4	plantation	high rate of mechanisation, no tillage	FAME	2010
5	plantation	high inputs (irrigation), no tillage	FAME	2020
6	plantation	high rate of mechanisation, tillage	FAME	2020
7	plantation	high rate of mechanisation, no tillage	FAME	2020

All settings are situated in Argentina, a country that has a lot of experience with soy cultivation. Over the last decades, soybean cultivation has grown substantially representing 37,000 hectares in the 1970/71 campaign to more than 17 million at present (INTA 2011a). The main product of the cultivation of soy is animal feed while the oil that is obtained from processing is considered a by-product. Therefore, the cost of feedstock production is only allocated to soy biodiesel by 20% (by mass). Soy cultivation in Argentina takes place on large scale plantations with high rates of mechanisation.

The use of no tillage is the most common practice in the country, which leads to better environmental performance through lower carbon and water footprint. Zero-tillage technology allows the farmer to lay seed in the ground at the required depth with a minimal disturbance of the soil structure. Specially designed farm machinery eliminates the need for plowing and minimizes the tillage required for planting. . In Figure 4-1 the average soybean yield development of national averages is shown.

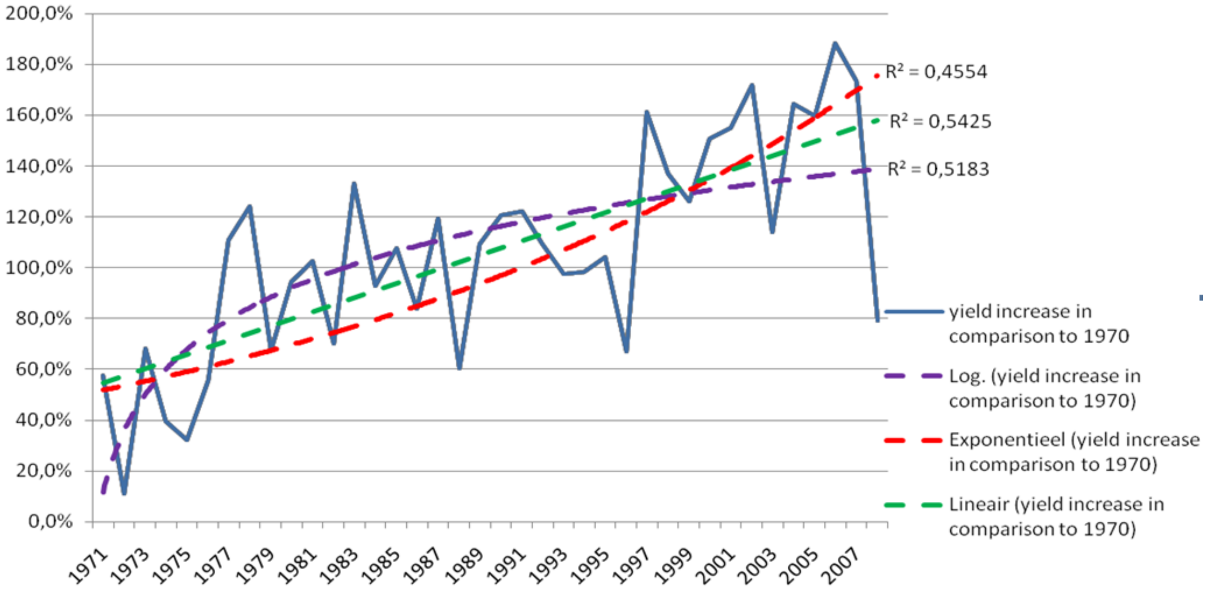


Figure 4-1 Average historic soy yield development – Argentina country level

Yields -- There are large differences between the individual provinces, with Cordoba reaching an average yield gain of around 300% in the last 10 years whereas Corrientes and La Pampa reached an average yield gain of around 60% in the same period. Increased yields are explained by a conjunction of factors including: agronomic, genetic, farm machinery and general management. There are good perspectives for this tendency to continue in the near future. Soybean BTRR2 specifically developed for the southern hemisphere could generate an increase between 10 and 15% in yields (INTA 2011a). See Table 4-2 for the yields used in the calculations, they are based on specific provinces in Argentina.

Table 4-2 Yield estimates used in the calculations with their respective regions source: (INTA 2011b)

Setting number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	smallholders	smallholders	plantation	plantation	plantation	plantation	plantation
Year	2010	2010	2010	2010	2020	2020	2020
average yield [t/ha]	2.8	2.8	3.6	4.5	4	4	5
Province	South of oba (rio Cuarto)	South of Cordoba (rio Cuarto)	Pergamino and Pehuajo (North and West of BA)	South of Santa Fe (Venado Tuerto)			

Costs -- Prices for inputs and soy beans change over time. The production costs of soy have increased since 2002, but dropped between 1991 and 2002, current costs are at a similar level as 1991, see Appendix E. Therefore the same prices for inputs in 2010 and 2020 were used. Wages are expected to increase from 3.18 $/hr in 2010 to 8.29 $/hr in 2020. See Figure 4-2 with a breakdown of all inputs for soybean production that are taken into account.

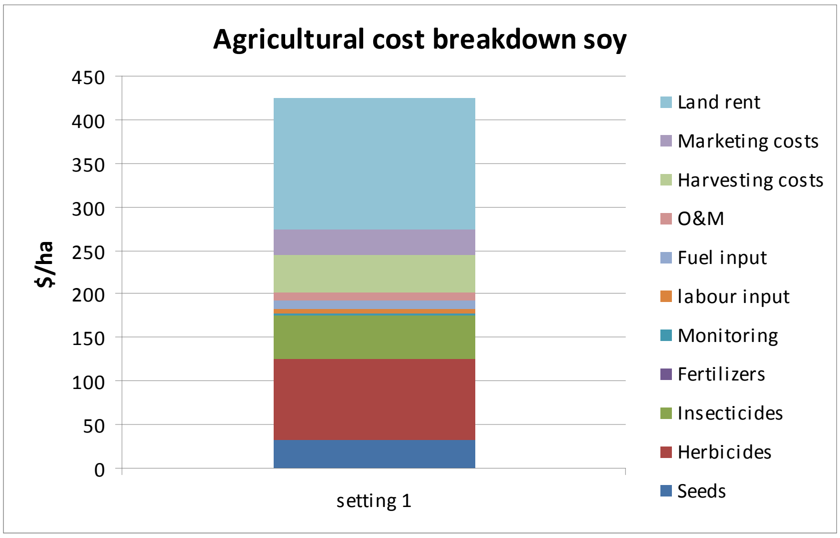


Figure 4-2 Cost breakdown for setting 1, Argentina

Transport distances vary greatly, since Argentina is a large country. For setting 1 and 2 an average of 400 km between field and conversion plant is taken, based on the production regions described above (INTA 2011b). The transport costs are 0.06 $/ton km (van Dam et al. 2009). The market price of soybeans is taken as 168.8 $/ton, this price can vary between 152-185 $/ton (INTA 2011b). All input data that is used in the calculations can be found in Appendix E.

4.4 Sugarcane

The settings that relate to sugarcane are located in Brazil and Mozambique. Both countries currently produce sugarcane and sugar, but only Brazil produces ethanol. In Brazil two production systems exist; large scale plantations and outgrowers who deliver to a central processing unit. The latter is used in our calculations. The production system is placed in North East Brazil (NE), a region which has higher production costs compared to the Central South region of Brazil (CS) (where sugarcane ethanol prices are globally the most competitive), but there is also quite a lot of room for improvement. Cultivation practices have not changed much in the last decade and are not optimal. Mechanised harvest is not practised at a very large scale in the NE, but policies in Brazil require a gradual implementation, which will potentially drive other improvements. Furthermore the NE has the advantage of having several large harbours that are relatively close to the production facilities.

Both production systems also exist in Mozambique. Outgrowers often obtain almost all inputs from the central processing mill, while their only input is labour. There is a large difference between very suitable soils and less suitable soils, (see Chapter Scale up and integration). Xhinavane is a production region close to Maputo that has been selected for irrigated production, while the Dombo region (more in the Central region) with more suitable soils is selected for non-irrigated production. Sugarcane is cultivated in 5-yrs ratoon cultivation, the crop is planted in year 0, harvested every subsequent year and is replanted in year 6.

Table 4-3 Setting specification for Sugarcane

Nr.	**Country**	**smallhol/pl**	**Management system**	**End product**	**Time-frame**
8	Brazil	centralised system (with outgrowers)	Mechanised harvesting, no irrigation (intermediate inputs)	EtOH	2010
9	Brazil	centralised system (with outgrowers)	Manual harvesting, irrigation (high inputs)	EtOH	2010
10	Brazil	centralised system (with outgrowers)	Mechanised harvesting, irrigation	Next EtOH	2020
11	Mozambique	centralised system (with outgrowers)	No irrigation (intermediate inputs)	EtOH	2010
12	Mozambique	centralised system (with outgrowers)	Irrigation (high inputs)	EtOH	2010
13	Brazil	centralised system (with outgrowers)	Mechanised harvesting, no irrigation (intermediate inputs)	EtOH	2020
14	Brazil	centralised system (with outgrowers)	Mechanised harvesting, irrigation (high inputs, high rate mechanisation)	EtOH	2020
15	Brazil	centralised system (with outgrowers)	Mechanised harvesting, irrigation (high inputs, high rate mechanisation)	Next EtOH	2030
16	Mozambique	centralised system (with outgrowers)	No irrigation (intermediate inputs)	EtOH	2020
17	Mozambique	centralised system (with outgrowers)	Irrigation (high inputs)	EtOH	2020

Two settings (10 and 15) consider both 1st and 2nd generation ethanol, ethanol produced from the juice (1st generation) and from the bagasse (2nd generation). Every ton of bagasse produces 88.3 l ethanol (CGEE 2009).

Yields -- The yield for the NE is based on (Herreras 2011) and is 60 ton cane/ha/yr for non-irrigated cane and 90 ton ha/yr for irrigated cane. The yields in Mozambique (76 t/ha/yr non-irrigated and 100 t/ha/yr irrigated) are based on (De Vries et al. 2011) and (van der Hilst, submitted). The higher yields in Mozambique are explained by the high climate suitability of ambique for sugarcane. Per ratoon year the yield is expected to decrease to respectively 96, 92, 88, 83 and 79% of the maximum yield. Yields are projected to increase with 5% in 2020 compared to 2010.

Other costs and inputs -- Transport costs in Mozambique are quite high; 0.096 $/ton km, for Beira region, while for Brazil they are 0.06 $/ton km (CEPAGRI et al. 2011). Land rent in Mozambique is assumed to be 22.05 $/ha/yr. Depending on the type of land (bare land, agricultural etc.) this price can vary, for example agricultural land that is leased from the Government has only a tax fee of around 0.5 $/ha/yr (MZM 15/ha/yr) (Investment Promotion Center 2009). See Figure 4-3 for a detailed cost breakdown. In Appendix E all other input data is shown.

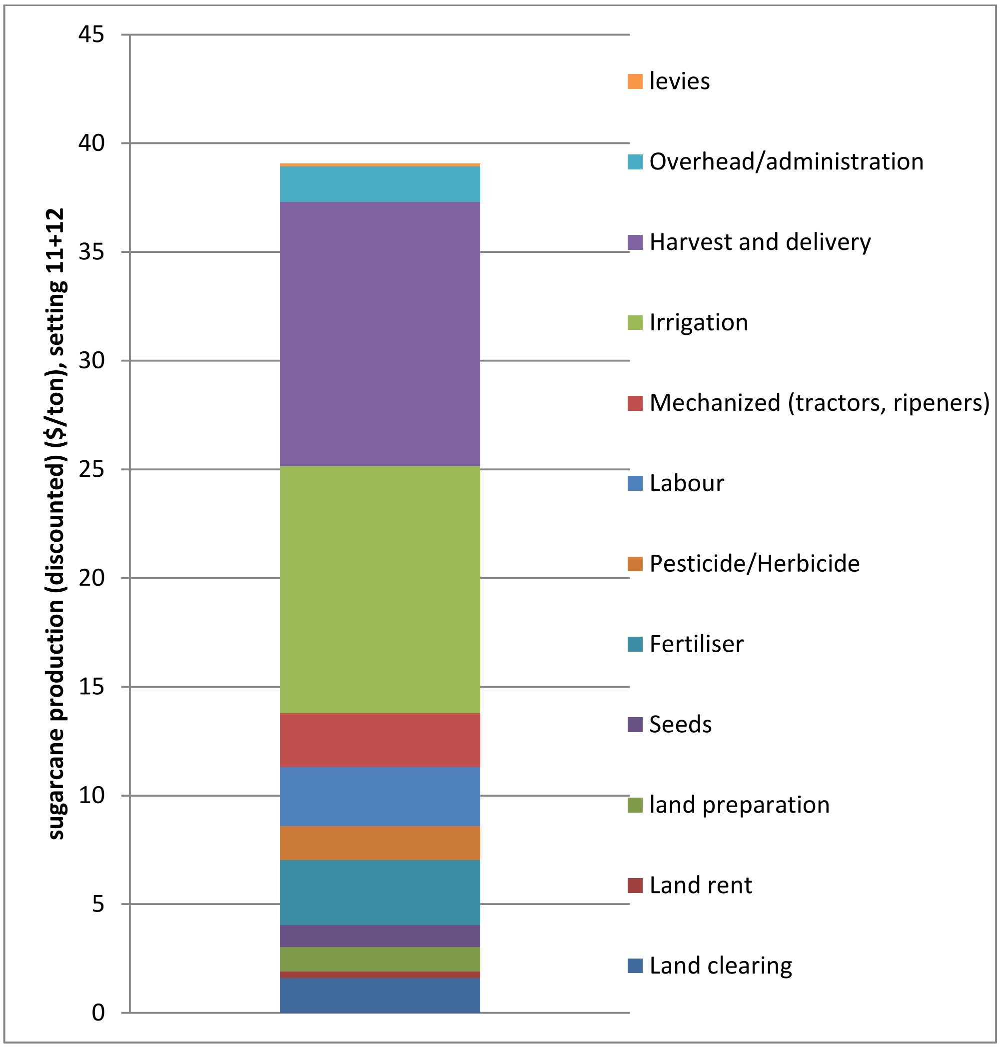


Figure 4-3 Breakdown of discounted costs for Mozambique ($/ton cane)

4.5 Palm oil

The palm oil settings that we selected refer to production in Colombia, Indonesia and Malaysia. Malaysia is the largest exporter of palm oil and is considered to operate on a best-practice base. Colombia currently has >400,000 ha of oil palm plantations and is the worlds' fifth producer (Fedepalma 2010a). See Table 4-4 for more details on the settings, for this cost calculation section we have added a setting for palm oil production 2020 in Colombia, setting 21b.

For Indonesia the setting is located in Jambi (Harapan Makmur village) on Sumatra. Outgrowers are mainly small-scale farmers, who on average each own a 2 ha farm. They obtain a relatively low yield, which appears to result from a range of factors related to sub-optimal management practices. Farmers farm their own land using family labour. Fertiliser application, the largest cost component of farmers'operating costs, is variable. Farmers currently apply a mix of inorganic fertilizers (Global Biopact 2011).

Table 4-4 Settings selected for palm oil production

Nr	Country	Smallholder/ plantation	Management system	End product	Timeframe	Byproducts
18	Indonesia	smallholders	intermediate inputs	SVO	2010	no pome use
19	Indonesia	smallholders	intermediate inputs	FAME	2010	no pome use
20	Indonesia	plantation	high inputs	FAME	2010	no pome use
21	Colombia	smallholders	intermediate inputs	FAME	2010	no pome use
22	Malaysia	plantation	high inputs	FAME	2010	no pome use
23	Indonesia	plantation	high inputs	FAME	2020	pome use
24	Malaysia	plantation	high inputs	FAME	2020	pome use
21b	Colombia	smallholders	Intermediate inputs	FAME	2020	

(POME=Palm Oil Mill Effluent, or waste water)

In Colombia production systems are present with small, medium and large scale oil palm growers. Especially for outgrowers, improvements in yield and the amount of hectares planted are expected to increase in the future. Cost data is derived from CENIPALMA (Investigación e Innovación Tecnológica en Palma de Aceite) and (Fedepalma 2010b). Data from Malaysia is obtained from (Ismail et al. 2003). The breakdown of the agricultural inputs are shown in Figure 4-4 and Figure 4-5, the costs structure is slightly different.

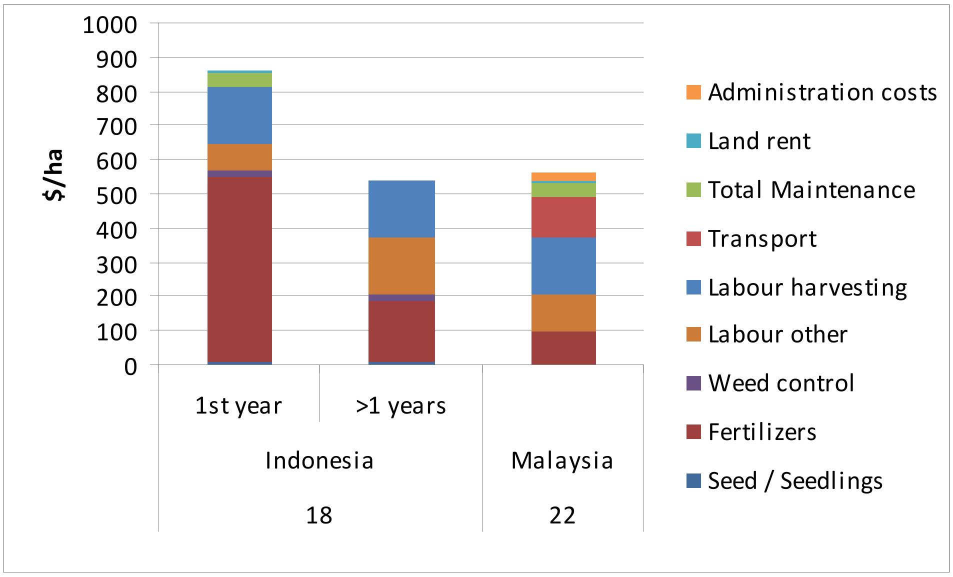


Figure 4-4 Breakdown of feedstock production costs Indonesia and Malaysia for setting 18 and 22

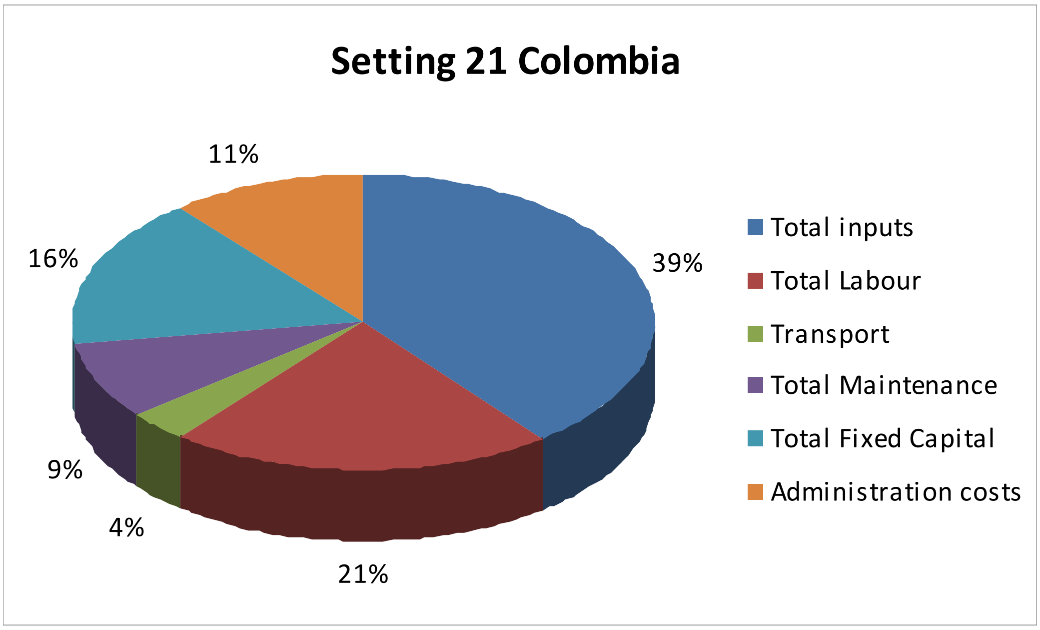


Figure 4-5 Cost breakdown of feedstock production for Colombia, setting 21

The major cost item for total inputs is fertiliser, followed by labour required particularly for harvesting.

Yield – Yield is expressed in Fresh Fruit Bunches (FFB). It is estimated that Indonesia (16 ton FFB/ha/yr) reaches the yield level of Malaysia (19 ton FFB/ha/yr) by 2020. This is relatively conservative since a case study plantation in Malaysia, analysed by Wicke et al. (2008), yielded 25 ton FFB/ha/yr. Better genetic varieties can increase yields. Also for Colombia the expectation is that yield levels will reach Malaysia. Although Bud rot disease can seriously affect yields and has done so in Colombia, hybrid materials have been developed but it takes some time before they are in production (Fedepalma 2010a).

Other input data can be found in the Appendix.

4.6 Jatropha

There are 17 settings that relate to Jatropha. Three countries are included: Tanzania, Mali and India as well as three different management settings: low inputs, intermediate inputs and high inputs. A production system with smallholders and a plantation is also considered (see Table 4-5).

Smallholders produce for a processor, either under a contract or independently. They often use family labour to cultivate their fields. Jatropha is planted as hedges around their farming plots, or planted with other crops on their fields. The seeds that are produced can be sold to the processor via a collector. Collection centers are located near strategic places, farmers bring their seeds in bags and company employees organise transport to a central place and then on to the central processing unit. The processor provides the farmers and collectors with extension services such as knowledge on cultivation practices and the initial planting material. A typical size for a smallholder plot is 0.5 to 2.0 ha (Mitchell 2008). Jatropha seeds are harvested from year 2-24, harvest periods in Tanzania are end of November (depending on the rainy period) and July-august. In India the harvest period is July-August and October-November in Karnataka (Estrin 2009).

Table 4-5 Different settings (17) considered for Jatropha

Nr	Country	Smallholder/ Plantation	Management system	End product	Timeframe
25	Tanzania	smallholders	low inputs, marginal land, no irrigation	SVO	2010
26	Tanzania	plantation	high inputs, good land, no irrigation	FAME	2010
27	Tanzania	plantation	intermediate inputs, marginal land, no irrigation	FAME	2010
28	Tanzania	smallholders	low inputs, marginal land, no irrigation	FAME	2010
29	Tanzania	smallholders	smallholder, intermediate inputs, marginal land	FAME	2010
30	Mali	smallholders	low inputs	FAME	2010
31	Mali	smallholders	intermediate inputs	FAME	2010
32	India	smallholders	low inputs	FAME	2010
33	India	smallholders	intermediate inputs	FAME	2010
34	Tanzania	plantation	high inputs, good land, no irrigation	FAME	2020
35	Tanzania	plantation	intermediate, marginal land, no irrigation	FAME	2020
36	Tanzania	smallholders	low inputs, marginal land	FAME	2020
37	Tanzania	smallholders	intermediate inputs, marginal land	FAME	2020
38	Mali	smallholders	low inputs	FAME	2020
39	Mali	smallholders	intermediate inputs	FAME	2020
40	India	smallholders	low inputs	FAME	2020
41	India	smallholders	intermediate inputs	FAME	2020

In a plantation system the land is cultivated by employees of the company, often with much higher rates of mechanisation. The land can be cultivated in patches of, for example, 200 ha each. Each patch is then managed by a block-manager/field officer. Employees of the company pick the seeds which are then processed. The fruit shells (capsules) are obtained when opening them to obtain the jatropha seeds. It is assumed that smallholders leave these on the field, while in a plantation system they are used as fuel.

All three countries produce jatropha, however experiences on commercial levels are limited. The amount of oil produced is relatively low, so therefore most cost data is derived from small-medium sized extraction plants or is estimated. Large investments have been made in jatropha research so efficiency improvements are expected; on the other hand some large scale operations halted their activities.

Feedstock production -- The cost factors are different for smallholders and a plantation system. The feedstock costs factors for the smallholder settings are shown per country.

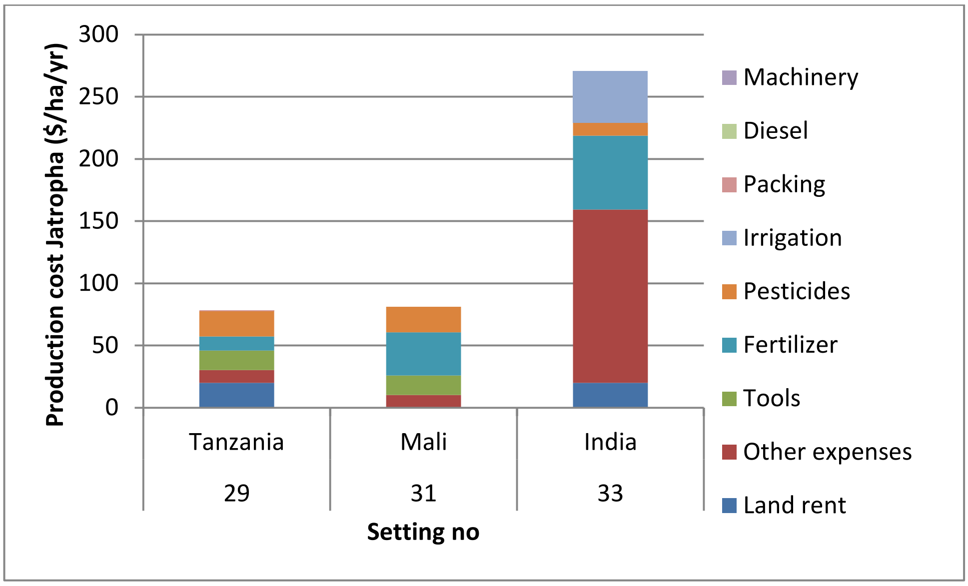


Figure 4-6 Feedstock production cost breakdown ($/ha)

A difference between the countries is that for Tanzania it is assumed that farmers have to pay for packaging, 0.45$ per bag of 60 kg, these expenses are not accounted for in Mali and India. Since bags are often re-used these expenses are not always accounted for by the farmers (also not in Tanzania (Van Eijck 2009)), this shows the difference in costs.

The plantation setting is situated in Tanzania, the low input setting (no 27) represents a plantation based with manual labour, while the intermediate input setting (26) represents mechanised harvesting. Since this is not currently applied globally, experimental data of the BEI-harvester has been used to estimate these costs. See Figure 4-7 and Figure 4-8 that visually illustrate the difference in cost structure of the two plantation settings.

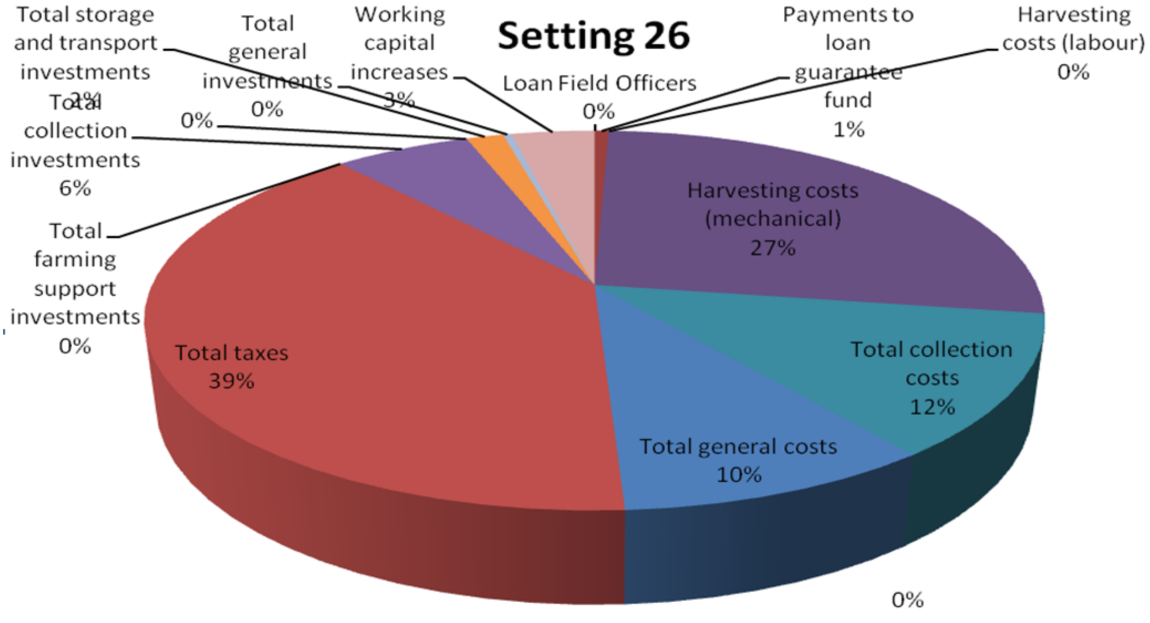


Figure 4-7 Cost structure setting 26, mechanised harvest

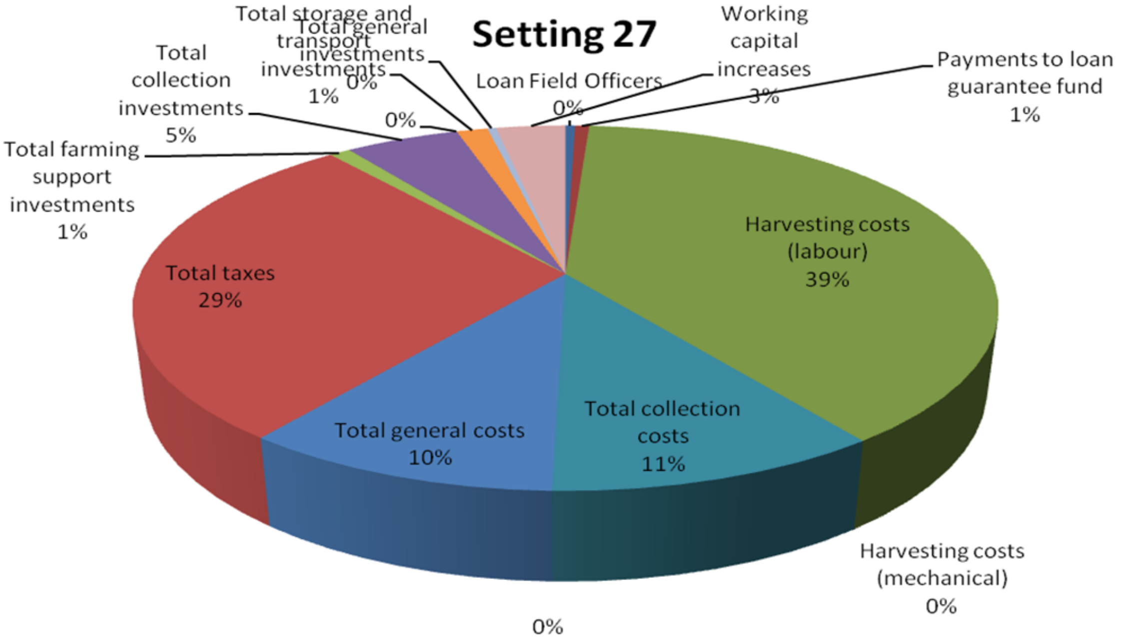


Figure 4-8 Cost structure setting 27, manual labour

In the 2020 settings, the parameters for the mechanised harvester are changed, the price is decreased by 60% (from 180,000$ per harvester to 60,000$) and the harvesting speed is increased from 1.5 ha/hour to 3 ha/hour. For both production systems the costs are linked to the yield. Wage rates are relatively low in the countries, and only low skilled labour is required for cultivation. Smallholders often do not count their labour hours, so this can also be seen as opportunity costs. For all three regions the labour requirements have been kept constant, total labour requirements for jatropha depend on harvest and vary between 30-120 days/ha/year. In Appendix E the range in labour days is given.

Wage rates are varied per country. India has the lowest wages with 1.29$/day (Rs 60/day), this is the minimum wage) (Altenburg et al. 2009), Tanzania has wages rates of 2$/day (van Eijck et al. 2011) and Mali 2.47 $day (API Mali 2010).

Yields -- Jatropha is a perennial crop with a productive lifetime of >30 years. For this study, an economic lifetime of 24 years has been used. The plant matures in 6 years' time; the first year 0% of the mature yield is expected. In the second year 10% of the yield is expected and 25%, 40% and 80% in the subsequent years until year 6, see Table 4-6. Furthermore, for 2020 the yields are expected to increase by 15% considering large efforts in Jatropha breeding programs (Hawkings and Chen 2011).

Conversion -- Since Jatropha production has not reached commercial levels, costs of conversion to SVO and biodiesel are relatively high; 0.20 $/l and 0.28 $/l respectively (van Eijck et al. 2011). In India there is a well-established oilseed sector, therefore the conversion costs to SVO are lower (0,14 $/l (Estrin 2009). Conversion and transesterification costs for 2020 are based on US biodiesel conversion plants that are also used by (Mulugetta 2009). Large efficiency improvements are expected.

All input data can be found in Appendix E.

Table 4-6 Maximum yield values for jatropha in 2010 and 2020

Setting number	Country	Yield (kg/ha/yr)
25	Tanzania	1,100
26	Tanzania	3,000
27	Tanzania	1,400
28	Tanzania	1,100
29	Tanzania	1,980
30	Mali	1,000
31	Mali	1,500
32	India	2,000
33	India	2,500
34	Tanzania	3,450
35	Tanzania	2,875

4.7 Cassava

Cassava is currently cultivated in large parts of the world, often by subsistence farmers as source for food. Cassava roots can be stored in the soil for two years, serving as food storage (Elbersen and Oyen 2009). Small scale farmers cultivate cassava as an additional crop on their land, and in between other crops. These cultivation management techniques are often far from best practice. In Thailand, more commercial farming of cassava exists and the first (pilot) cassava to ethanol conversion plants have already been established. In Mozambique and Tanzania such facilities do not exist yet. Data on cassava cultivation is obtained from (van Eijck et al. 2011), IIAM Mozambique, (Nguyen et al. 2008), (Silalertruksa and Gheewala 2009) and through personal communication with Prof. Gheewala (The Joint Graduate School of Energy and Environment King Mongkut's University of Technology Thonburi, Bangkok, Thailand), Thea Shayo in Tanzania (Shayo feb. 2010) and Sicco Colijn in Mozambique (2010). There are 16 settings related to cassava feedstock, see Table 4-7.

Input costs – The labour days required for cultivation in Mali and Tanzania are expected to reduce in 2020 to only half of the amount of 2010. This is due to increased mechanisation that enables labour rates more equal to Thailand. The labour requirements for Mozambique and Tanzania are based on (van Eijck et al. 2011). 142 labour days per year are required for the low input system and 165 days/ha/yr for the intermediate input systems. The difference is due to the labour days required for additional management such as fertiliser, pesticide and herbicide application and pruning. Since there are currently no large scale plantations for cassava cultivation, these are only included for 2020, when it is expected that commercial plantations will start up.

Yields -- Cassava is harvested every year, but for comparison reasons a system lifetime of 24 years is taken. In the low input system in Mozambique and Tanzania it is assumed that due to a lack of suitable levels of fertiliser applied, the yields decline by 2% per year. In Thailand, current practice is to apply fertiliser, therefore yields are assumed to be stable over the years. For the settings that relate to 2020, it is assumed that Mozambique reaches yield levels of Tanzania, and Tanzania reaches yield levels of Thailand, see Table 4-8.

Input costs – The labour days required for cultivation in Mali and Tanzania are expected to reduce in 2020 to only half of the amount of 2010. This is due to increased mechanisation that enables labour rates more equal to Thailand. The labour requirements for Mozambique and Tanzania are based on (van Eijck et al. 2011). 142 labour days per year are required for the low input system and 165 days/ha/yr for the intermediate input systems. The difference is due to the labour days required for additional management such as fertiliser, pesticide and herbicide application and pruning.

Table 4-7 Definition of settings related to cassava

No	**Country**	**smallhol/pl**	**Management system**	**End product**	**Time-frame**	**Byproducts**
42	Mozambique	smallholders	low inputs	EtOH	2010	Cake as fertilizer
43	Mozambique	smallholders	intermediate inputs	EtOH	2010	Cake as fertilizer
44	Tanzania	smallholders	low inputs	EtOH	2010	Cake as fertilizer
45	Tanzania	smallholders	intermediate inputs	EtOH	2010	Cake as fertilizer
46	Thailand	smallholders	low inputs	EtOH	2010	Cake as fertilizer
47	Thailand	smallholders	intermediate inputs	EtOH	2010	Cake as fertilizer
48	Mozambique	smallholders	low inputs	EtOH	2020	Cake as fertilizer
49	Mozambique	smallholders	intermediate inputs	EtOH	2020	Cake as fertilizer
50	Mozambique	plantation	high inputs	EtOH	2020	Cake as fertilizer
51	Tanzania	smallholders	low inputs	EtOH	2020	Cake as fertilizer
52	Tanzania	smallholders	intermediate inputs	EtOH	2020	Cake as fertilizer
53	Tanzania	plantation	high inputs	EtOH	2020	Cake as fertilizer
54	Thailand	smallholders	low inputs	EtOH	2020	Cake as fertilizer
55	Thailand	smallholders	intermediate inputs	EtOH	2020	Cake as fertilizer
56	Thailand	plantation	high inputs	EtOH	2020	Cake as fertilizer

Table 4-8 Yield levels for cassava

Setting number	**Input system**	**Yield (t/ha)**	**Region**	**Literature source**
42	Low inputs	4	Mozambique	FAO average
43	Intermediate inputs	6	Mozambique	FAO average
44	Low inputs	6	Tanzania	(van Eijck et al. 2011)
45	Intermediate inputs	12	Tanzania	(van Eijck et al. 2011)
46	Low inputs	20	Thailand	(Office of Agricultural Economics (OAE) 2009)*
47	Intermediate	22	Thailand	(Office of Agricultural Economics (OAE) 2009)* average of country averages 2007-2009
54	Low	32	Thailand	(Silalertruksa and Gheewala 2010)*
55	Intermediate	34	Thailand	(Silalertruksa and Gheewala 2010)*
56	High	44	Thailand	Estimate IFEU/UU

* also based on personal communication Prof. Gheewala, Bangkok, Thailand

The amount of labour days for Thailand is much lower (around 44 days/ha/yr (Nguyen et al. 2008)) but the use of agricultural equipment is higher. The labour costs for Thailand are based on averages from 2005-2008 (Office of Agricultural Economics (OAE) 2009). There are no costs for fertiliser included in the low input settings for Mozambique and Tanzania, this is done because the fertiliser applied (e.g. 13.6 k N per ha for setting 42, see GHG calculations) is expected to be derived from manure that is freely available. The input costs for Thailand are averages from 2005-2008 (Office of Agricultural Economics (OAE) 2009). The average farm gate price of fresh cassava roots in Thailand (2006-2008) is 1400 THB/t or 45 $$_{2010}$/t. See Figure 4-9 for a breakdown of input costs. All input data can be found in Appendix E.

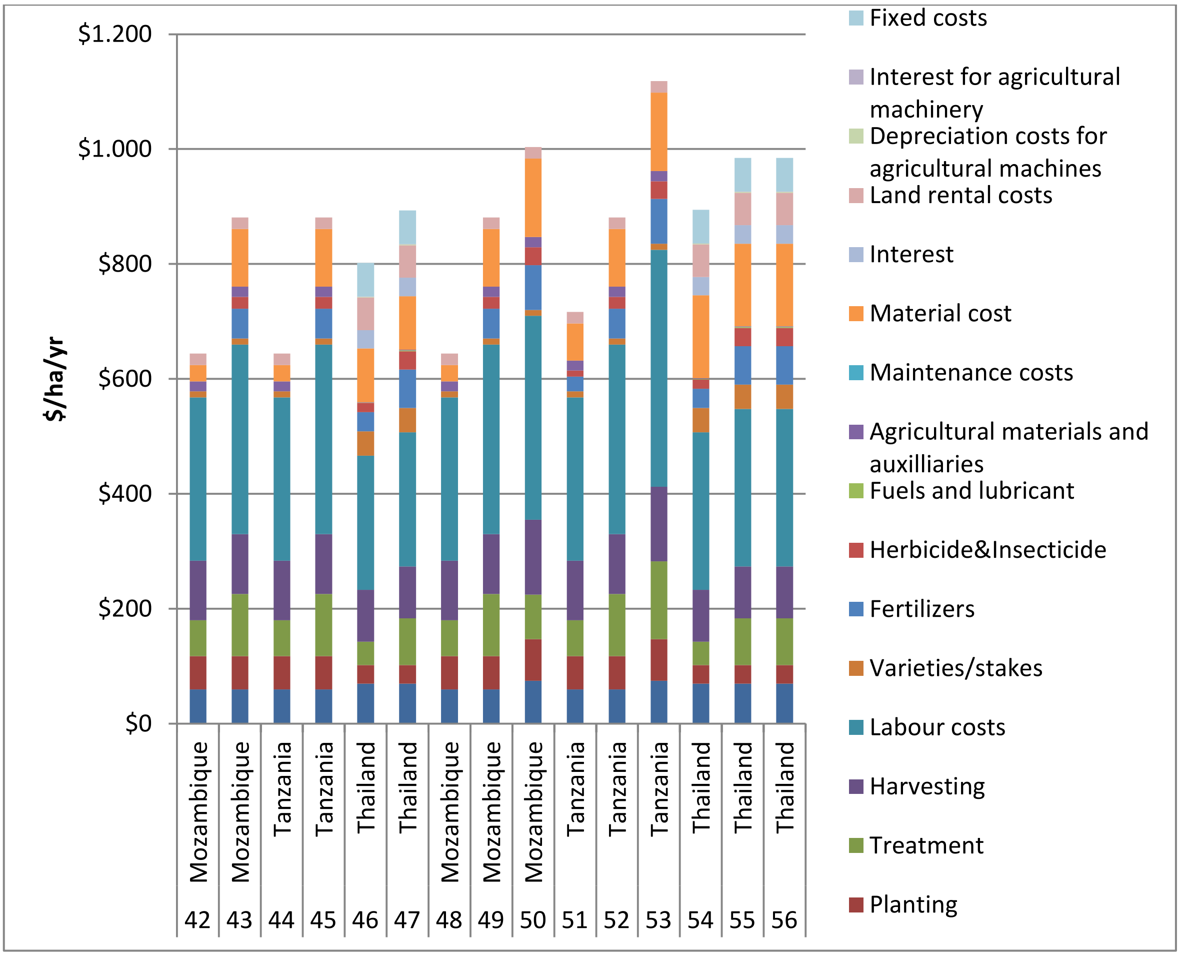


Figure 4-9 Input costs for cassava settings ($/ha)

4.8 Costs of liquid biofuels production

The results of the total production costs per feedstock are presented in this chapter.

4.8.1 Soy biodiesel

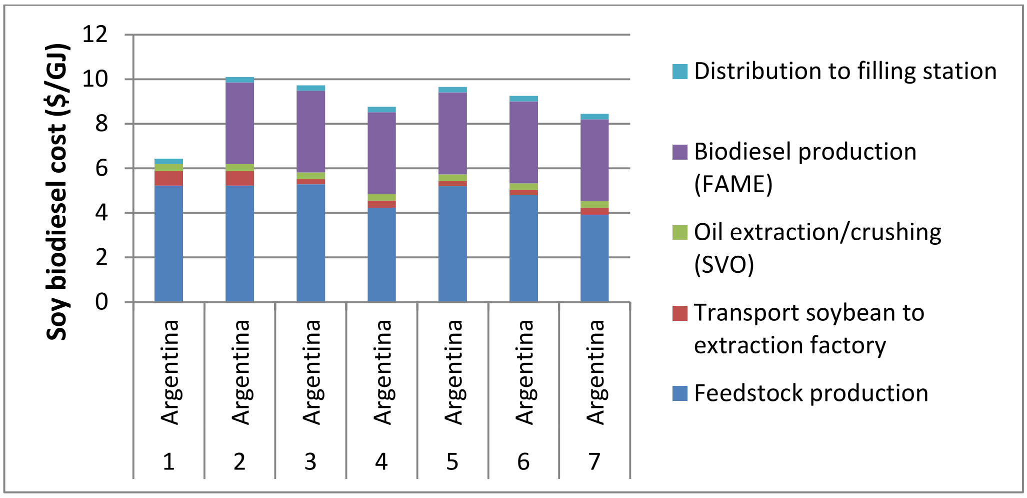


Figure 4-10 Cost price $/GJ for settings 1-7; (energy content 32.9 MJ/l)

The price per GJ for soy biodiesel in Argentina is relatively low, this is due to the high value of the (main) product; soy meal. Of the feedstock costs 20% is allocated to soy biodiesel (by mass). The breakdown of discounted expenses for soy production (Figure 4-11) shows that land rent is a relatively high contributor. The value of land rent that is used in the calculations is 150 $/ha/yr. This value is actually quite low, considering other sources that mention prices of 200 $/ha/yr (INTA 2011b) or even higher (commercial) rates of almost 520 $/ha/yr.

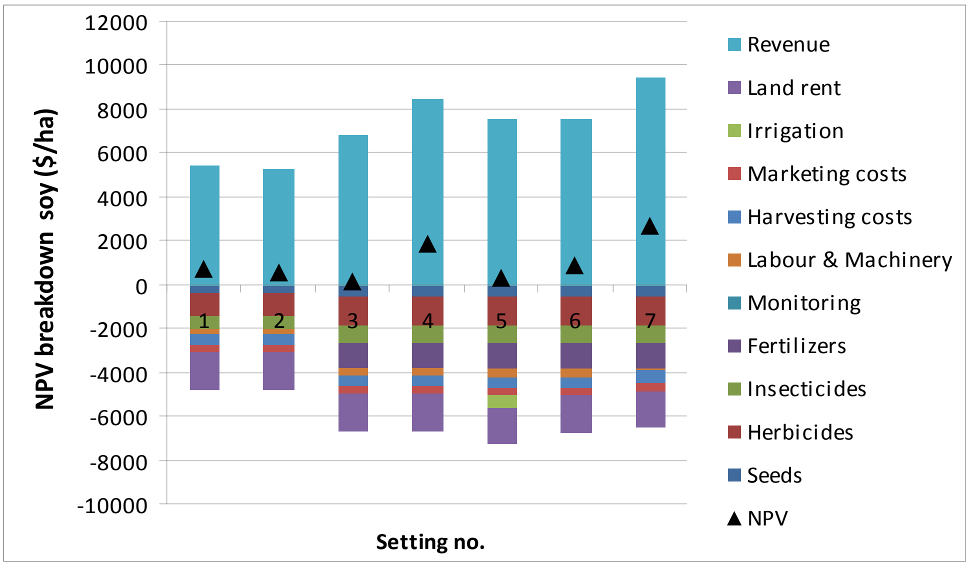


Figure 4-11 NPV per ha for soy settings

4.8.2 Sugarcane ethanol

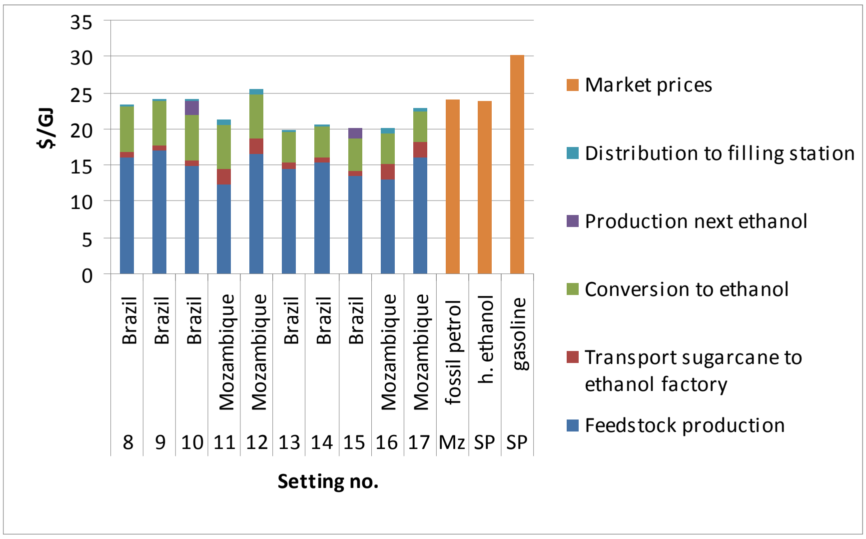


Figure 4-12 Cost price per GJ for setting 8-17 (SP is Sao Paulo, market price of hydrated ethanol and gasoline: (van den Wall Bake et al. 2009), Mz is price of petrol in Mozambique in 2009 (excluding taxes), ethanol energy content 26.4 MJ/l

Information on the market prices for sugarcane (26.4 MJ/l) has to be included for NPV calculations. These prices fluctuate with the global sugar prices and therefore are very volatile.

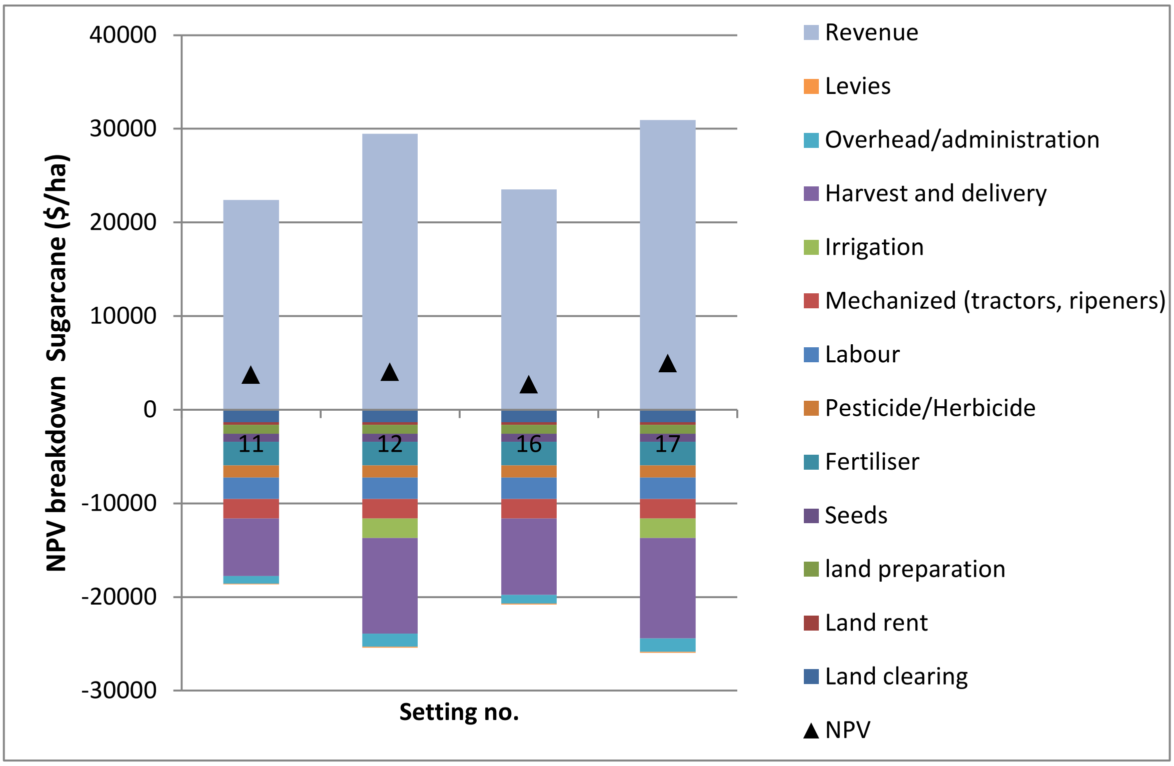


Figure 4-13 NPV per ha for sugarcane Mozambique settings

All NPVs for Mozambique are positive. Note that in setting 12 and 17, it is assumed that the instalment costs for irrigation are accounted for by the central producer; the outgrower has to account for the labour that is associated with irrigation.

4.8.3 Palm oil (CPO and FAME, Indonesia-Colombia-Malaysia)

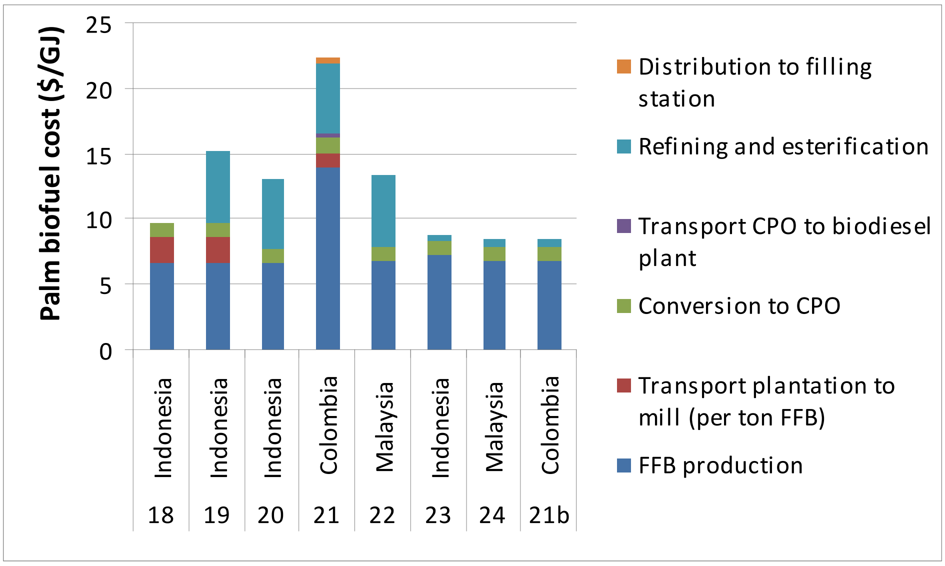


Figure 4-14 Cost of Palm oil production (CPO and biodiesel) in Indonesia, Colombia and Malaysia; energy content 36.92 MJ/l (Yáñez Angarita et al. 2009)

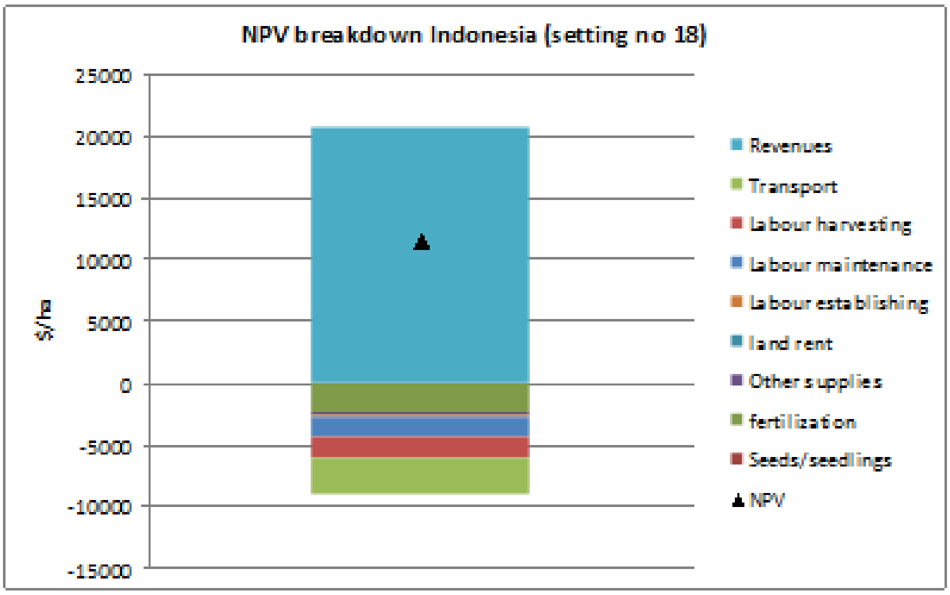


Figure 4-15 NPV for Setting 18

The NPV for Indonesian farmers is very high. This is due to the relatively high yields we have incorporated in our calculations. Smallholders also have to pay for transport expenses to the mill which is included in the calculations. FFB prices are volatile and since they have to be processed within a short time frame, farmers often do not have a choice but to sell them for a (set) price to the mill.

4.8.4 Jatropha oil and biodiesel

In Figure 4-16 the costs of Jatropha SVO and biodiesel in Tanzania, Mali and India are shown.

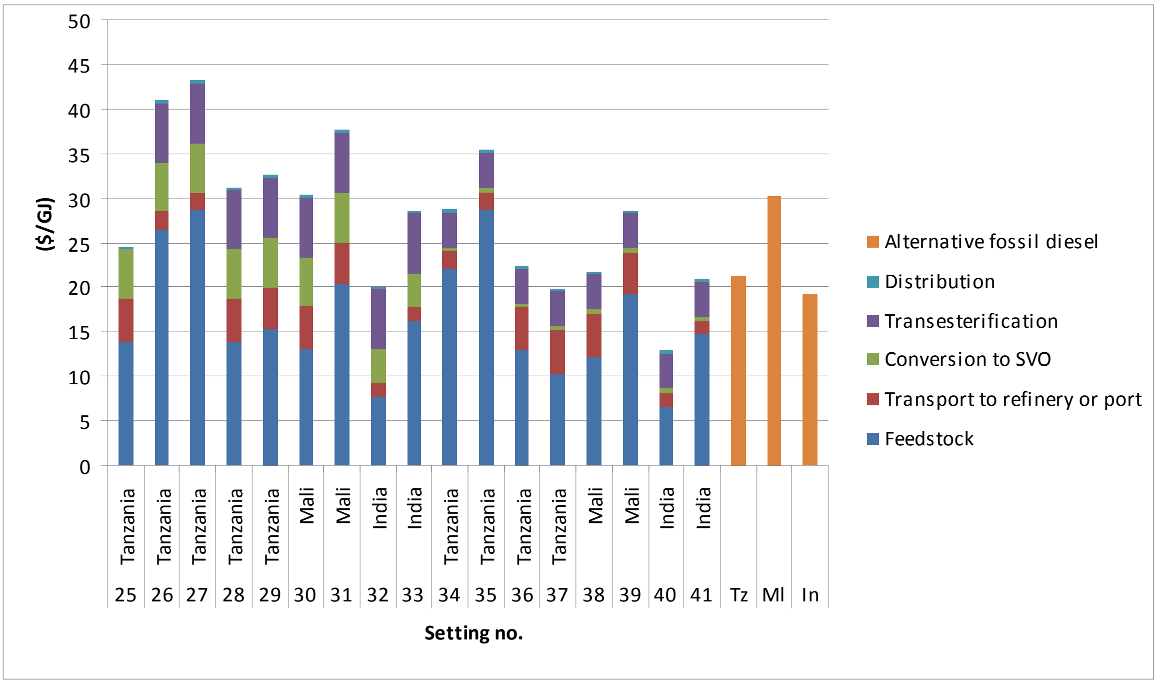


Figure 4-16 Costs per GJ for Jatropha SVO and Biodiesel for setting 25-41, compared to the price per GJ of the locally available fossil diesel (36.2 MJ/l)

The cultivation of Jatropha is very labour intensive. That is why wage rates have a large influence on feedstock production costs. The wage rate of India is relatively low (60rs/day or 1.29 $/day), compared to Tanzania (2$/day). The wage rate of Mali is (slightly) higher with 2.46 $/day. Intermediate inputs in India also includes irrigation which is why this setting (33 and 41) has higher costs than cultivation without irrigation (32 and 40). Transport expenses are quite low in India compared to the African countries. If infrastructure improves these costs can be lowered but this has not been taken into account in the analysis. The NPV is shown in Figure 4-17.

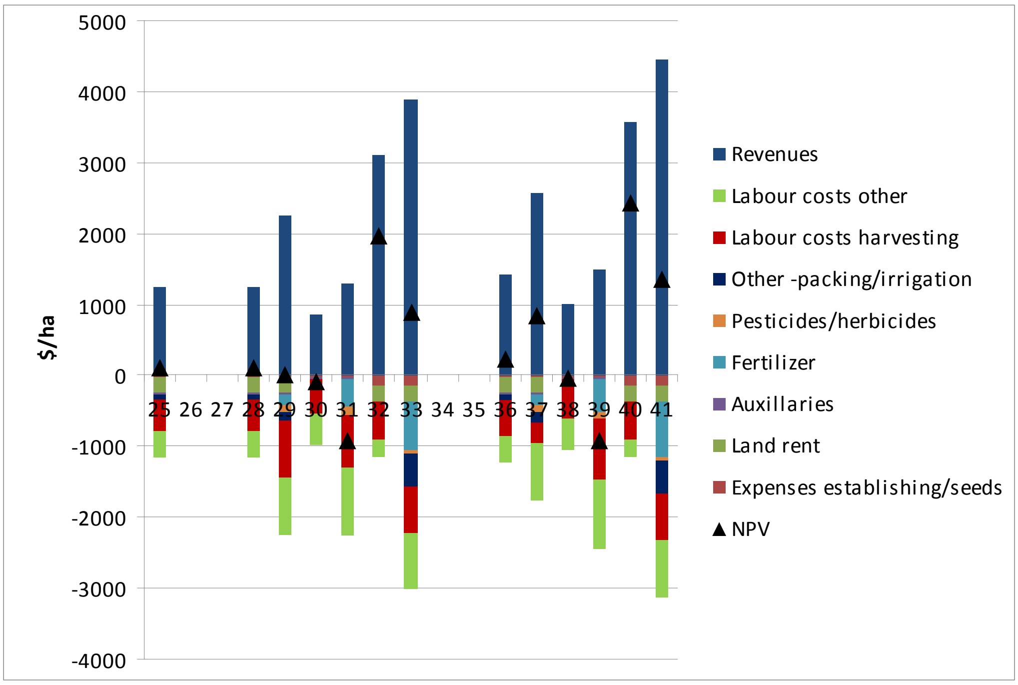


Figure 4-17 NPV for Jatropha settings (excluding plantation settings)

For quite a number of settings the NPV is negative. The profitability for farmers mainly depends on the yield that can be obtained. Intermediate inputs do not lead to higher NPV's. With relatively low labour costs (or family labour when there are limited other options) and an average yield the NPV can be high; 2,437 $ (India, setting 40).

The two plantation settings are different in their production system and cost structure, in setting 26 (mechanized labour) production costs per kg are 0.24 $/kg seeds, while in setting 27 (manual labour) these costs are 0.26 $/kg seeds. The difference is due to the relatively high price of the harvester, which is expected to decreases in the future.

4.8.5 Cassava ethanol

Figure 4-18 shows the costs of cassava ethanol production for the different settings in Tanzania, Mozambique and Thailand. In 2010 prices, none of the settings can obtain cassava ethanol for a price below current fossil petrol prices. However, with anticipated increase in yields (see data input section) and a reduction of conversion costs from 0.23 $/l to costs equal to corn ethanol conversion costs (0.14 $/l (Hettinga et al. 2009)), all 2020 settings could be competitive to current fossil petrol prices. The price of 0.23 $/l is derived from a pilot factory in Thailand where efficiency improvements and cost reductions are likely. Prices of inputs are assumed to remain the same over the decade. Several factors influence these prices. Inflation could increase prices and revenues, while more efficient management techniques, better varieties etc. could reduce prices. Also, fertiliser prices are linked to fossil prices that are highly volatile. More research is required to quantify these effects. The NPV for producing cassava feedstock in the different settings is shown in Figure 4-19.

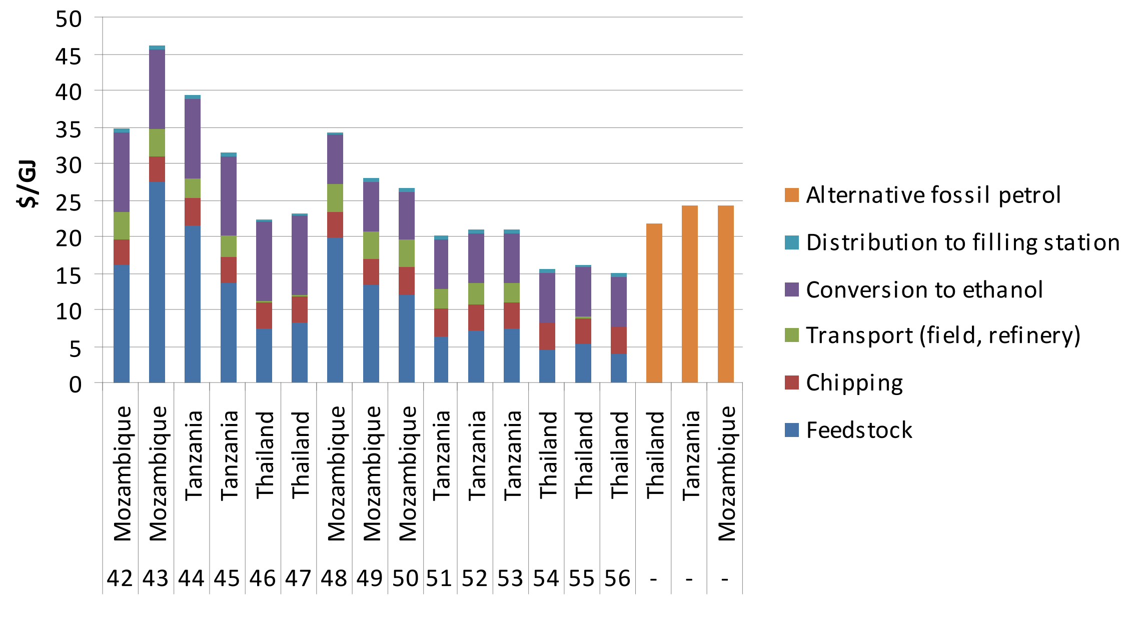


Figure 4-18 Life cycle cost calculations for cassava ethanol (20.88 MJ/L)

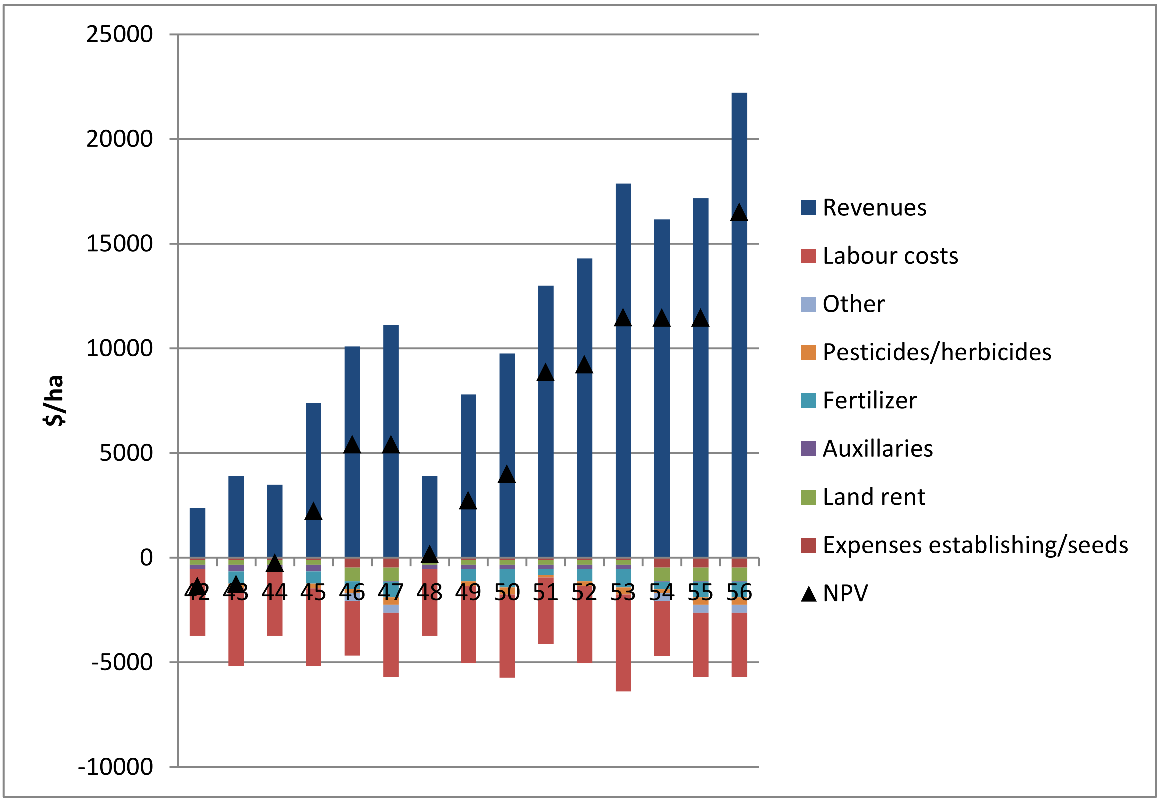


Figure 4-19 Costs, revenues and NPV for cassava in different settings ($/ha)

Setting 42, 43 and 44 do not have positive NPVs, which means that at current market prices for fresh cassava roots, and current (low) yields, cassava cultivation is not profitable in these regions (Mozambique and Tanzania). Settings 45, 46 and 47, however, (all

2010 settings) are quite profitable (Tanzania and Thailand). This is due to the higher yields that make up for additional expenses on fertiliser and other inputs.

All settings that relate to 2020 (setting 48-56) have positive NPVs (from 180-16,000 $/ha). Labour costs are the major cost contributor, while for Thailand land rent is also a relatively large contributor.

4.9 Competitiveness of liquid biofuels and improvement strategies

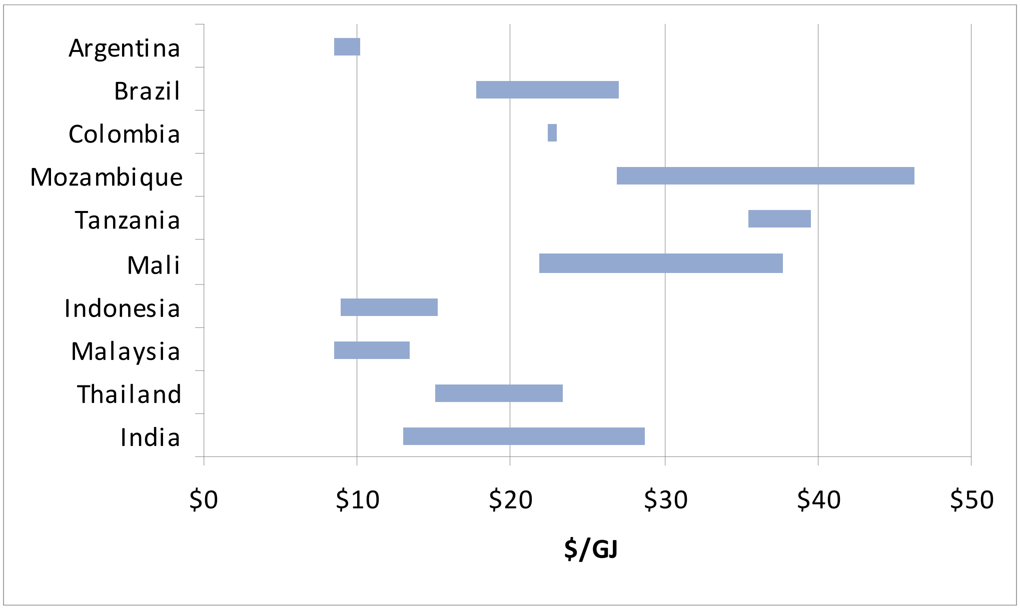


Figure 4-20 Ranges of biofuel cost prices ($/GJ) per region

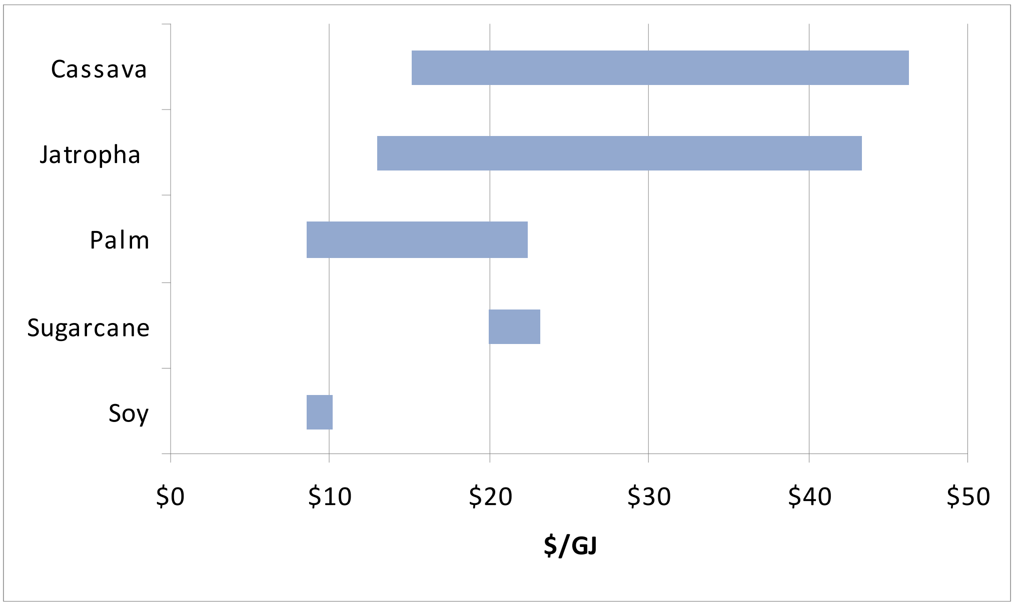


Figure 4-21 Ranges of biofuel production costs ($/GJ) per feedstock

4.10 Sensitivity analysis

Discount rates are varied from the original 8.2% to 6% and 15%, see Figure 4-22. This only influences the costs of the perennial crops.

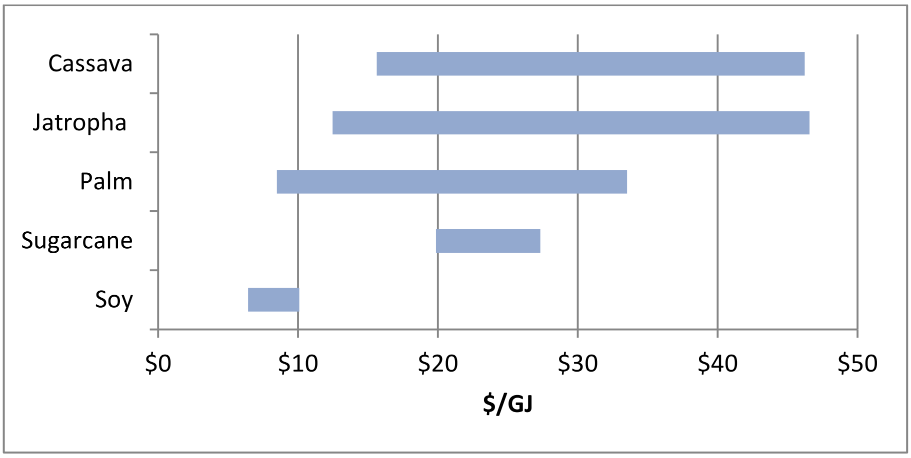


Figure 4-22 New ranges for variation in discount rates, 6%-15%

Wages/labour costs

Wage rates for Argentina used in calculations are 3.18 $/h in 2010 and 8.29 $/h in 2020. For this sensitivity analysis they are varied from 1$/h to 15 $/h. Sugarcane labour costs are varied from zero to double. Palm lacks specific data on labour. Jatropha labour rates are varied from 0 to 7.5 $/day. The zero labour costs represent family labour. And finally for cassava the wage rates are varied from 0 to 8 $/day (8 is the double rate of the 4 $/day that is used for 2020 Moz.).

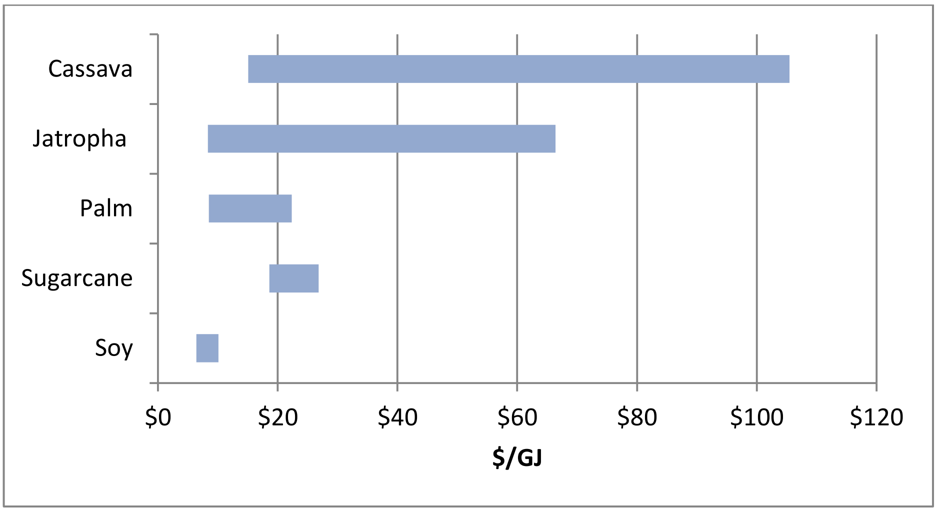


Figure 4-23 New ranges for variation in wage rates

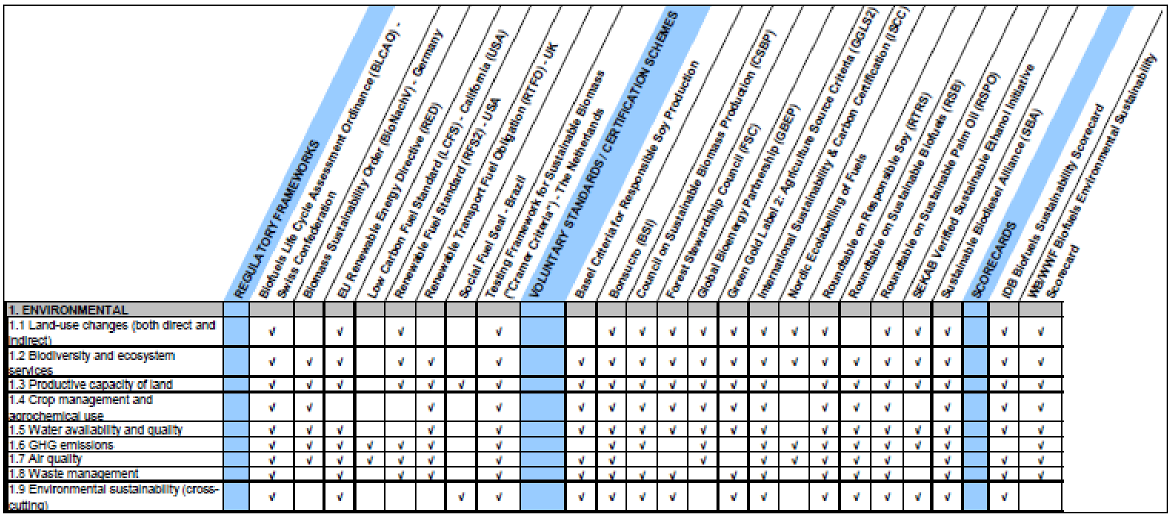
The influence of wages is large especially for cassava ethanol, jatropha SVO and biodiesel. The influence on soy is minimal. The price of inputs has been considered constant.

5 Global non-GHG environmental impacts of biofuels

5.1 Environmental standards, criteria and indicators for biofuels

This section provides a compilation of science-based criteria and indicators relevant for the non-GHG environmental impacts of biofuels. It should be noted that the compilation was **not** restricted to criteria and indicators compatible with international trade law[7]. Since the beginning of the international discussion on the environmental sustainability of biofuels in the early 2000's[8], a variety of studies were prepared on the issue so that this study can rely on a substantial body of work[9]. The FAO BEFSCI Project compiled an overview table (see below) of regulatory and voluntary schemes for biofuels and their respective "coverage" of environmental issues.

Figure 5-1 Environmental Sustainability Aspects/Issues Addressed under the Initiatives reviewed by BEFSCI



	REGULATORY FRAMEWORKS	Biofuels Life Cycle Assessment Ordinance (BLCAO) - Swiss Confederation	Biomass Sustainability Order (BioNachV) - Germany	EU Renewable Energy Directive (RED)	Low Carbon Fuel Standard (LCFS) - California (USA)	Renewable Fuel Standard (RFS2) - USA	Renewable Transport Fuel Obligation (RTFO) - UK	Social Fuel Seal - Brazil	Testing Framework for Sustainable Biomass ("Cramer Criteria") - The Netherlands	VOLUNTARY STANDARDS / CERTIFICATION SCHEMES	Basel Criteria for Responsible Soy Production	Bonsucro (BSI)	Council on Sustainable Biomass Production (CSBP)	Forest Stewardship Council (FSC)	Global Bioenergy Partnership (GBEP)	Green Gold Label 2: Agriculture Source Criteria (GGLS2)	International Sustainability & Carbon Certification (ISCC)	Nordic Ecolabelling of Fuels	Roundtable on Responsible Soy (RTRS)	Roundtable on Sustainable Biofuels (RSB)	Roundtable on Sustainable Palm Oil (RSPO)	SEKAB Verified Sustainable Ethanol Initiative	Sustainable Biodiesel Alliance (SBA)	SCORECARDS	IDB Biofuels Sustainability Scorecard	WB/WWF Biofuels Environmental Sustainability Scorecard
1. ENVIRONMENTAL																										
1.1 Land-use changes (both direct and indirect)		√		√		√			√			√	√	√	√	√	√	√	√		√	√	√		√	√
1.2 Biodiversity and ecosystem services		√	√	√		√	√		√		√	√	√	√	√	√	√	√	√	√	√	√	√		√	√
1.3 Productive capacity of land		√	√	√		√	√	√	√		√	√	√	√	√	√	√		√	√	√	√	√		√	√
1.4 Crop management and agrochemical use		√	√				√		√		√	√	√	√	√	√	√		√	√	√		√		√	√
1.5 Water availability and quality		√	√	√			√		√		√	√	√	√	√	√	√		√	√	√	√	√		√	√
1.6 GHG emissions		√	√	√	√	√	√		√			√	√		√		√	√	√	√	√	√	√			√
1.7 Air quality		√	√	√	√	√	√		√		√	√			√		√	√	√	√	√		√		√	√
1.8 Waste management		√		√		√	√		√		√	√	√	√		√	√		√	√	√		√		√	√
1.9 Environmental sustainability (cross-cutting)		√		√				√	√		√	√	√	√		√	√		√	√	√	√	√		√	

Source: FAO (2011a), edited by Oeko-Institut

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[7] GEF funding considerations for biofuel projects are not subject to trade law. This is in contrast to **mandatory** sustainability schemes such as the EU RED which restrict their scope of criteria to those which are in compliance with WTO rules, e.g. focussing on the "global commons" for which UN Conventions exist, e.g., biodiversity and climate change (ICTSD 2009). Thus, GEF rules for the sustainability of biofuel projects can – similar to voluntary approaches - be stricter than mandatory certification schemes.

[8] There is no "real" beginning of this debate, as there were already critical discussions on liquid biofuels in the 1980's. Still, the OECD workshop on biomass and agriculture in 2003 (OECD (2004) can be seen as an "official" beginning.

[9] Relevant studies are e.g. Lewandowski/Faaij (2004; 2006), CIFOR (2010), Dam (2009, 2010), FAO (2011a), IFEU (2008), OEKO/IFEU (2010), OEKO/IFEU/CI (2010), SLU (2010A), UNEP (2009), UNEP/DC/MNRA (2007), Winrock (2010)

The compilations of the BEFSCI screening are in accordance with key findings of other studies[10]: which agree that the most relevant non-GHG environmental impacts of biofuel projects are

- air emissions (section 5.4)
- biodiversity impacts (section 0)
- soil (section 5.6)
- water (section 5.7)

In following up on a recent study which considered the specific resource restrictions of biomass as a relevant sustainability issue (OEKO 2011), **resource use efficiency** is added as a further category (section 5.3).

5.2 Methodological Approach

During the environmental sustainability analysis of biofuel projects, the type of biomass feedstock is evidentially of significance, while the downstream processes within the supply chain typically show lower relevance[11]. A key distinction is between biomass feedstock cultivation which can have high environmental risks at the field level and the collecting of organic residues and wastes which has very low risks[12].

Environmental risks vary strongly with the biomass origin and their downstream processing between different environmental areas of concern, such as biodiversity, soil, and water. For example, excessive collection of agricultural residues can decrease soil fertility and functioning, but agro-biodiversity and water availability may be less affected[13].

Due to these differences and in order to structure sustainability requirements accordingly, the following categories of biomass feedstock type and downstream processing were developed:

- Cultivating feedstocks and co-products, and their conversion
- Collection of primary residues, waste and secondary residues

As 67 of the 71 settings analysed in this study refer to dedicated biofuel feedstock cultivation and only four concern organic wastes as input for advanced biofuel production, the main focus of the analysis is on the **cultivation systems** and, where relevant, the respective downstream processing.

The methodology used to identify, define and quantify (where possible) the main environmental criteria regarding air, biodiversity, soil and water aims to suggest **thresholds** for a **traffic light system** applicable for the screening of GEF biofuel projects.

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[10] see IFEU (2008), OEKO/IFEU (2010), OEKO/IFEU/CI (2010), SLU (2010A), UNEP (2009), UNEP/DC/MNRA (2007), Winrock (2010)

[11] An exception of this “rule of thumb“ is possible water contamination from feedstock conversion.

[12] Handling and converting organic wastes may show higher environmental risks than agricultural and forestry residues if wastes are contaminated. This is excluded in the settings defined for this study.

[13] Similarly, non-routine operation of conversion plants bears risks for biodiversity (downstream ecosystems) and water (contamination of water bodies), but soils are very unlikely affect in this context. This study only concerns routine operations.

For **each** environmental category, this approach allows identifying project conditions with

- **high** risks which cannot be mitigated (**STOP**)
- **potential** risks which **could** be mitigated by specific project designs (**CHECK**)
- **no** relevant risks or designs **adequately mitigating** such risks (**GO**).

The traffic light approach was presented in an earlier phase of this study, and is compatible with the logic of the UN Energy Decision Support Tool for Bioenergy (2010).

Indirect effects of biofuel feedstock cultivation: In case that the cultivation of feedstocks and co-products displace former biomass production ("growing-out"), indirect effects may occur because the previous cultivation will most likely still be produced, but somewhere else - e.g. in the neighbourhood or, due to global markets, elsewhere in the world, and may cause direct effects at the new production site.

Due to this "non-local" nature of indirect effects they are not under the control of a specific project and, thus, are difficult to address. Indirect effects may especially impact biodiversity (Hennenberg et al. 2009) and to some extent soil. However, in contrast to GHG emissions, no methodological approach is currently available to assess indirect effects with regard to the non-GHG environmental categories.

5.3 Optional Category: Sustainable Resource Use

The biomass feedstocks used for biofuels are a renewable resource, but two specific features distinguish it from all other renewable energy sources:

- The conversion efficiency of solar energy into chemical energy in plants is only 1-2% which implies significantly more land needed to indirectly harvest solar energy through terrestrial biomass cultivation than through more concentrated hydro, direct solar or wind energy systems[14].
- Any changes in natural biomass production, e.g. replacing natural vegetation with cultivated plant varieties or improving crop yields, could have positive or negative impacts on ecosystem services and, through food/feed chains, human livelihoods.

Therefore, land is a **fundamental** issue closely related to biofuels and the sustainability of biofuels depends on the productivity of the land use[15]. As biofuels can also be derived from biogenic residues and wastes which stem from "earlier" biomass production or are co-products from agriculture or forestry, the efficiency of converting such secondary resources into biofuels is another aspect of sustainable resource use to be addressed.

5.3.1 Indicator: Land Use Efficiency

The efficiency of converting cultivated bioenergy feedstocks into biofuels should be considered in terms of useful biofuel energy per hectare of land used for feedstock production. Land is a finite and increasingly scarce resource around the world and non-biofuel

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[14] see Fritsche/Sims/Monti (2010), and Graebig/Bringezu/Fenner (2010)

[15] Possible effects of land use changes associated with the incremental production of bioenergy are discussed with regard to GHG emissions in Section 3.

uses such as food/feed, and fibre production as well as nature protection, ecosystem services, and recreation are competing with land use for biofuels. During the calculation of the land use efficiency, by- and co-products along the biofuel life cycles should be taken into account.

With regard to the settings under consideration in this study, the following tables give the results of such a calculation[16].

Table 5-1 Biofuels life-cycle land use efficiency for cassava-EtOH settings

				$GJ_{biofuel}$/ha	
Country	**setting**	**input level**	**cultivation**	**2010**	**2020**
MZ	42	low	smallholders	13	
MZ	43	intermediate	smallholders	19	
TZ	44	low	smallholders	19	
TZ	45	intermediate	smallholders	38	
TH	46	low	smallholders	64	
TH	47	intermediate	smallholders	70	
MZ	48	low	smallholders		19
MZ	49	intermediate	smallholders		38
MZ	50	high	plantation		48
TZ	51	low	smallholders		64
TZ	52	intermediate	smallholders		70
TZ	53	high	plantation		87
TH	54	low	smallholders		102
TH	55	intermediate	smallholders		108
TH	56	high	plantation		140

Source: own computation with GEMIS 4.7

Table 5-2 Biofuels life-cycle land use efficiency for Jatropha FAME settings

				$GJ_{biofuel}$/ha	
Country	**setting**	**input level**	**cultivation**	**2010**	**2020**
TZ	26	high	plantation	22	
TZ	27	intermediate	plantation	19	
TZ	28	low	smallholder	8	
TZ	29	intermediate	smallholder	14	
ML	30	low	smallholder	7	
ML	31	intermediate	smallholder	11	
IN	32	low	smallholder	12	
IN	33	intermediate	smallholder	18	
TZ	34	high	plantation		36
TZ	35	intermediate	plantation		31
TZ	36	low	smallholder		9
TZ	37	intermediate	smallholder		17
ML	38	low	smallholder		8
ML	39	intermediate	smallholder		13
IN	40	low	smallholder		14
IN	41	intermediate	smallholder		20

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[16] The calculation use GEMIS (www.gemis.de) which was calibrated for the settings of this study.

Source: own computation with GEMIS 4.7

The bandwidth of land use efficiency for cassava-based EtOH is about a factor of 10, with low and intermediate inputs in smallholder settings differing between 13 and 102, and 19 and 108 $GJ_{biofuel}$/ha, depending on the country.
For high input plantations, the range between countries is 87 to 140 $GJ_{biofuel}$/ha.

Reasons for the large bandwidths are differences in cultivation practices, soil conditions, and climatic conditions, especially water availability.

For Jatropha- and Palm-based FAME, the differences in land use efficiency are smaller, as shown in Table 5-3. For sugarcane-based EtOH, the range between settings is again more significant:

Table 5-3 Biofuels life-cycle land use efficiency for palmoil FAME settings in 2010

				$GJ_{biofuel}$/ha	
Country	**setting**	**input level**	**cultivation**	**2010**	**2020**
ID	19	intermediate	smallholder	113	
ID	20	high	plantation	120	
CO	21	intermediate	smallholder	133	
MY	22	high	plantation	140	
ID	23	high	plantation		150
MY	24	high	plantation		150

Source: own computation with GEMIS 4.7

Table 5-4 Biofuels life-cycle land use efficiency for sugarcane EtOH settings

				$GJ_{biofuel}$/ha	
Country	**setting**	**input level**	**harvest**	**2010**	**2020**
BR	8	intermediate	mechanised	131	
BR	9	high	manual	197	
MZ	11	intermediate	manual	147	
MZ	12	high	manual	193	
BR	13	intermediate	mechanised		138
BR	14	high	mechanised		207
MZ	16	intermediate	mechanised		131
MZ	17	high	mechanised		230

Source: own computation with GEMIS 4.7

Based on these results, the suggested traffic light thresholds are given in Table 5-5.

Table 5-5 Traffic Light Threshold for Biofuel Land Use Efficiency

setting	**GO**	**CHECK**	**STOP**	**unit**
low input, marginal land	>25	10-25	< 10	$GJ_{biofuel}$/ha
intermediate input, marginal land	>50	25-50	< 25	$GJ_{biofuel}$/ha
high input, good land	>100	50-100	< 50	$GJ_{biofuel}$/ha

Source: compilation by Oeko-Institut

5.3.2 Indicator: Secondary Resource Use Efficiency

For advanced biofuels stemming from the conversion of secondary resources such as residues and wastes, a minimum value for the resource use efficiency should be considered, expressed in terms of the heating value of the biofuel output divided by the heating value of the secondary resource input.

In calculating the resource efficiency, by- and co-products along the biofuel life cycles should be taken into account.

With regard to the settings under consideration in this study, Table 5-6 gives the results of such a calculation.

Table 5-6 Advanced EtOH biofuels life-cycle secondary resource use efficiency

Feedstock	own	setting	year	$GJ_{biofuel}/GJ_{residue}$
rice straw	CN	71	2020	89%
rice straw	CN	73	2030	89%
wheat straw	UA	72	2020	63%
wheat straw	UA	74	2030	63%

Source: own calculation with GEMIS 4.7

Based on these results, the suggested traffic light thresholds are given in Table 5-7.

Table 5-7 Traffic Light Threshold for Biofuel Land Use Efficiency

GO	CHECK	STOP	unit
>60	50-60	< 50	%

Source: compilation by Oeko-Institut

5.4 Category: Air emissions

Some biofuels can help improve air quality during the **use phase**, depending on feedstocks and combustion methods. A 20% blend of biodiesel, for example, can reduce particulate matter by 30% and SO_2 by nearly 100%. This is due to the significantly higher sulphur content of fossil transport fuels in developing countries – especially diesel[17].

However, during the feedstock production for biofuels, air pollution can be significant, e.g. due to burning of crop wastes. Furthermore, ammonia emissions from fertiliser application can increase local air pollution. Thus, the evaluation of airborne life-cycle emissions of non-GHG pollutants[18] from bioenergy should be limited to those of competing fossil fuels, and possibly perform better.

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[17] For a discussion of air emissions from biofuels used for cooking and electricity generation, see section 9.

[18] The GBEP Sustainability Task Force proposes to also include air toxics (e.g. heavy metals, volatile organic compounds) in this indicator, see GBEP (2011). Due to restrictions of available data and severe data uncertainties and variability, we refrain from doing so here.

5.4.1 Indicator: Emissions of SO_2 equivalents

Air pollutants causing acidification are SO_2, NOx and NH_3 and can occur along biofuel life-cycles. They should be limited to the life-cycle emissions of the fossil fuel comparator, expressed in terms of SO_2 equivalents. The emissions should be calculated in accordance to the life cycle emission methodology for GHG (see section 3), i.e. by- and co-products along the biofuel life cycles should be taken into account. With regard to the settings under consideration in this study, Table 5-8 gives the results of such a calculation[19].

Table 5-8 Biofuel life-cycle SO_2-eq emissions for all settings

fuel	setting	country	year	SO_2eq	SO_2	NO_x	NH_3
Soybean SVO	1	AR	2010	0.159	0.049	0.111	0.017
Soybean FAME	2	AR	2010	0.154	0.046	0.110	0.016
	3	AR	2010	0.113	0.036	0.096	0.006
	4	AR	2010	0.148	0.046	0.107	0.014
	5	AR	2020	0.149	0.047	0.125	0.008
	6	AR	2020	0.149	0.047	0.125	0.008
	7	AR	2020	0.197	0.062	0.141	0.019
Sugarcane EtOH	8	BR	2010	0.192	0.051	0.143	0.022
	9	BR	2010	0.238	0.048	0.214	0.022
	10	BR - 2G	2020	0.203	0.054	0.155	0.022
	11	MZ	2010	0.247	0.051	0.223	0.022
	12	MZ	2010	0.247	0.051	0.223	0.022
	13	BR	2020	0.202	0.051	0.146	0.026
	14	BR	2020	0.194	0.052	0.145	0.022
	15	BR - 2G	2030	0.213	0.054	0.158	0.026
	16	MZ	2020	0.197	0.053	0.147	0.022
	17	MZ	2020	0.194	0.052	0.145	0.022
Oil palm SVO	18	ID	2010	0.087	0.021	0.081	0.004
Oil palm FAME	19	ID	2010	0.093	0.027	0.082	0.004
	20	ID	2010	0.144	0.044	0.131	0.004
	21	CO	2010	0.092	0.026	0.083	0.004
	22	MY	2010	0.131	0.040	0.119	0.004
	23	ID	2020	0.123	0.039	0.110	0.003
	24	MY	2020	0.121	0.038	0.109	0.003
Jatropha SVO	25	TZ	2010	0.245	0.113	0.189	0.000
Jatropha FAME	26	TZ	2010	0.476	0.140	0.315	0.062
	27	TZ	2010	0.309	0.083	0.158	0.062
	28	TZ	2010	0.254	0.120	0.191	0.000
	29	TZ	2010	0.311	0.124	0.204	0.024
	30	ML	2010	0.259	0.123	0.194	0.000
	31	ML	2010	0.316	0.127	0.207	0.024
	32	IN	2010	0.258	0.127	0.187	0.000
	33	IN	2010	0.325	0.135	0.209	0.024
	34	TZ	2020	0.477	0.140	0.316	0.062

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[19] The calculation was based on the GEMIS model (version 4.7) which was calibrated for the settings of this study. The model and database is freely available at www.gemis.de

fuel	**setting**	**country**	**year**	**SO_2eq**	**SO_2**	**NO_x**	**NH_3**
	35	TZ	2020	0.305	0.081	0.154	0.062
	36	TZ	2020	0.255	0.120	0.192	0.000
	37	TZ	2020	0.312	0.124	0.205	0.024
	38	ML	2020	0.259	0.123	0.194	0.000
	39	ML	2020	0.316	0.127	0.207	0.024
	40	IN	2020	0.258	0.127	0.187	0.000
	41	IN	2020	0.325	0.135	0.209	0.024
Cassava EtOH1	42	MZ	2010	0.361	0.101	0.218	0.057
	43	MZ	2010	0.410	0.106	0.231	0.076
	44	TZ	2010	0.410	0.106	0.230	0.076
	45	TZ	2010	0.410	0.106	0.230	0.076
	46	TH	2010	0.349	0.105	0.237	0.042
	47	TH	2010	0.466	0.122	0.287	0.076
	48	MZ	2020	0.406	0.103	0.229	0.076
	49	MZ	2020	0.406	0.103	0.229	0.076
	50	MZ	2020	0.556	0.158	0.365	0.076
	51	TZ	2020	0.318	0.095	0.207	0.042
	52	TZ	2020	0.405	0.102	0.228	0.076
	53	TZ	2020	0.554	0.158	0.363	0.076
	54	TH	2020	0.345	0.104	0.236	0.041
	55	TH	2020	0.465	0.121	0.287	0.076
	56	TH	2020	0.550	0.154	0.363	0.076
SRC Eucalyptus EtOH2	57	MZ	2020	0.681	0.212	0.354	0.118
	58	BR	2020	0.673	0.209	0.347	0.118
	59	BR	2020	0.667	0.207	0.341	0.118
	60	MZ	2030	0.678	0.211	0.352	0.118
	61	BR	2030	0.675	0.210	0.349	0.118
	62	BR	2030	0.669	0.207	0.343	0.118
SRC Poplar BtL	63	UA	2020	2.243	0.033	0.369	1.038
	64	UA	2020	0.994	0.020	0.194	0.446
	65	UA	2030	2.243	0.033	0.369	1.038
	66	UA	2030	0.994	0.020	0.194	0.446
Switchgrass EtOH2	67	AR	2020	0.593	0.245	0.438	0.023
Switchgrass BtL	68	AR	2020	0.394	0.125	0.289	0.025
Switchgrass EtOH2	69	AR	2030	0.593	0.245	0.438	0.023
Switchgrass BtL	70	AR	2030	0.394	0.125	0.289	0.025
Rice straw EtOH2	71	CN	2020	0.521	0.203	0.318	0.051
Wheat straw EtOH2	72	UA	2020	0.448	0.193	0.291	0.028
Rice straw EtOH2	73	CN	2030	0.521	0.203	0.318	0.051
Wheat straw EtOH2	74	UA	2030	0.448	0.193	0.290	0.028
fossil fuel comparators (upstream only)							
diesel, EU		DE	2010	0.048	0.030	0.025	0.000
diesel, generic		**IN**	**2010**	**0.282**	**0.204**	**0.112**	**0.000**
diesel, syncrude		DE	2010	0.359	0.290	0.099	0.000
gasoline, EU		DE	2010	0.057	0.036	0.030	0.000
gasoline, generic		IN	2010	0.104	0.056	0.068	0.000

Based on these results, the thresholds to be used in the evaluation of SO_2 equivalent emissions from GEF biofuel projects are given in Table 5-9.

Table 5-9 Traffic Light Threshold for Biofuel Life-Cycle Air Emissions (SO_2 equivalents)

GO	CHECK	STOP	unit
< 100	100-250	> 250	% of generic fossil fuel comparator

Source: compilation by Oeko-Institut

5.4.2 Indictor: Emissions of PM_{10} and use of non-renewable primary energy

Besides air pollutants causing acidification, the emission of fine particles (PM_{10}) is a key health issue in many countries, and these emissions can also occur along the biofuel life-cycles. Similar to other air emissions, PM_{10} should be limited to the life-cycle emissions of the fossil fuel comparator. The emissions should be calculated in accordance to the life cycle emission methodology for GHG (see section 3), i.e. by- and co-products along the biofuel life cycles should be taken into account. Furthermore, the **non-renewable** primary energy use for biofuel feedstock production is an issue.

With regard to the settings under consideration in this study, Table 5-10 gives the results of the calculation for PM_{10}, and non-renewable primary energy use[20].

Table 5-10 Biofuel life-cycle PM_{10} emissions for all settings

Name	**no.**	**country**	**year**	**PM_{10} g/MJ$_{biofuel}$**	**non-renewable primary energy MJ/MJ$_{biofuel}$**
Soybean SVO	1	AR	2010	0.017	0.24
Soybean FAME	2	AR	2010	0.016	0.26
	3	AR	2010	0.010	0.23
	4	AR	2010	0.013	0.25
	5	AR	2020	0.014	0.28
	6	AR	2020	0.014	0.28
	7	AR	2020	0.017	0.31
Sugarcane EtOH	8	BR	2010	0.036	0.14
	9	BR	2010	0.167	0.13
	10	BR - 2G	2020	0.039	0.14
	11	MZ	2010	0.168	0.14
	12	MZ	2010	0.168	0.14
	13	BR	2020	0.036	0.14
	14	BR	2020	0.036	0.14
	15	BR - 2G	2030	0.039	0.14
	16	MZ	2020	0.036	0.14
	17	MZ	2020	0.036	0.14
Oil palm SVO	18	ID	2010	0.083	0.12
Oil palm FAME	19	ID	2010	0.080	0.13

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[20] see footnote 19

Name	no.	country	year	PM$_{10}$ g/MJ$_{biofuel}$	non-renewable primary energy MJ/MJ$_{biofuel}$
	20	ID	2010	0.083	0.20
	21	CO	2010	0.072	0.14
	22	MY	2010	0.073	0.19
	23	ID	2020	0.067	0.17
	24	MY	2020	0.066	0.17
Jatropha SVO	25	TZ	2010	0.065	0.34
Jatropha FAME	26	TZ	2010	0.058	0.58
	27	TZ	2010	0.044	0.39
	28	TZ	2010	0.064	0.43
	29	TZ	2010	0.065	0.46
	30	ML	2010	0.065	0.44
	31	ML	2010	0.066	0.46
	32	IN	2010	0.067	0.44
	33	IN	2010	0.071	0.47
	34	TZ	2020	0.058	0.58
	35	TZ	2020	0.043	0.39
	36	TZ	2020	0.064	0.44
	37	TZ	2020	0.065	0.46
	38	ML	2020	0.065	0.44
	39	ML	2020	0.066	0.46
	40	IN	2020	0.067	0.44
	41	IN	2020	0.071	0.47
Cassava EtOH1	42	MZ	2010	0.059	0.17
	43	MZ	2010	0.061	0.21
	44	TZ	2010	0.061	0.21
	45	TZ	2010	0.061	0.21
	46	TH	2010	0.060	0.16
	47	TH	2010	0.065	0.25
	48	MZ	2020	0.060	0.19
	49	MZ	2020	0.060	0.19
	50	MZ	2020	0.079	0.38
	51	TZ	2020	0.057	0.13
	52	TZ	2020	0.060	0.18
	53	TZ	2020	0.079	0.37
	54	TH	2020	0.059	0.15
	55	TH	2020	0.065	0.24
	56	TH	2020	0.078	0.35
SRC Eucalyptus EtOH2	57	MZ	2020	0.045	0.22
	58	BR	2020	0.045	0.21
	59	BR	2020	0.044	0.21
	60	MZ	2030	0.045	0.22
	61	BR	2030	0.045	0.22
	62	BR	2030	0.044	0.21
SRC Poplar BtL	63	UA	2020	0.011	0.11
	64	UA	2020	0.008	0.06
	65	UA	2030	0.011	0.11
	66	UA	2030	0.008	0.06

Name	no.	country	year	PM_{10} g/$MJ_{biofuel}$	non-renewable primary energy MJ/$MJ_{biofuel}$
Switchgrass EtOH2	67	AR	2020	0.049	0.31
Switchgrass BtL	68	AR	2020	0.030	0.33
Switchgrass EtOH2	69	AR	2030	0.049	0.31
Switchgrass BtL	70	AR	2030	0.030	0.33
Rice straw EtOH2	71	CN	2020	0.039	0.17
Wheat straw EtOH2	72	UA	2020	0.034	0.11
Rice straw EtOH2	73	CN	2030	0.039	0.17
Wheat straw EtOH2	74	UA	2030	0.034	0.11
fossil fuel comparators (upstream only)					
diesel, EU		DE	2010	0.004	1.14
diesel, generic		**IN**	**2010**	**0.043**	**1.30**
diesel, syncrude		DE	2010	0.015	1.60
gasoline, EU		DE	2010	0.004	1.20
gasoline, generic		**IN**	**2010**	**0.021**	**1.19**

Source: own calculation with GEMIS 4.7

Based on these results, the thresholds to be used in the evaluation of PM_{10} emissions from GEF biofuel projects are given in Table 5-11.

Table 5-11 Traffic Light Threshold for Biofuel Life-Cycle PM_{10} Emissions

GO	CHECK	STOP	unit
<100	100-250	> 250	% of generic fossil fuel comparator

Source: compilation by Oeko-Institut

For non-renewable primary energy use, the performance of biofuels is quite well, i.e. the non-renewable primary energy requirement for biofuel production is typically less than 50% of the energy content of the biofuels so that no specific threshold is needed.

5.5 Category: Biodiversity and Land Use

Due to the land use associated with biofuel feedstock cultivation, the protection of biodiversity is a core global benefit concern and as such a key issue for possible GEF biofuel projects. Effects can be positive or negative, strongly depending on location, agricultural and forestry practices, previous and indirect land-use, and the conversion systems used in the downstream chain (processing, distribution and consumption).

During the 9th meeting of the Conference of the Parties at the CBD, parties emphasised the challenge of promoting the positive impacts of biofuel production on biodiversity while minimizing negative effects. The international literature on protecting biodiversity as well as the indicators recently agreed on by the GBEP focus on the following two key issues for risk-mitigation strategies:

- Conservation of **areas of significant biodiversity** value, and
- **promotion** of agricultural and forestry **practices** with low negative impacts on biodiversity.

As the land use is quantitatively far more relevant for the cultivation stage of biofuel lifecycles, the risks related to routine operations of downstream processes (conversion, distribution) are usually much smaller.

Conservation of areas of significant biodiversity value

Habitat loss as a result of direct and indirect land-use changes is the major threat to biodiversity, with over 80% of globally threatened birds, mammals and amphibians affected wholly or in part by habitat loss. Areas of significant biodiversity value are qualified through

- the presence of threatened or endemic species, and
- rare and threatened ecosystems.

These areas are particularly concentrated in the Tropics. Prominent factors causing the decline of biodiversity are deforestation, conversion of wetlands, habitat fragmentation and isolation, land-use intensification and overexploitation, invasive species and adverse climate-change impacts.

Key for biodiversity conservation is to identify and conserve those areas harbouring relevant portions of biodiversity (i.e., areas of significant biodiversity value). Protected areas (PAs), areas with public or private conservation status, provide the cornerstones of national and regional conservation strategies and often represent the minimum threshold for areas of significant biodiversity value because of their legal recognition. One objective of a PA network is to represent the biodiversity of each region and to protect this biodiversity from threats. Yet, existing PAs throughout the world are still far from fulfilling either global biodiversity commitments or the needs of species and ecosystems. Thus, existing PAs alone do not guarantee a sufficient protection of biodiversity.

To avoid risks for biodiversity from biofuel production, an assessment is needed of areas of significant biodiversity value, whether protected or unprotected. Several processes were developed and tested to guide identification and mapping of such areas at a level of resolution practical for planning and management purposes. Prominent examples are the mapping of

- Key Biodiversity Areas (KBA),
- Important Bird Areas (IBA),
- Important Plant Areas (IPA),
- Alliance for Zero Extinction sites (AZE), and
- World Intact Forest Landscapes.

Existing mapping tools can assist land managers in meeting requirements to identify and protect biodiversity on a project level (e.g., High Conservation Value Network)[21].

Box: Biodiversity mapping for marginal and degraded land

In the discussion of indirect land-use change (ILUC) effects, a key option to avoid ILUC is to cultivate biofuel feedstocks on land not in competition with food, feed and fibre. There is considerable land worldwide not currently used for agriculture or forestry, but biodiversity may be an issue (besides social effects) if that land would be used for biofuel feedstocks.

However, there is still significant uncertainty about the actual biofuel potential from these lands and about costs and environmental and socio-economic impacts of such land into production. The extent of this land has not yet been quantified in detail, but is anticipated to be in the range of 0.5 to 2 billion ha worldwide, and only some parts of this land could potentially be suitable for sustainable and economically viable biofuel feedstock production. The biofuel potential from degraded land has been estimated for a range of 10-100 EJ (OEKO/IFEU 2010; OEKO/UNEP 2009; Schweers (2010, Wicke 2011).

Part of this land is actually too degraded to be converted to biomass cultivation, while in other cases it would simply be too expensive. In addition, making this land productive will not always be a sustainable action: this land may actually have biodiverse vegetation on it and could provide habitats for endangered species (Hennenberg et al. 2009).

On the other hand, some portion of these currently uncultivated lands as well as the local communities is likely to benefit from bioenergy cultivation, as it may improve the overall quality of the soil by, for example, increasing nutrient and carbon content, reducing erosion and retaining (rain) water, and thereby stimulate the local economy.

There is still quite some debate and significant uncertainty about the current extent of these types of land, on their sustainable biofuel potential and on the investments required to develop them accordingly.

As part of a recent global study (OEKO/IFEU 2010), country studies were carried out in Brazil, China and South Africa to identify degraded lands potentially suitable for biofuel feedstock cultivation. Local ground truthing was used at selected degraded land areas. From theses country studies the following key conclusions were drawn:

Combining top-down and bottom-up analysis to identify suitable degraded areas for bioenergy production is feasible and can make use of globally available data. If more appropriate national data is available, global and national data can be combined. However, the hit-rate of suitable areas depends on the quality of the top-down data. It also became very clear that the bottom-up analysis is evidentially needed. Information from top-down data is sometimes incorrect (e.g. degraded land and carbon stock) or incomplete (e.g. biodiversity) and important aspects are inadequately covered by available data (e.g. land use).

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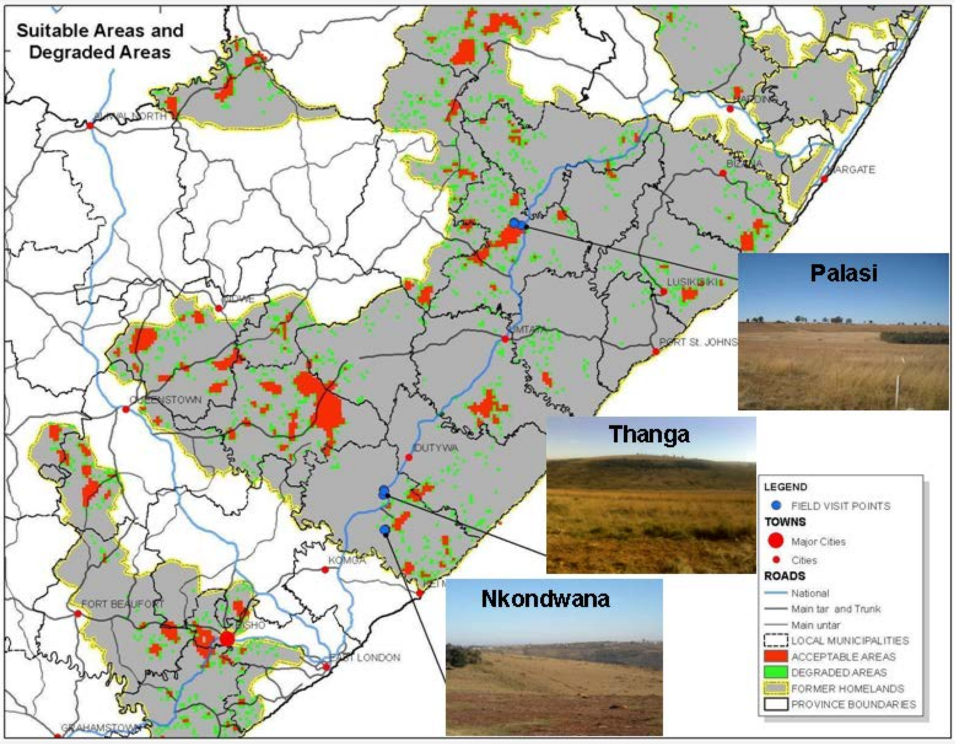
[21] Annex F gives an overview of such tools.

The amount of degraded land potentially available for sustainable biofuel feedstock cultivation appears to be 5-10 times lower than earlier estimated, but further ground truthing is needed to derive better data.

The country studies showed that there is certainly potential for producing biofuel feedstocks on unused degraded lands. If managed well, this production can achieve the promised positive impacts, viz. reduction of GHG emissions, rehabilitation of degraded areas and opportunities for rural development, including access to modern energy.

In the following figure, degraded land identified as being potentially suitable for biomass cultivation in the South African Eastern Cape is shown together with the location of test sites. These “acceptable areas” and “degraded areas” show no concerns regarding biodiversity and carbon stocks.



Cultivation is likely to impact the biodiversity value of the area if the cultivation of feedstocks and co-products and the collection of primary residues are located in an area of significant biodiversity value (e.g. primary forest).

Such risk exists especially for high input systems, but they cannot be excluded for intermediate and low input systems. Thus, proof is needed that the cultivation area is not located in an area of significant biodiversity value.

As a starting point, the proof should consider existing GIS data listed in the following table.

Table 5-12 Datasets to be considered for proofing the location of areas of significant biodiversity value

Data Source	Content / area types
IBAT	Information on national and international protected areas (PA), Key Biodiversity Areas (KBA), Important Bird Areas (IBA), Important Plant Areas (IPA) and Areas of Zero Extinction (AZE)
Global Forest Watch and World Intact Forests	Indicator for the location of primary forests
Global Distribution of Mangroves	Location of mangroves by UNEP-WCMC
Global Forest Resources Assessment	Location of primary forests (available in 2012)
Regional and national grassland datasets	Location of high-biodiverse grasslands (see Annex F

Source: compilation of Oeko-Institut

In addition to this data, national authorities responsible for nature protection should be consulted to request further datasets indicating areas of significant biodiversity value.

If no adequate mapping data is available, an on-site assessment is needed to verify that the cultivation area has no significant biodiversity value. For the assessment, well established methods may be applied or reference must be given to a mapping comparable activity considering the cultivation area.

Table 5-13 Biodiversity requirements for conventional biofuels feedstock cultivation

Environmental Component	applicable to	GO	CHECK	STOP
Conservation of areas of significant biodiversity value	all setting except those using wastes	Proven that cultivation land is **not** located in area of significant biodiversity value (GIS data + on-site assessment)	if located in such an area: management plan to ensure cultivation and harvest do not interfere with nature protection purposes.	if located in such an area and management plan is missing or not detailed enough to demonstrate non-interference
Promotion of agricultural practices with low negative impacts on biodiversity	**not** applicable for **low-input** settings	Proven that cultivation practices with low negative impacts on biodiversity are applied (description of management practices)	description of management practices not detailed enough	description of management practices missing

Source: compilation by Oeko-Institut

The collection of organic wastes and secondary biomass residues bears very low risks to impact biodiversity, as this biomass is not related to a specific production area. Thus, these biomass sources can be used without further requirements ("**GO**").

Advanced biofuel settings use lignocellulose which can come from dedicated energy crops such as perennial grasses or short-rotation coppices or from either agricultural (straw) or forestry (wood chips) residues. For **all** these settings, the requirements of Table 5-16 apply.

The **conversion** of feedstocks, residues and wastes may impact areas of significant biodiversity value mainly due to liquid effluents from the conversion plants. To assess related risk, information on the location of the conversion plants in relation to valuable areas (e.g. downstream) is required. In case that the effluents of a conversion plant may impact such an area, the management plan muss show that the amount of biological oxygen demand (BOD) and other water pollutants is low enough to avoid negative impacts on these valuable areas.

Further sufficient mitigation measures for non-routine operation must be elaborated in the management plan (see 5.7).

Table 5-14 Biodiversity requirements for biofuels feedstock conversion

Environmental Component	**applicable to**	**GO**	**CHECK**	**STOP**
Conservation of areas of significant biodiversity value	all settings	Proven that it is not located in areas of significant biodiversity value **and** that the areas in vicinity will not be negatively affected by effluents of conversion plant	if located in such an area: sufficient mitigation measures for non-routine operation; downstream impacts of pollutants below thresholds; management plan to avoid interfere with nature protection purposes.	if located in such an area and inadequate mitigation measures and management plan missing or not detailed enough to demonstrate non-interference
Promotion of agricultural practices with low negative impacts on biodiversity	**not** applicable for conversion			

Source: compilation by Oeko-Institut

5.6 Category: Soil

Apart from providing the base for biomass cultivation, soils also perform numerous environmental functions such as the storing, filtering and transformation of substances (nutrients, contaminants and organic carbon) and serve as habitats for species. All these functions are essential and need protection.

Since soil formation and regeneration processes are extremely slow whereas degradation can be very rapid, soil must be considered a non-renewable resource in human time scales.

Soil degradation defined as the loss of the soil's ecosystem functions and services has a major impact on other sustainability aspects, e.g., surface and groundwater quality, climate impacts due to losses in soil carbon stocks and food insecurity as a result of a decline in soil fertility. Land conservation and rehabilitation are an essential part of sustainable agricultural development. To prevent soil degradation from agricultural changes, improved agronomic practices will play a key role.

Various types of human activities and natural causes may result in direct soil degradation impacts, which need to be evaluated in the light of biofuel feedstock production.

Direct impacts from biofuel feedstock production can occur from improper soil and crop management, as well as from deforestation, removal of natural vegetation and overexploitation of vegetation, including negative impacts from conversion and overuse of natural habitats on ecosystem functions. The protection of natural habitats is not covered here, but a focus is put on the mitigation of soil degradation that emerges from soil and crop management while cultivating biofuel feedstock. Key issues leading to soil degradation that may relate to bioenergy feedstock production include the following:

- erosion,
- decline of soil organic carbon (SOC),
- compaction, and
- salinization.

Soil erosion represents the most prominent degradation factor in agriculture that leads to loss of fertile top-soil within in periods of years, whereas soil formation by natural processes can take hundreds to thousands of years. Any biofuel feedstock cultivation practice should reduce soil erosion to a level near or below the natural erosion rate.

The decline of **soil organic carbon** due to improper soil and crop management impacts the fertility of soils, but also the environment (e.g. nutrient leakage into water bodies, GHG emissions from SOC loss). Factors leading to SOC decline are climate, soil characteristics, natural vegetation type, topography, and land management. Good agricultural practices for biofuel feedstock production systems need to guarantee balanced SOC processes and should aim to increase SOC to improve soil fertility.

Soil compaction is mainly caused by agricultural machinery. The degree of compaction depends on the type of machine, applied loads and frequency of use, which are related to the production system and the type of biofuel feedstock. The impact of machinery also depends on soil types and especially water content, i.e. the timing of machinery use is an important factor. Thus, soil compaction may especially be a risk for high yield biofuel feedstock harvested under wet soil conditions.

Salinization is the process that leads to an excessive increase of water-soluble salts in the soil. Primary salinization involves salt accumulation through natural processes due to a high salt content of the parent material or in groundwater. Secondary salinization is caused by human interventions such as inappropriate irrigation practices, e.g. with salt-rich irrigation water and/or insufficient drainage. Soil salinization, e.g. due to inefficient irrigation systems, poor on-farm management practices and inappropriate drainage management, also reduces crop yields.

These four key issues are strongly interlinked. For example, erosion leads mostly to a loss of the top soil where most soil carbon is found. Compaction can increase the run-off of water increasing erosion and a loss of SOC can increase the risk of salinization due to an increase in soil evaporation. Similarly, individual soil protection measures can have positive effects on all factors – e.g. mulching reduces the erosion rate and increases SOC which in turn can increase the stability of soil texture and may reduce the risk of salinization at sensible sites. As a consequence, these key issues are not evaluated as single parameters but more in the sense of soil conservation measures. However, depending on the biomass origin and production stage, single relevant key issues are highlighted. Details on data for soil are given in Annex F.

Table 5-15 Requirements for biofuel cultivation regarding soil impacts

Environmental Component	**applicable to**	**GO**	**CHECK**	**STOP**
Productive Capacity of Soil	all settings except those using wastes; **not** applicable for conversion	Soil conservation measures are in place guaranteeing that SOC will not decline within the applied crop rotation scheme	No measurements for positive SOC balance. Proof needed that cultivation or residue extraction will not negatively affect SOC balance over crop-rotation period	Cultivation area on land with low SOC (e.g., < 1%; threshold depending on soil conditions)
Soil Erosion		Area is located in region with low erosion risks (e.g., flat slope) and low risk of salinization (e.g., climate and salt content of ground water	Site has risks of erosion, proof needed on suitable soil protection measures adapted to the site conditions	No soil conservation measures planned

Source: compilation by Oeko-Institut

5.7 Category: Water

The unsustainable management of water resources is a key global environmental challenge. Freshwater is already scarce in some regions of the world and existing freshwater resources are under heavy threat from overexploitation due to growing population and changing diets, pollution, and climate change.

Access to safe water resources is a limiting factor for sustainable development, and water resources have a key role in socio-economic development: Without better water management, the Millennium Development Goals for poverty, hunger and a sustainable environment cannot be met, since improvements in the water sector will directly improve access to safe drinking water, basic sanitation, food security and poverty reduction efforts.

Developments in the agricultural sector for food and non-food crops will have important implications for water usage and availability. In this context, water demand for bioenergy feedstock production could lead to increasing agricultural water use worldwide, since bioenergy crops optimised for rapid growth are likely to consume more water than natural flora and many food crops. Agricultural products already take 70% of the freshwater withdrawals from rivers and groundwater. In some countries especially in the Mediterranean and Sub-Saharan Africa, this could lead to further water stress in regions where water is already scarce and rainfall is highly variable, which might induce increased competition over water resources.

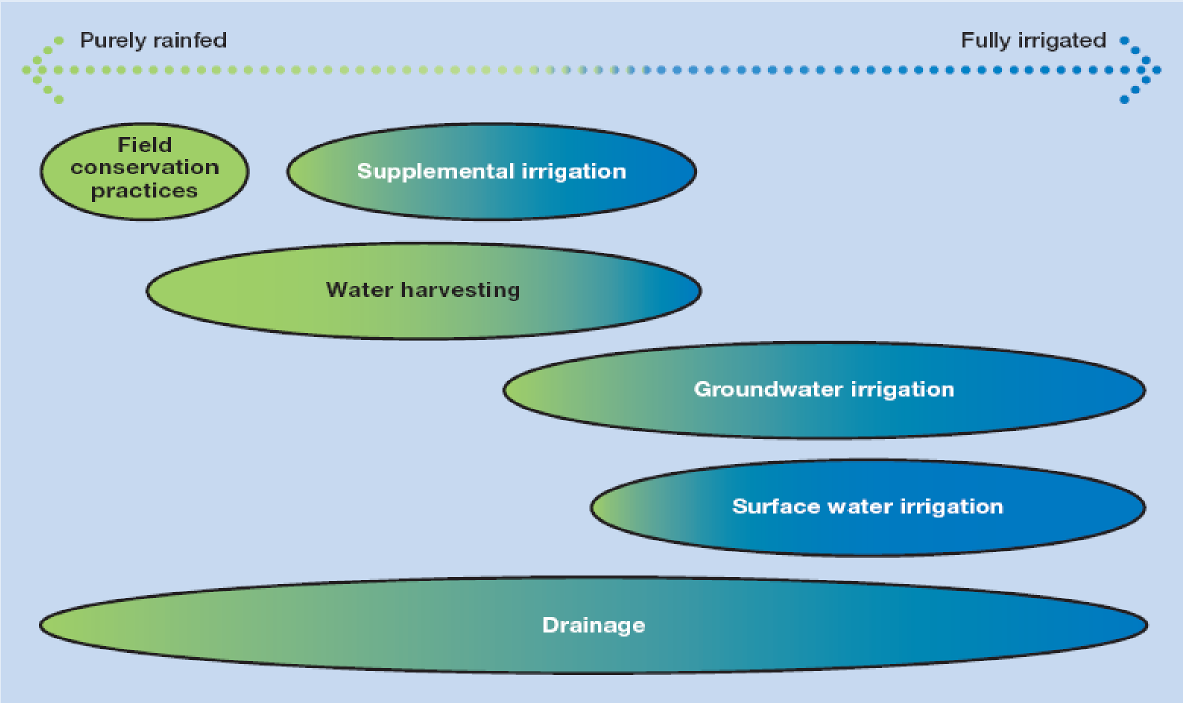
The International Water Management Institute predicts that without further improvements in water productivity and efficiency in the agricultural sector or major shifts in production patterns, the amount of water consumed by evapotranspiration in agriculture will increase by 70%–90% (IWMI 2007). The amount of water needed to produce fiber and biomass for energy as well as conversion of biomass to biofuels would add to this, so that competition between agricultural, industrial, domestic and environmental water requirements as well as pollution risks for water bodies could be intensified by biofuel feedstock production and processing. In this context, the mitigation of water scarcity and the protection of water resources against contamination have been identified as key issues that should be addressed on a project scale:

- Water scarcity risk at a catchment scale and downstream
- Water contamination risk from cultivation
- Water contamination risk from processing

Water scarcity at a catchment scale and downstream
Options for water use in agriculture stretch from rainfed agriculture with improved storage of water in the soil to supplemental irrigation from water storages and full irrigated cultivation (Figure 5-2). Today 55% of the gross value of our food is produced under rainfed conditions on nearly 72% of the world’s harvested cropland, while 28% use irrigation.

Water withdrawal leads to hydrological changes, i.e. reduction of runoff in rivers and lowering lakes and groundwater level, and, in extreme situations, rivers temporarily do not reach the sea (e.g. Colorado River, USA) or lakes dry up and get salty (e.g., Aral Sea).

Figure 5-2 Options for agricultural management with regard to water



Source: IWMI (2007)

Problems caused by irrigation are most often associated with physical water stress or scarcity in arid regions. Sufficient water supply for high-productive bioenergy crops in such regions is very likely to increase existing problems. In consequence, any additional irrigation needs to be embedded in sound water management plans and policies to optimise water use by all relevant sectors – from agriculture to industry and municipals. Furthermore, future demands, environmental constraints, feasibility of water storage as well as water needs in downstream neighbouring countries require consideration. This is also needed for regions with abundant water resources to avoid a development towards water stress or water scarcity.

In some cases it might be more beneficial for local people or agriculture industries to shift water use from existing cultivation systems or from industries – especially when producing commodities for international markets – to bioenergy cropping systems. However, as irrigation represents a high risk for negative impacts on water resources, it should not be the standard practice for cultivating biofuel feedstocks.

Instead, **rain-fed cultivation should be preferred**, as under most circumstances, these cropping systems rely on water from precipitation, and competition with other water demands is limited. The greatest potential for increases in yields are in rain-fed areas, especially through enhanced management of soil moisture and improving soil fertility management.

Thus, decision makers should give strong priority to rain-fed bioenergy cropping systems during the planning processes and to cultivation practices that improve drought resistance, especially in regions where water is already scarce.

Still the displacement of former natural vegetation (e.g., forests or woodlands) may have decreased evapotranspiration and soil absorption capacities and levels of groundwater table and water run-offs may have increased. In case that these additional water recourses are used today for purposes such as irrigation or industry, rain-fed bioenergy feedstock cultivation with high water use rates similar to former natural vegetation may result in water competition.

The mitigation of water scarcity should mainly be addressed at two levels, the catchment scale and downstream needs. The catchment scale (up to some square kilometers) is chosen because most water withdrawals and related negative effects occur at this scale. Furthermore, when water scarcity is avoided at catchment scale, risk of water scarcity at basin scale is relatively low. Larger downstream water demands from municipals and industries, and from environmental flow (e.g., peat lands, river flood plains) needs are also considered and may require water-use restrictions upstream. Details on available databases for regional water scarcity are given in Annex F.

The contamination from agricultural, and bioenergy feedstock, production is a major threat to water bodies, especially leakage of nitrogen from fertilisers (organic or inorganic) and pesticides to groundwater and surface waters.

The challenge is to reduce such leakage of nutrients and pesticides to a minimum without implying significant losses in yields. For this, existing Good Agricultural Practices (GAP) give useful guidance to producers and decision makers. On a global level, FAO provides an internet portal on GAP including a database covering studies, reports and information materials on various agricultural systems from different regions of the world.

Low-input cultivation systems can reduce contamination risks of water bodies. For example, organic farming practices generally avoid the application of pesticides and chemical fertiliser, leading to significantly lower contamination risks.

A further significant source for contamination of water bodies could come from inadequate irrigation with waste water. Besides contamination of soils with e.g., heavy metals, waste water pollutants can be transported to water bodies by direct run-off from irrigation or by washing-out during heavy rain events. Therefore, the use of waste-water irrigation systems should comply with, e.g., WHO guidelines on the safe use of waste water, excreta and grey water to reduce risks for human health and for the environment.

The plants for **processing** biomass to liquid biofuels, especially ethanol plants and oil mills, imply risks of significant organic discharges due to high on-site stocks of process water. Respective nutrient inputs from non-routine operation (leakage, accidental spills, tank rupture etc.) could contaminate adjacent water bodies. In case that biomass wastes are processed, additional contamination risk might occur due to other pollutants (e.g. heavy metals). To reduce those risks, the sitting of conversion plants should consider adequate distances from sensible wetlands and water protection areas, and licensing procedures should ensure necessary (technical and managerial) safeguards against non-routine discharges. During typical operation, waste water pollution can be reduced through:

- recirculation systems
- waste-water treatment (including potential biogas use from anaerobic treatment) to reduce routine organic loads below critical threshold of local water bodies
- re-use of certain waste-water treatment sludges as fertilizers

Table 5-16 summarises the environmental sustainability requirements for the water category.

Table 5-16 Requirements for biofuels regarding water impacts

Environmental Component	**applicable to**	GO	CHECK	STOP
Water scarcity risk, catchment and downstream	all settings except those using wastes	**no** irrigation, **or** irrigated cultivated land not in risk area **and** water management plan exists	no irrigation, **no** data on risk area; water management plan exists	irrigation, **no** data on risk areas
Water contamination		local/regional legal requirement met	local/regional legal requirement unclear	**no** local/regional legal requirement

Source: compilation by Oeko-Institut

6 Social impacts of liquid biofuel production

6.1 Social standards, criteria and indicators for biofuels

As mentioned already in section 5, sustainability aspects of biofuels were mainly discussed in the context of **voluntary** standards for biomass until the early 2000's. After that, the development of **mandatory** criteria for sustainable liquid biofuels mainly in the EU changed the focus. Besides GHG emissions and other environmental effects, the social impacts of biofuels were also addressed.

Outside of the EU, countries such as Argentina, Brazil and Mozambique as well as Thailand, among others, have or are in the process of establishing and implementing national legislation and subsequent or alternative voluntary schemes with criteria and standards for bioenergy development, especially regarding biofuels for transportation.

Internationally, the GBEP Sustainability Task Force recently agreed list of sustainability indicators for the national level also includes, after extensive debate, social impacts (GBEP 2011).

In parallel, the International Standardization Organization (ISO) is aiming to develop voluntary criteria for sustainable bioenergy, but results of this process cannot be expected before late 2012 or early 2013. However, among these standards there are **no binding rules** for biofuels concerning social impacts, only reporting obligations and the RED scheme in the EU.

The already mentioned FAO BEFSCI overview of regulatory and voluntary schemes for biofuels also addresses social issues (see next tables).

Figure 6-1 Social sustainability aspects/issues addressed under the initiatives reviewed by BEFSCI – Regulatory Framework

	Biofuels Life Cycle Assessment Ordinance (BLCAO) - Swiss	Biomass Sustainability Order (BioNachV)	RED	Low Carbon Fuel Standard LCFS (USA)	Renewable Fuel Standard - USA	Renewable Transport Fuel Obligation - UK	Social Fuel Seal (Brazil)	Testing Framework for Sustainable Biomass (NL)
Land tenure/access and displacement			x			x		x
Rural and social development						x	x	x
Employment, wages and labor conditions			x			x		x
Health/Safety				x		x		x
Energy security/access								x
Food availability				x				x
Food access				x				x
Food utilisation						x		x
Food stability							x	

Source: FAO (2011a), edited by Oeko-Institut

Figure 6-2 Social sustainability aspects/issues addressed under the initiatives reviewed by BEFSCI – Voluntary Standards/Certification Schemes

	Basel Criteria for Responsible Soy Production	**GBEP**	**International Sustainability and Carbon Certification**	**Nordic Ecolabelling of Fuels**	**RTS**	**RSB**	**RSPO**	**SEKAB**	**SBA**
Land tenure/access and displacement	x	x	x		x	x	x		
Rural and social development	x	x	x	x	x	x	x	x	x
Employment, wages and labor conditions	x	x	x	x	x	x	x	x	x
Health/Safety	x	x	x	x	x	x	x		x
Energy security/access	x	x	x		x	x	x		x
Food availability			x	x					x
Food access			x		x				
Food utilisation	x		x		x		x		
Food stability									

Source: FAO (2011a), edited by Oeko-Institut

Figure 6-3 Social sustainability aspects/issues addressed under the initiatives reviewed by BEFSCI – Scorecards

	IDB	**WB/WWF**
Land tenure/access and displacement	x	x
Rural and social development	x	
Employment, wages and labor conditions	x	x
Health/Safety	x	x
Energy security/access	x	
Food availability		x
Food access		x
Food utilisation	x	
Food stability		

Source: FAO (2011a), edited by Oeko-Institut

The BEFSCI screening is in accordance with key findings from other studies (see CIFOR (2010, 2011), IFEU (2008), SLU (2010a), UNEP (2009), Winrock (2010)): The most relevant social impacts of biofuel projects are:

- food security (section 6.2),
- land access and tenure (section 6.3),
- workforce issues, health and safety (section 6.4), and
- employment effects (section 6.5).

Additionally, gender issues must be considered.

6.2 Category: Food security impacts of biofuels

Food security as a key element of social sustainability is defined by FAO as follows (World Food Summit, Rome 1996):

"*Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life*".

Still, the reality for more than one billion people is food insecurity (FAO 2010k), and hunger is the unfortunate reality for several hundred million people, especially in Africa. In that context, potential food security impacts of biofuel development are not only important, but concern a basic human right (UNGA 2010).

The intense discussions on biofuel policy impacts of food prices and respective food security impacts of the last years[22] cannot be adequately presented here, but the recent literature agrees that such impacts are relevant, and need consideration[23].

Before presenting project-based requirements for GEF it should be noted, though, that adequate food supply to meet growing global demand faces severe challenges in the next decades[24].

However, global sustainable biomass potentials could still be significant enough without compromising the global food base[25]. Biofuel investments in developing countries, if managed adequately, could contribute to secure future food supply, and access[26]. The impact of biofuels on food security is not only a function of the crop grown, the land used, conversion technologies used, and how the bioenergy supply chain is integrated into agricultural, social and economic systems. It depends on the level of poverty, the potential positive effects on rural development and household income (FAO 2008).

Furthermore, food security impacts of biofuel development are different for net agro-commodity exporting or net food importing countries, and differ within countries between rural and urban populations, i.e. the vulnerability towards negative food security effects varies (FAO 2010e-j).

Thus, for the analysis of food security impacts of **biofuel** development, three principal effect levels need to be considered:

a) Direct effects on land competition and food production
b) indirect effects on food prices, including yield increases, oil price changes, and dietary changes
c) net direct and indirect effects on income from biofuel development, including oil price changes

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[22] See e.g. see e.g., Chakravorty (2011), FAO (2011b), IEED (2010a), IFPRI (2010), IIASA (2009), HLPE (2011), Kaye-Blake (2010), Mueller/Anderson/Wallington (2011), NBER (2011), Ratmann/Szklo/Schaeffer (2010), SLU (2010b), Tyner (2010), UNGA (2010)

[23] see FAO/OECD (2011), UNCTAD (2011); WB (2010a+b, 2011)

[24] see e.g. FAO (2009, 2010b+c), Grethe/Dembélé/Duman (2011), Nature (2010).

[25] see e.g. Beringer/Lucht/Schaphoff (2011), Cai/Zhang/Wang (2011), CE/OEKO (2010, IEA (2009), IFF (2009), IPCC (2011)

[26] see Best (2008), Faaij (2008, 2010), FAO (2008, 2011c); FAO/IFAD (2010), Fritsche (2011), MNP (2008), Raswant (2011)

In this study, the discussion of food security impacts addresses only the potential impacts from biofuel developments. It should be noted, though, that, given the comparatively small share of current global land use dedicated to biofuel feedstock production (Faaij 2010, IEA 2009, IPCC 2011), the majority of food security impacts for the majority of people depend on other "drivers" such as weather, dietary changes, oil price development, and food stock market dynamics, among others (Schneider 2011).

The suggested approach for food security impacts of GEF biofuel projects under evaluation is, therefore, structured into three levels (tiers).

6.2.1 Simplified Screening (Feedstock Level – Tier 1)

The most simple – and, given the complexity, potentially misleading – level is to consider which feedstock a biofuel project will use, and on which land the cultivation will occur.

Land to cultivate biomass feedstocks for biofuels is a limited resource that may already be in use, so that increased competition for this land from biofuel feedstock production might affect food security both directly in crowding out food and/or feed production (impact on food availability and access to food), and indirectly through food and feed price feedbacks which might negatively impact affordability of food.

To avoid such effects and to ensure that bioenergy feedstock production does not directly worsen food security in the country or region where bioenergy feedstock cultivation will occur, edible (staple) feedstocks should be considered as a **STOP** indicator. Another STOP-indicator would be if non-edible crops are cultivated on land in direct competition with food production.

Table 6-1 Requirements for biofuels regarding food security – feedstock level

Social Component	**applicable to**	**GO**	**CHECK**	**STOP**
food security – tier 1 (feedstock level)	all settings	**non-edible** feedstock grown on marginal land **not** in competition with food/feed, or intercropping or agroforestry or unused/underused marginal land	**non-edible** feedstock grown on marginal land for which competition is unclear	**edible** feedstock or **non-edible** feedstock grown on marginal land **in competition** with food/feed

Source: compilation by Oeko-Institut

6.2.2 Causal-Descriptive Analysis (Project/Country Level – Tier 2)

Clearly, the Tier 1 considerations give only a very rough first-order view on potential food security implications. The more elaborate analysis suggested for Tier 2 goes beyond the immediate project vicinity and considers the potential impact on the national "food basket".

This explores the impact of biofuel use and domestic feedstock production on the price and supply of a – country-specific - food basket which includes staple crops, i.e. the crops that constitute the dominant part of the diet in a country. The analysis should consider the methodologies suggested by GBEP (2011), and concerns

- the determination of the relevant food basket(s) and of its components;
- an initial indication of changes in the price and/or supply of the food basket(s) and/or of its components expected in the context of biofuel developments;
- a "causal descriptive assessment" of the role of biofuels in those expected changes, taking into account other factors such as oil price and trade developments

The causal descriptive assessment aims to provide an indication of the probability that a biofuel project in a country led to reduced supply and increased prices - of the relevant food basket(s), i.e. it represents a **risk**. This analysis could also lead to considering possible corrective actions/measures to be taken in order to mitigate the identified risks.

Table 6-2 Requirements for biofuels regarding food security – project/national level

Social Component	**applicable to**	**GO**	**CHECK**	**STOP**
food security – tier 2 (project/ country level)	all settings	as Tier 1, but **no** restriction to non-edible feedstocks if analysis indicates low price risk, **and** project improves agricultural infrastructure	as Tier 1, but analysis indicates some price risk, and unknown effect on agricultural infrastructure	as Tier 1, but analysis indicates significant price risk; **or** large project using existing infrastructure, risk of smallholder exclusion or restricted access

Source: compilation by Oeko-Institut

6.2.3 Detailed Analysis (Country/International Level – Tier 3)

The scope of the Tier 2 analysis is restricted to national effects, but food security impacts could also occur outside due to international trade. Furthermore, income effects need to be considered which might compensate (some of) the price effects.

Thus, the Tier 3 analysis will apply computable general equilibrium (CGE) or partial equilibrium (PE) modeling of the impacts of the biofuel production on the price and supply of the national food basket, and could also identify possible effects outside of the country ("leakage").

It should be noted that the data needs, analytical skills and access to modeling required for Tier 3 are significant and usually go well beyond capacities and resources available to project developers and the GEF staff reviewing projects.

In that regard, Tier 3 analyses should be seen in the context of country studies considering sustainable biofuel (and bioenergy) development options.

For the further development of the methodology, it is recommended to follow closely the GBEP indicator work on food security.

The GBEP proposes a four-step approach to measure food security in combination with welfare impacts of households. The approach is described in the following (GBEP 2011):

Table 6-3 Requirements for biofuels regarding food security – Tier 3 (country/international level)

Social Component	**applicable to**	**GO**	**CHECK**	**STOP**
food security – tier 3 (country/ international level)	all settings	as Tier 2, but analysis demonstrates positive income effects which offset low price risk, and that agricultural infrastructure improvements increase food availability and access; no "leakage" of food security risks to other countries	as Tier 2, but analysis indicates unclear income effects and some leakage risks	as Tier 2, but analysis indicates insufficient income effects and significant leakage risk

Source: compilation by Oeko-Institut

Step 1: Determination of relevant food basket and of its components

The first step should be the identification of the "representative" food basket. This basket, which reflects current food consumption patterns, may be determined, for instance, by ranking crops based on their contribution to the average per capita calorie in-take (either through direct consumption or via the foods that these crops are processed into), with the 'main staple crops' providing the highest share. Therefore, the most significant food items in people's diets will be included in the food basket. Large countries with significant differences in diets across regions and/or segments of the population should identify regional food baskets.

Generally, food consumption patterns are not subject to rapid variations, especially in developing countries, due to a number of factors (both economic and non-economic). If these changes occur, the composition of the food basket should be adjusted accordingly. In this case, it would be important to identify and analyse the main drivers of these changes, in order to assess the role (if any) played by biofuels.

In particular, one would need to monitor the effects of biofuel use and domestic production on the nutritional quality of the food basket over time. In order to do this, the "representative" food basket would need to be compared with a "nutritious" food basket, which fulfills basic nutritional guidelines while reflecting the range of foods typically eaten in a country. This "nutritious" food basket should contain a sufficient amount of food per day and contain specific food and nutrient groups that are typical of a country's food consumption patterns.

Step 2: Indication of changes in prices and/or supply of the food basket in the context of biofuels

It is necessary to get an initial indication of whether biofuel production and/or use has increased significantly in the country of its value added chain components. In particular, if levels of biofuel production and/or use have increased significantly, the following variables should be tracked:

- Supply of the food basket(s) and its components disaggregated by end-use
- "Real" (i.e. inflation adjusted) prices of the food basket(s) and its components.

Domestic supply of a given crop is the sum of domestic production and imports minus exports. If a crop is stockpiled, then domestic stocks should be considered and analysed. Once the domestic supply of a given crop has been determined, it should be possible, through market surveys and based on expert judgment, to estimate the share of this supply that is used for feed and fibre and the share that is available for food. This would provide a preliminary indication of the role (if any) played by biofuel production and use, should a decrease in the supply of food basket components for food be observed.

If biofuel production is distributed across the country in proportion to the production patterns of main staple crops, then a national focus should suffice. However, if biofuel is produced in regions close to urban centers or major transport hubs (as it is likely to be), then local price levels, and variations, should be considered as well. For instance, prices of the food basket(s) and its components might be distinguished between rural and urban areas. This split would implicitly capture: differences in the import-content of urban households' food baskets, and transaction costs associated with moving foods from rural to urban areas. With regard to rural areas, it would be especially important to focus on those where food production is displaced. Particular attention should be given to local price variations in food insecure and vulnerable areas. Mapping these areas and identifying the most vulnerable groups would be quite useful in this context, as it would help countries target the analysis of the domestic impacts of bioenergy.

If there is a significant increase in the price of the identified food basket(s) and/or of its components, it is important to also get an initial indication of the resulting welfare implications at both national and household levels. In order to do so and identify countries and population groups that are likely to benefit and those that are likely to be worse off, the net trading position of both the country as a whole and of poor households should be determined with respect to the food basket components that experienced a price increase. An increase in the price of a certain commodity will have positive welfare effects on countries that are net exporters and households that are net producers of that commodity. On the other hand, net importing countries and net consuming households will be negatively affected by this price increase. The estimate of household and national welfare impacts should be based on experts' opinion.

If in the context of increasing levels of biofuel production and/or use, the "initial indication" detects a decrease in the supply of the food basket(s) and/or of its components for food and/or an increase in the "real" prices of such basket(s) and/or components, a Causal descriptive assessment of the role of bioenergy (in the context of other relevant factors) in the observed supply decreases and/or price increases should be conducted. This assessment would also be useful in case of significant variations in the composition of the food basket(s), especially when the diversity of the latter is reduced.

CGE Modeling of the impacts of biofuel production

Food price is an intrinsically multivariate indicator that captures many of the factors that can determine whether a biofuel project is socially and economically sustainable. The variables to be considered will vary country-by-country. Using the data collected on the factors affecting the price of national food basket countries can perform straightforward economic analyses to estimate the relative effects of these many factors (including bioenergy production) on the price of a national food basket. The multivariate nature of the problem invites a computational approach.

CGE models are a standard tool widely used to analyse the impacts of economic changes and are suitable to study the impacts of a nascent biofuel sector. Advanced partial equilibrium forward-looking models can be employed to more thoroughly explore the impact of biofuels on the price of a national food basket. These models highlight challenges and opportunities that might materialise in some countries/commodity markets as they analyse key relationships and trends that could develop in agricultural markets.

Forward-looking models are based on historical inputs, but require sets of assumptions and parameter estimation. As such, it is essential that they be utilised with appropriate caveats and clear expression of the underlying assumptions. Forward-looking projections are an established component of modern agricultural economics. They are resource intensive and require considerable support.

Partial equilibrium models facilitate policy and market analysis of agricultural markets by allowing the modeller to observe the impact of various changes in policies and/or market conditions, such as the development of a bioenergy sector. The described approach is not immediately applicable for a potential GEF Tier 3 work. Published country analyses are available for Cambodia, Peru, Tanzania and Thailand,. FAO is currently working to expand these country studies.

Furthermore, FAO recommend that policy makers have to identify the risks of price changes for food staples within a country. One method is the measurement of the household welfare impact. The household welfare impact based on the fact that price changes can have positive or negative impacts on a country. Due to the influence on the household level the net household position (net consumer or net producer) has to be analysed. In a net consumer household the income from crops is less than total purchases. In a net producer household the income from the crop exceeds total purchases. The overall household impact is measured by the effect of the price change on a household's net welfare. The analysis it based on household income data and expenditure surveys and requires expertise in household data handling, household data analyses, market knowledge and price movements. Therefore, it can be expected that for GEF Tier 3 work, such data will become available. It is the responsibility of countries/governments to analyse the characteristics of their own country and then data can possibly be divided into regional differences.

Example Cambodia (FAO 2010e): The household level analysis for Cambodia showed that from a food security perspective, the price of rice should be monitored closely for particular segments of the population. Rice is the most important food crop in Cambodia and Cambodia is a net rice exporter. Especially lower rural income households benefit from price increases, while urban households do not profit. Furthermore households without landownership and woman households are vulnerable due to price increases. Therefore land tenure and gender issues influence the results.

Example Tanzania (FAO 2010g): Maize and cassava are the most important staple foods in Tanzania. Dependent on the income level other staple foods play a role, e.g. rice and wheat are more important for high-income consumers in urban areas. Cassava and sorghum are more important in low-income households in rural areas. Maize is an intermediate position and is a staple food in both urban and rural areas. Over the last few years there does not appear to be a close connection between world prices and domestic markets.

Example Thailand (FAO 2010h): It can be ascertained that factors like household sizes, rural or urban location, small or high income and landownership are very closely connected to the question of food security.

Further methodological issues are given for Thailand in Appendix G.

6.3 Category: Social Use of Land

Land use is not only a key issue for biodiversity and climate protection, but also has direct implications in the social realm. As biofuel development could be socially beneficial from a development point of view, possible negative impacts associated with land use should be minimised in the near-term and avoided in the longer-term.

The social use of land is primarily related to the theme of access to land, water and other natural resources. Land access is a consequence of land tenure. From a social sustainability perspective, this might be one of the major concerns associated with bioenergy development in some areas.

The social sustainability of bioenergy development is directly related to changes in land tenure and access. In many developing countries no land market has been established. The local poor population grow agro-products (food and feed mainly) even without having any kind of legal title or security of the land used. Similarly common permanent meadows and pasture lands are essential to communities' livelihoods that depend on breeding livestock and consuming livestock sub-products. When arable lands and lands under permanent crop, permanent meadows and pastures and forest areas are given in concession or leased to private bioenergy investors, the local poor population might lose their capabilities to ensure their life subsistence.

Land to be leased by the state or a domestic authority and/or sold through one-to-one negotiations to individual or corporate investors for biofuel development will require some kind of formal contract or titles from the government. As land tenure as well as local communities' livelihood conditions are influenced by land customary rights, land acquisition for biofuel development must acknowledge these conditions.

Foreign land acquisition is on the rise. The High Level Panel of Experts on Food Security and Nutrition (HLPE) formulated policy recommendations according to land tenure in the following three areas (HLPE 2011):

1. the respective roles of large-scale plantations and of small scale farming, including economic, social, gender and environmental impacts
2. reviewing the existing tools allowing the mapping of available land
3. comparative analysis of tools to align large scale investments with country food security strategies

The report reflects that many problems due to land investment could be dealt with through more effective enforcement of existing policy and legislation on national and local levels. Governments and investors get a better balance by differentiation in terms of sector, level and actors involved (HLPE 2011).

All measures, instruments or standards include that food security is paramount. For GEF biofuel projects, two aspects are key:

- Degree of legitimacy of the process related to the transfer (i.e. change in use or property rights) of land for new bioenergy production. This legitimacy can stem from either a legal process or a socially recognised domestic authority, including customary ones.
- Extent to which due process is followed in the determination of the new title. Following due process with regard to land transfers means that all procedural requirements are followed, including the assessment and recognition of the rights of current owners and users under the national legal framework and customary practices; and compensation measures according to the assessment results.

If the land used by investors is recognised as community/common land it is important to require adequate mechanisms of participation or consultation carried to be out by the investors with the local community (FAO 2011d).

If the land is recognised as land with secure rights by national legislation, it is important to provide evidence of the negotiation agreement for any contingent compensation between the investor and the land owner. Table 6-4 summarises the suggested requirements for GEF biofuel projects.

Table 6-4 Requirements for biofuel cultivation regarding land tenure

Social Component	**applicable to**	**GO**	**CHECK**	**STOP**
land rights	all settings except those using wastes	Titles, contracts or other formal registration of land tenure held by actors in a national or local registry	Titles, contracts or other formal registration of land tenure subject to negotiations	no titles, contracts or other formal registration of land tenure available
public land allocation		procedure follows due process	procedure unclear	no procedure
dispute settlement		effective access to fair adjudication, including court system or other dispute resolution processes	access to settlement unclear; adjudication system possibly unfair	no access
inclusion of landless people		no restriction on access	access unclear	no access, uncompensated displacement risk

Source: compilation by Oeko-Institut

6.4 Category: Labor Conditions and Healthy Livelihoods

Labor conditions and human health are closely related, as workers occupied in crop cultivation and harvesting procedures can be exposed to human health risks from pesticides, emissions from burning fields, and occupational accidents.

Therefore, the key labor standards and principles of the ILO Declaration on Fundamental Principles and Rights of Work must be met which will massively reduce possible negative impacts on the overall livelihoods of people living in bioenergy feedstock cultivation areas.

While biofuel production includes employment opportunities, labor conditions are key, especially with regard to wages, child labor, and safety. Jobs in the bioenergy sector should adhere to nationally recognised labor standards consistent with the ILO Declaration on Fundamental Principles and Rights at Work. This includes the following ILO standards:

- freedom of association and collective bargaining
- elimination of forced and compulsory labor and abolition of child labor
- elimination of discrimination in respect of employment and occupation
- health and safety
- working conditions and wages.

In Table 6-7 the suggested requirements for GEF biofuel projects are summarised.

Table 6-5 Requirements for biofuel projects regarding workforce

Social Component	**applicable to**	GO	CHECK	STOP
ILO standard on wages	all settings	**fully** implemented in country, **enforced & monitored** on project level	implemented in country, enforcement & monitoring on project level unclear	**not** implemented in country or **no** enforcement & monitoring on project level
ILO standards on labor				
ILO standards on discrimination				
ILO standards on health & safety				
scheme of small-scale farmers		smallholder or outgrower schemes	centralised outgrower scheme, use of non-local workforce	

Source: compilation by Oeko-Institut

6.5 Category: Gender

Gender discrimination has to be paid attention due to the importance of biofuel production for poverty reduction. Resilience to shocks, vulnerability and stress factors is a gender-specific challenge, where especially women have to be involved. Gender inequality is a social risk, which is as important as economic risks. Both economic and social risks are influenced by gender dynamics and have important impacts on men and women (FAO 2011e).

On the political level exist a lack of understanding and consideration of differentiated socio-economic impacts on male and female households. Due to biofuel production men and women face different risks according to access to land, employment, employment conditions and food security.

Example: In several Sub-Saharan African countries women are often allocated low quality lands by their husbands. Traditionally women cultivate crops for household consumption on marginal lands. In the case of energy crop cultivation could cause a partial or total displacement of women towards marginal lands, with negative impacts on women's ability to meet household obligations like food security. Unequal rights to land create unequal opportunities to profit from biofuel production (FAO 2010l).

Despite the fact that gender induced risks influence the sustainability of biofuel production, all biofuel strategies have to be gender sensitive. GEF should be ensure that women and female headed households have the same opportunity as men and men headed households to engage in and benefit from the sustainable production of biofuels. Especially for the growing number of households headed by women (42% in Africa), particularly in food insecure countries, the access of women to land must be ensured. This would improve the welfare of families and increase the agricultural productivity (FAO 2011l).

Table 6-6 Requirements for biofuel projects regarding gender equity

Social Component	**applicable to**	**GO**	**CHECK**	**STOP**
Land rights	all settings	men and women have the same opportunities and benefits	Women have higher risks and are vulnerable due to socio-economic shocks	Project **threatened** food security of households due to unequal land rights, emloyment conditions etc.
employment				
Employment conditions				
Food security				

Source: compilation by Oeko-Institut

6.6 Category: Employment effects of biofuels

ILO refers to the "employed" as comprising all persons above a specified age who during a specified brief period, either one week or one day, were in "paid employment" (at work or with a job but not at work), and/or "self-employment" (FAO 2008).

Employment within biomass fuel cycles consists of direct and indirect jobs:

- Direct employment results from the construction and operation of plants and fuel production. This refers to the total labour necessary for crop production, for the construction, operation and maintenance of the conversion plant and for transporting feedstocks and the respective products.
- Indirect employment means jobs generated within the economy as a result of expenditure related to said fuel cycles. Input-output analysis is used to derive indirect employment estimates from multiplier impacts.

In addition, induced employment, which stems from spending additional wages and profits from both biomass production and conversion activities, should be recognised. Furthermore employment creation is distinct and different for traditional and modern bioenergy systems. It differs in such areas as skilled and unskilled labour, direct and indirect labour, formal and informal sectors and direct and indirect impacts (FAO 2003). Nevertheless bioenergy can contribute to employment on local, regional and national levels. Numbers vary depending on the methodology.

Due to data limitations, input-output analyses can be a methodology but is difficult for developing countries. The quantity and quality of employment depends on the stage of the bioenergy system, the conversion process, the specific country setting and whether it's labour intensive or mechanised. There is a large difference between developing and developed countries. Several studies have been carried out that focus on employment effects of bioenergy production on specific regional areas. They use different calculation methods or focus not only on bioenergy but also on renewable energies themselves.

The question of jobs created has been a key part of the debate over the economic and environmental merits of biofuels. Job effects vary according to the feedstocks that are produced. Biofuels require about 5 times more (such as Jatropha and oil palm) workers per joule of energy content produced than fossil fuels. Oilseed crops in developing countries hold the most promise for job creation because of manual harvesting.

Job potentials of advanced biofuels are estimated e.g. for the US with 123,000 jobs by 2010 and up to 20,000 new jobs for every billion gallons of cellulosic fuels. This roughly translates into 0.25 jobs/$TJ_{biofuel}$. Job potentials in the bioethanol and sugarcane industry in Brazil say that 36,000 people are employed permanently and 326,000 people will be employed permanently (FAO 2003).

An FAO (2003) study estimated employment within the bioenergy sector for several countries: such as Brazil, India, Ivory Coast, Kenya and Cameroon, Pakistan, and the Philippines. The study concluded that

- employment required for the production of bioenergy is about 5 times higher than that of fossil fuels
- the level of direct jobs needed for the operation of bioelectricity systems is about four times higher than that required for the operation of fossil fuel power plants
- bioelectricity production requires far more direct jobs (15 times) than the production of nuclear electricity

The ratio between direct and indirect employment generated by a general biofuel system is 79 persons (direct) to 34 persons (indirect). The direct employment resulting from the biofuel system is as follows (30 MWel): 14 persons (construction), 42 persons (fuel production), 4 (logistics), 19 (conversion). This is equivalent to 0.37 man-years per GWh, or 0.29 jobs/TJ_{input} (FAO 2003).

Some general comparisons and conclusions from employment in the bioenergy sector are:

- larger projects tended to have less specific impacts on employment and income as opposed to small projects, mostly due to economies of scale
- multiplier effects appear to be slightly lower than what is found in the general literature and may be caused by the methodology used
- detailed calculations were extremely difficult to perform due to the variable quality of data and the complexities of the variables to be considered (FAO 2003).

Further methodological issues are given for Thailand in Appendix G.

6.6.1 Indicator: Direct Employment Effects

The determination of direct employment along the value chain can be derived from industrial surveys. Direct employment is generated in cultivation, harvesting and processing. A detailed analysis and description of the employment situation in Thailand can be seen in Appendix G. Table 6-7 shows direct employment effects for the settings.

Table 6-7 Direct employment effects of biofuel production

			Direct employment	
Feedstock	**Country**	**Setting/year**	**jobs/ha/yr**	**jobs/TJ**
Palm	ID	> 1 year/2010	0.38	3.4
Palm	MY	> 1 year/2010	0.30	2.4
Sugarcane	BR	2010	0.27	1.6
Sugarcane	MZ	11/2010	0.14	0.9
Sugarcane	MZ	12/ 2010	0.23	1.2
Sugarcane	MZ	16/2020	0.23	1.5
Sugarcane	MZ	17/2020	0.23	1.1
Jatropha	IN, low input	average of 0 and 23 plantation years/2010	0.11	9.7
Jatropha	IN, intermed.	average of 0 and 23 plantation years/2010	0.28	16.5
Cassava	MZ, low input	42/2010	0.32	24.9
Cassava	MZ, intermed.	43/2010	0.37	19.3
Cassava	TZ	44/2010	0.24	9.3
Cassava	TZ	45/2010	0.28	7.2
Cassava	TH	46/2010	0.11	1.8
Cassava	TH	47/2010	0.11	1.6

Source: Oeko-Institut calculations based on setting results

The results for palm and sugarcane compare well with other studies, while for Jatropha in India and cassava in Mozambique and Tanzania; the figures indicate quite immature situations. The cassava data for Thailand compare well with sugarcane data.

6.6.2 Indicator: Indirect Employment Effects

The calculation of indirect employment effects is based on input-output analysis. In the case of Thailand, a hybrid approach was tested (see Appendix G). Based on this approach it is possible to calculate indirect employment effects for each country. The OECD statistics provide, for some countries, input-output tables for further calculations (e.g. Argentina, Brazil, China, India, Indonesia, South Africa, Thailand, Vietnam).

Country-specific databases have to be checked when using the hybrid approach. Especially within developing countries an analysis is restricted due to lack of data. By using a combination of an analytical approach for the micro level and the input output model for the macro level, the investigation of employment effects could be assessed. The analytical approach uses the production process analysis. A detailed analysis description in the case of Thailand can be seen in Appendix G.

7 Next generation of liquid biofuel production

More than 99% of all currently produced biofuels are classified as “first generation” (i.e. fuels produced primarily from cereals, grains, sugar crops and oil seeds) (IEA, 2008b). “Second generation” or “next generation” biofuels, on the other hand, are produced from lignocellulosic feedstocks such as agricultural and forest residues, as well as purpose-grown energy crops such as vegetative grasses and short rotation forests (SRF). These feedstocks largely consist of cellulose, hemicellulose and lignin. Conversion to bioethanol fuel is via hydrolysis of the cellulose and hemicellulose to sugar, after which fermentation of sugar is performed. These feedstocks can also be converted to fuel via gasification or pyrolysis to produce synthetic diesel, bio-oil and other fuels. To be competitive with fossil fuels, there is a need to overcome several technical challenges – which is the focus of current R&D.

Generally, the advantage of next generation biofuels (over 1st generation biofuels) is their ability to utilise many different types of lignocellulosic materials as feedstock and lower land use impacts. However, the environmental impact of lignocellulosic biofuels depends on the conversion route, the feedstock and site-specific conditions. Moreover, unlike the mature 1st generation biofuels, next generation biofuel technologies are still under development (pilot and demonstration stages), and commercialisation is anticipated in the next decade.

This section analyses the short term and long term technical and economic performance as well as the potential development of next generation biofuel industries in five developing countries under some defined settings as shown in Table 7-1.

Table 7-1 Settings for “Component 6” next generation biofuels

Setting No.	Country	Feestocks	Time-frame	Land quality[27]	Biofuel technology
67/68 69/70	Argentina	Switchgrass	2020 2030	Less suitable	BtL/ Next EtOH
58/59 61/62	Brazil	Eucalyptus	2020 2030	Less suitable/ Suitable	Next EtOH
10		Sugarcane bagasse	2020 2030	-	Next EtOH
71 73	China	Rice straw	2020 2030	-	Next EtOH
57 60	Mozambique	Eucalyptus	2020 2030	Less suitable	Next EtOH
63/64 65/66	Ukraine	Poplar	2020 2030	Less suitable/ Suitable	BtL
72 74		Wheat straw	2020 2030	-	Next EtOH

Lignocellulosic feedstocks selected for this analysis include: perennial crops, such as eucalyptus species in Brazil and Mozambique; poplar in Ukraine; switchgrass in Argentina and agricultural residues, such as rice and wheat straw in China and Ukraine.

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[27] Suitable land is equivalent to good agricultural land while less suitable land refers to marginal or degraded land

7.1 Feedstock production and supply

The performance of the selected cropping and residue systems for each country is provided in this section. Development of energy crop plantations involves four major phases: site preparation, planting, maintenance and harvesting. Specific activities at each stage depend on the site quality which influences the degree of site preparation that is necessary; choice of species, planting density, and rotations; required cultural management and soil amendments (fertilisation, weed control, animal control, and pest management); as well as transport and logistics.

At each stage in the production of biomass, cost factors such as labour, machinery investment, fuel costs as well as chemical and energy inputs have to be accounted for. The technical specification of equipment such as tractors is also incorporated into the calculations. An important aspect in energy plantations, especially short rotation woody crops such as eucalyptus, is the ability to coppice over successive rotations periods until it is finally stumped out and replanted.

It is assumed that all feedstock production systems are carried out under well managed agricultural systems – meaning the proper application of appropriate amounts of fertiliser (to replenish plant nutrient extraction and support high biomass growth), pesticide and herbicides (to ensure protection of energy crops against diseases, pests and weeds). It also assumes adequate silvicultural management, but does not take into account irrigation. Planting is assumed to be done during the rainy season to take advantage of rain-fed growth. However, some water may be applied to young seedlings, during the first three weeks of growth, should they encounter moisture stress.

Appendix 1 provides details of the general approach used to estimate production costs of energy crops – from land preparation until biomass is harvested and forwarded to the roadside ready for transportation to the processing plant. Key assumptions for each crop relate to:

- Plant spacing and yields
- Fertiliser, herbicide, pesticide application
- Mechanised/manual operations
- Planted seedlings/cuttings
- Plantation lifetime and coppice cycle
- Harvesting and forwarding technology

7.1.1 Eucalyptus production costs in Brazil and Mozambique

Eucalyptus is considered as the energy crop for Mozambique and Brazil. In Mozambique, it is assumed that seedlings are planted manually at a spacing of 3x3-m in a semi-arid region. Extensive manual weeding and chemical pesticide application are required during the first 3 years, before the eucalyptus trees reach full canopy cover. Harvesting is carried out every 8 years over 24 years before the stand is re-established. It is assumed that in Mozambique, harvesting is done using chainsaws. Forwarding to the roadside is done using a skidder.

Table 7-2 Cost elements for eucalyptus production in Mozambique

Cost Item	Description
Land	Costs of land vary between 20 $/ha/yr (2009) for agricultural land uses depending on locations (CPI, 2009).
Labour	Minimum wage is 0.3 $/hr in the agricultural sector
Diesel	36 litres per ha at cost of 1.02 $/litre
Seeds	1,333 plants per ha at cost of 0.20 $/plant
Herbicides	3 litres/ha at costs of 2.23 $/litre
Pesticide	0,1 kg/ha of fungicides and 0.6 litres/ha of pesticides at average cost of 9.55 $/litre
NPK	60 kg/ha of N fertiliser, 23 kg/ha of P fertiliser and 48 kg/ha of K fertiliser at average cost of 0.77 $/kg

Chemonics and IFCD (2007); Laclau et al (2003); van der Hilst et al. (2011)

Eucalyptus productivity in Mozambique is estimated to vary from 4.5 to 35 tdm/ha (Batidzirai etal 2006; van Eijck et al. (2011); Laclau et al 2003; Ugalde etal 2001; Savcor, 2006). For a given species, the biomass yield is a function of the management applied as well as climate and soil conditions. According to Van Hilst (forthcoming), the mean annual increase (MAI) is estimated to be 1.5% per annum. The projected maximum attainable yield in 2030 is still well below the estimated maximum attainable yield for Mozambique.

Table 7-3 Eucalyptus production performance in Mozambique on marginal land

	2020	2030
Yield (tdm ha^{-1} yr^{-1})	7	10
Production costs (USD/tdm)	75	62

Source: Van de Hilst (forthcoming)

The estimated biomass feedstock production from eucalyptus in Mozambique is 3.96$/GJ in 2020 and 3.27$/GJ in 2030 at the farm gate. This is equivalent to a production cost of 37.6 $/ton,wet (2020) and 31.1$/ton,wet (2030) assuming a moisture content of eucalyptus at harvest of 50%. Fertilisation contributes the most to the total production costs at 30%, while land clearing (18%) and stand establishment (17%) are also significant. Harvesting and extraction contributes only 13% to the total costs, because in this case manual harvesting is assumed.

Future changes in feedstock production cost -- Long term pressure on land is expected under a business as usual scenario and thus the cost for land is likely to increase, pushing up biomass production costs. Similarly, as Mozambique's economy grows, it is expected that labour wages will increase. When labour costs increase, efficient machinery will become more attractive. Energy input costs are also expected to grow, but with improving infrastructure, diesel distribution costs could go down. When diesel prices go up, full mechanisation will be less attractive. In the future, improved seeds and breeding as well as technological learning about seed technology are expected to result in higher biomass yields which will result in decreasing production costs. Globally, fertiliser prices will increase due to higher fossil fuel prices and to P fertiliser scarcity. Locally, prices could go down when there is critical mass for the establishment of domestic production. All these factors are expected to have varied impacts on the biomass production costs, but increase in yields is likely to have a much bigger impact on overall costs – and thus future costs are expected to decrease.

Eucalyptus production costs in Brazil -- For Brazil, eucalyptus production costs are estimated using a set of assumptions shown in Appendix 2. For the different soil qualities, the required amount of fertiliser and corresponding biomass yields are shown in Table 7-4 and Table 7-5 respectively.

Table 7-4 Fertiliser requirements for eucalyptus production in Brazil by land suitability

Required fertiliser amounts (kg/ha)	**Suitable**	**Less suitable**
NH_4	83	60
P_2O_5	32	23
K_2O	67	48
CaO	97	70
Total	279	201

The highest reported yield level was 85 m^3 ha^{-1} yr^{-1} with harvesting at the age of 6 years (van de Bost, 2010). In this most optimistic case (using current technology), the cost of the feedstock at the plant gate would be reduced to 1.95 $/GJ, or represent 5 $/GJ of ethanol at an energy efficiency of 39%. Current Brazilian average yields of eucalyptus are around 42 m^3 ha^{-1} yr^{-1}, from very marginal soils to the very suitable soils. Projections for the Brazilian potential average vary, but are generally estimated to be around 50 m^3 ha^{-1} yr^{-1} (ABRAF, 2009; SBS, 2009; IPEF, 2008).

Table 7-5 Eucalyptus production performance in Brazil on different suitable land quality

	2020		**2030**	
Land quality →	Suitable	Less suitable	Suitable	Less suitable
Yield (tdm ha^{-1} yr^{-1})	22	10	24	12
Production costs (USD/tdm)	40	56	35	47

Source: Smeets et al 2009

The various cost items for eucalyptus production in Brazil are listed in Table 7-6 below and further details are given in Appendix 2. Land rent differ depending on soil quality and range from 49-146 $/ha. Harvesting is assumed to be mechanised using Claas harvesters which cost about 322,000$.

In Brazil, the estimated biomass feedstock production from eucalyptus is given in Table 7-6 and the cost by component is shown in Figure 7-2. For marginal soils, the cost of biomass production is estimated to be 3.3$/GJ in 2020 and 2.9$/GJ in 2030 at the farm gate. This is equivalent to per hectare production costs of 4,684 $ in 2020 and 3,887 $ in 2030. Similarly, for the more suitable land quality, eucalyptus production is estimated to be about 2.44$/GJ in 2020, while decreasing to 2.22$/GJ in 2030. In per hectare terms, production costs are 7,834 $ in 2020 and 6,500 $ in 2030. Due to the use of mechanised harvesting, the contribution of harvesting to overall costs is very high in Brazil (at 27% for marginal soils and 29% for good quality land). Fertilisation also contributes significantly at

21% (for marginal land) and 24% (for good quality soils). Land costs are also high contributing between 10-14% depending on land quality. As shown in Figure 7-2, other important eucalyptus production cost elements include stand establishment (9-15%), extraction (10-13%) and weeding (5-8%).

Table 7-6 Value of cost items for eucalyptus production in Brazil

Cost Item	Value	Unit	Source
Wages-Field workers	2.87-7.74	$/h	calculated
Tractor	13.13	$/h	WSRG, 2004
Fencing -material and machinery	439.17	$/ha	Faundez, 2003
Plant costs	0.07	$/plant	various, own calculations
Herbicides	126	$/ha	Faundez, 2003
Fertilisers	68.6-207.2	$/ha	various, own calculations
Pesticides Chemicals	8.4	$/ha	Faundez, 2003
Fungicides Chemicals	4.2	$/ha	Faundez, 2003
Land rent	49-145.6	$/ha	World Bank
Harvesters - Claas harvester	322	k$/machine	Gillard
Harvesters - tractor & trailer	135.8	k$/machine	Gillard

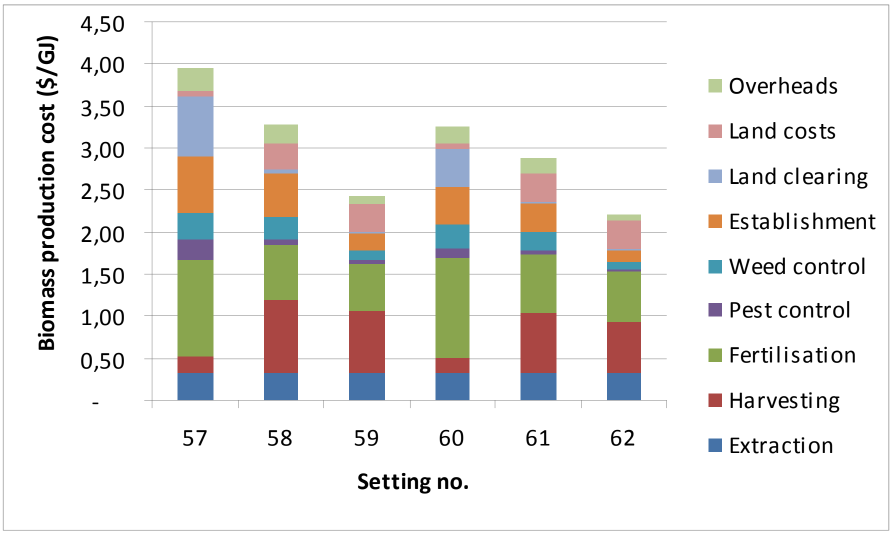

Figure 7-1 Eucalyptus production costs in Mozambique and Brazil by component

In the long term (2030), the contribution of the various cost elements to the production costs vary slightly compared to the short term (2020). As expected, land costs increased marginally from 10% to 11% for marginal land, and from 14 to 15% for the suitable areas. Fertilisation costs increase and their contribution correspondingly increase from 21 to 24% for marginal areas, while for good quality land they increase from 24 to 27% of overall costs.

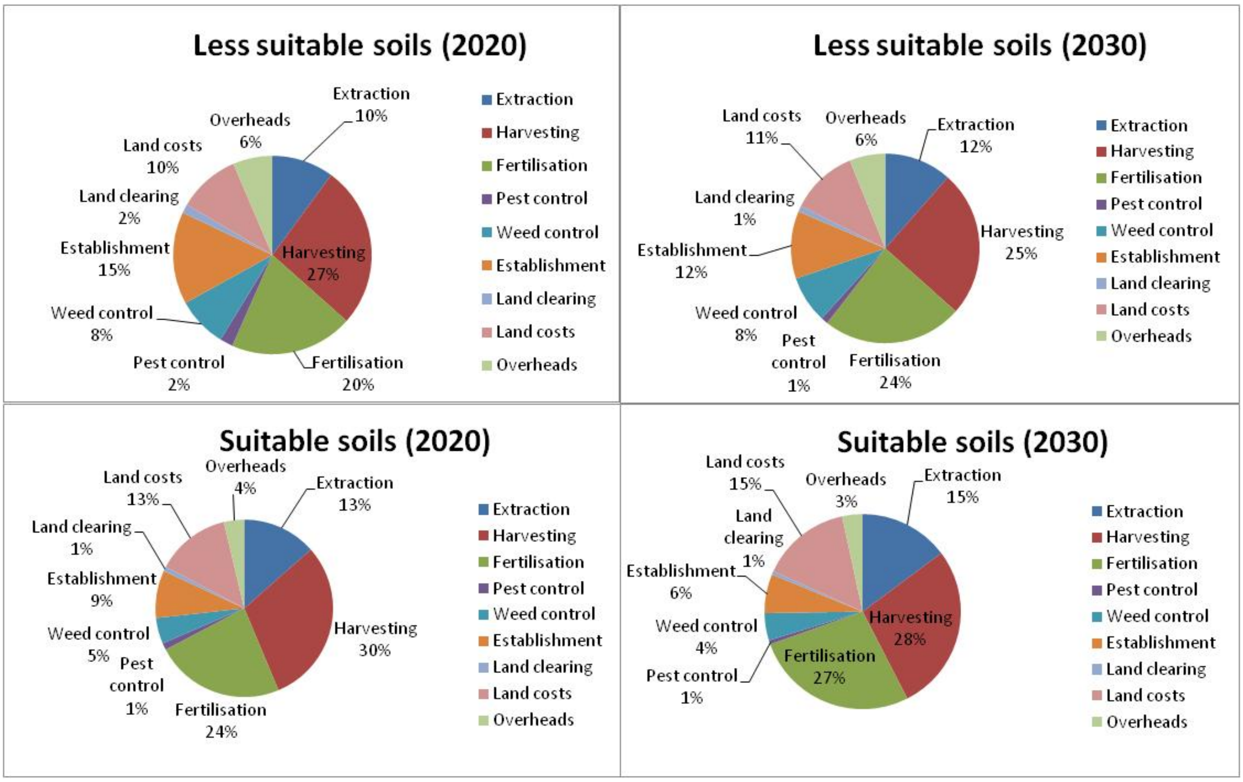

Figure 7-2 Breakdown of eucalyptus production costs in Brazil (2020 – 2030)

7.1.2 Poplar production costs in Ukraine

Currently there is no poplar production in Ukraine except for a few test plantations. Studies indicate that the optimal planting density of seedlings in Ukraine would be 4,000-6,000 plants/ha (Fuchylo et al 2009). In this case, a planting density of 5,300 is assumed with 2 year rotation over 10 years. Poplar productivity is estimated to vary from 6 to 14 tdm $ha^{-1}yr^{-1}$ in marginal areas and suitable soils respectively. Table 7-7 shows the corresponding amounts of fertiliser input requirements by land suitability. Wages vary from 0.63-2.1 $/hr, while land rent is about 38 $/ha. Fuel costs range from 960 $/ton for diesel to 1080 $/ton for petrol. Current inflation and discount rates are 10.7% and 17% respectively.

Table 7-7 Poplar SRC yields and fertiliser inputs in Ukraine by land suitability classes

	Suitable	**Marginally suitable**
Yield (tdm $ha^{-1}yr^{-1}$)	14	6
NH4 input (kg/ha)	71	34
P2O5 input (kg/ha)	20	10
K2O input (kg/ha)	52	24
Manure (organic fertiliser equivalent*) (tons/ha)	20	11

** According to SEC Biomass (2011) manure is used instead of chemical fertilisers and estimates are based on a range of 11-40 tons per hectare. Equivalent chemical fertilisers are estimated by Smeets and Faaij (2009).*

Poplar production costs are estimated to be 3.5$/GJ on marginal soils in the short term, decreasing to about 3$/GJ in 2030. Similarly, on good quality land, poplar can be produced at a cost of 2.26$/GJ in 2020 and at 2.02$/GJ in 2030. Production costs per hectare (without considering the productivity are higher for suitable soils (4,670 $/ha in 2020 and 3,875 $/ha in 2030) compared to 3,528 $/ha in 2020 and 2,927 $/ha in 2030 (for less suitable soils). As shown in Figure 7-3, harvesting represents the largest cost component for both marginal (35-38%) and good soils (29-31%), with the latter representing the long term. Fertilisation is also an important cost component contributing up to 29% of poplar production cost. Another important cost element is stand establishment, ranging from 11-19%.

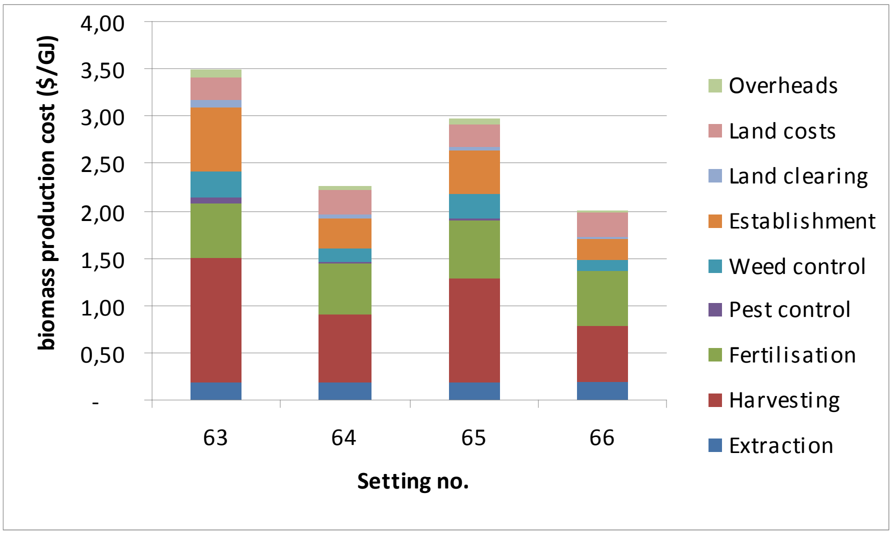

Figure 7-3 Poplar production costs in Ukraine by component

7.1.3 Switchgrass production costs in Argentina

Switchgrass is already being produced in Argentina and is mainly used for forage production for livestock (INDEC, 2006). It is assumed that the switchgrass plantation is established solely on marginal soils using imported seeds and the plantation is expected to last a lifetime of 15 yrs before it is re-established. The productivity for switchgrass on marginal land is assumed to be 5 tdm/ha/year. Future yield increases are estimated to be between 32–67% in 2030 compared to the current situation (van Dam, et al 2009).

Land rent in Argentina ranges from 100 to 300 US$/ha/year depending on land suitability type and location. In 2030, land prices for marginal land remain constant; however for good quality land prices go up from 300 to 450$/ha. Labour wages range from 2.18-3.18 $/hr and in 2030; labour rates are expected to go up to between 3.98-8.29$/hr. Switchgrass seeds are imported from Texas at 20 US$/kg compared to a possible local production cost of only 10 US$/kg. Fertiliser costs in Argentina vary from 0.315 US$/kg (P) to 0.48 US$/kg (N) (Margenes 2007). Aggregate switchgrass input production costs per hectare are shown in Table 7-8.

Switchgrass production costs are estimated to be 3.22$/GJ (306 $/ha) in 2020 and 2.97$/GJ (373 $/ha) by 2030. See Figure 7-4 and Table 7-8. The major cost elements in switchgrass production are machinery costs (37% short term and 44% for long term).

Land costs are also quite significant (at 29% in 2020 and 36% in 2030). Fertiliser costs increase significantly from 3% in the short term to 12% in the long term.

Table 7-8 Cost assumptions of key switchgrass production inputs in Argentina

Item	2020	2030	Units
Land rent	110	110	$/ha/yr
Seeding input	22.5	22.5	$/ha
Fertiliser input	12.0	49.5	$/ha
Herbicides input	2.85	6.41	$/ha
Labour costs	295.87	552.04	$/ha
Fixed costs machinery	1,964	2,015	$/ha
Fuel costs	493.11	688.30	$/ha
Aggregate costs	306	373	$/ha

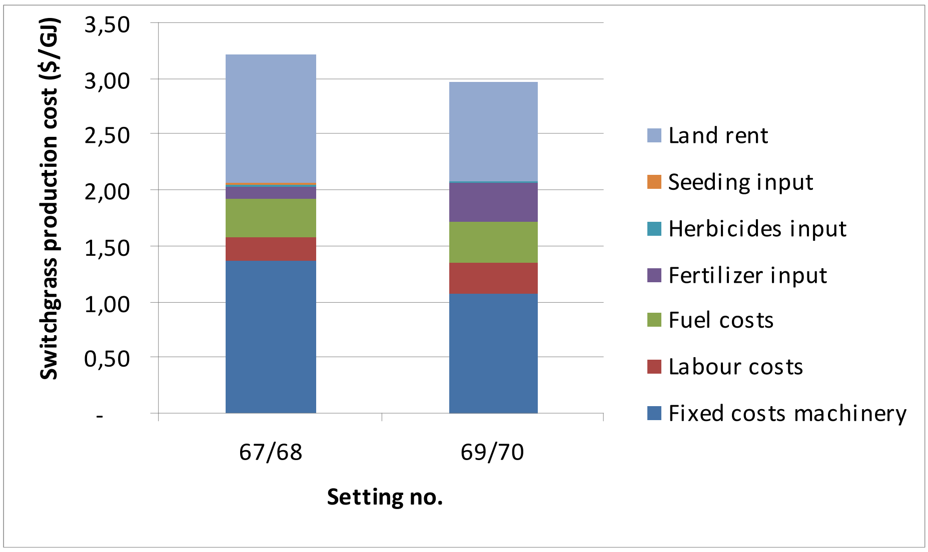

Figure 7-4 Switchgrass production costs in Argentina by component

7.1.4 Rice and wheat straw production

Rice and wheat straw have advantages as biomass feedstock because utilising them does not require recovering land costs, which are already covered in the grain enterprise. The cost of the straw supply is taken as the opportunity cost of the agricultural residue at a grain plantation (usually taken as its fertiliser value or alternatively compared to the next application such as fodder). Cost elements include chopping/cutting/swathing, raking, baling and on-farm hauling of crop residues. Because unused residues may have value (in that they reduce fertiliser needs or soil erosion), appropriate adjustments must be included in cost estimates. However, estimating nutrient requirements is very site specific and needs detailed soil analysis to evaluate sustainable residue removal rates.

Wheat straw production in Ukraine -- Table 7-9 shows the cost estimates for wheat straw collection and packaging in a typical Ukrainian facility. Sustainable wheat straw yields are estimated to be about 1 tons per ha at 15% moisture content.

Table 7-9 Cost estimates of wheat straw collecting and packaging in Ukraine

Straw harvesting activity	**Tractor**		**Fuel**		**Labour**	
	$/ha	$/hr	$/ha	$/hr	$/ha	$/hr
Cutting and raking	35	97	35	100	0.4	1
Baling (square baler + tractor) Bales 30kg	20	33	14.5	25.2	0.58	1
Forwarding to roadside (500m)/baler pick up (tractor front end loaders)	20	40	10	22	0.48	1

The production cost of wheat straw is estimated to be 2.88 $/GJ in 2020 and 1.89 $/GJ in 2030. As shown in Figure 7-5, cutting and raking wheat straw is the most costly item in straw production, contributing nearly 50% of the total costs. Baling is also a significant cost adding another 25% to the overall costs while bale collection and forwarding also contributes about 21%. Roadsiding and storage adds another 5% to the costs.

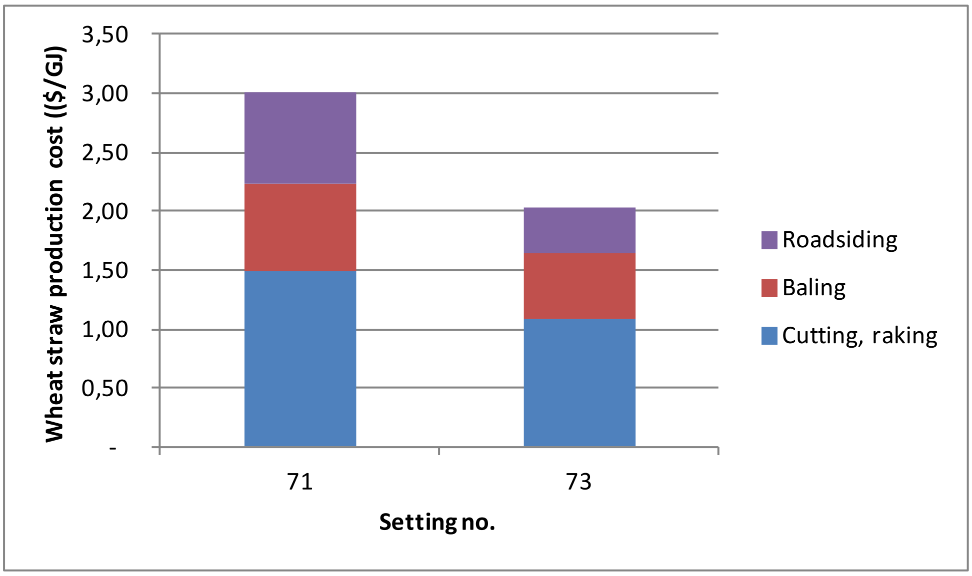

Figure 7-5 Wheat straw production costs in Ukraine by component

Rice straw in China -- Production of rice straw also involves swathing, raking, baling and roadsiding as shown in Figure 7-6. Sustainable rice straw yield is estimated to be about 1 ton/ha. Rice straw is estimated to cost 2.24 $/GJ in 2020 and 1.47 $/GJ in 2030 at the farm gate in China. Swathing and baling dominate the overall costs at 43% and 38% respectively, both in the short term and long term. Raking and roadsiding contribute about 10% each.

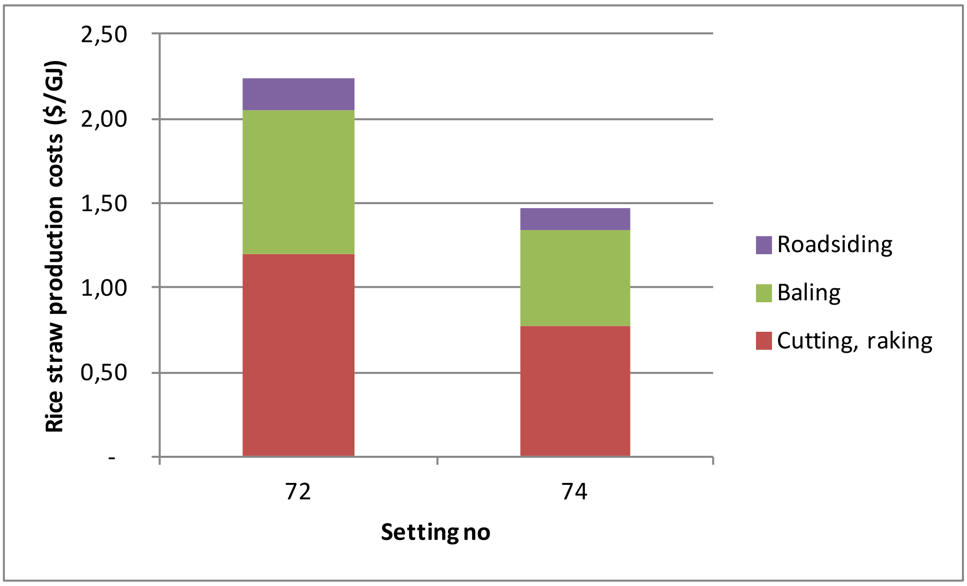

Figure 7-6 Rice straw production costs in China by component

7.2 Supply chain analysis

Biomass energy supply chains start with the feedstock production until final biomass fuel is delivered in the market as shown in Figure 7-7. The number of intermediate stages in a chain varies depending on the feedstock characteristics, pre-treatment requirements and infrastructure. Generally harvested biomass is collected at production sites and transported to a gathering point (GP) at a road or railway siding. Trucks provide first transport to the GP while second transport to a central gathering point (CGP) is by truck or train. At the CGP, biomass undergoes pre-treatment, e.g., sizing, drying, densification but also conversion to liquid fuels like bioethanol and synthetic fuels. The purpose of pre-treatment is to increase energy density, improve fuel homogeneity and reduce handling costs.

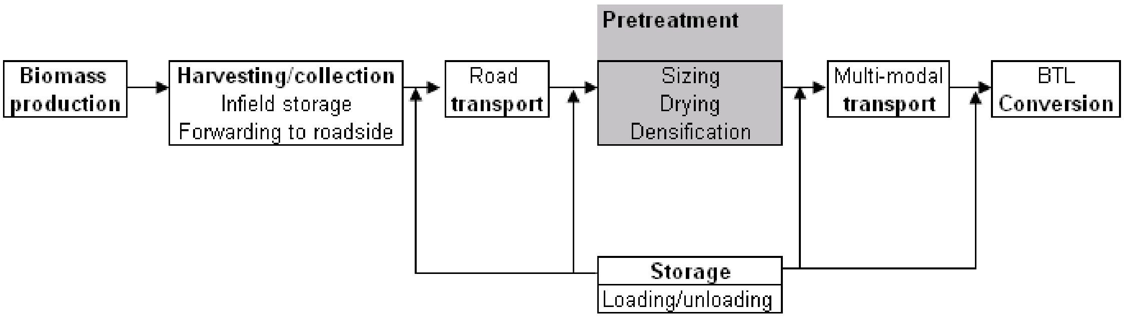

Figure 7-7 Outline of typical biomass energy supply chain logistic elements

7.2.1 Biomass pre-treatment options

Pretreatment of biomass is necessary to improve logistic efficiency. It includes sizing, drying and densification. The purpose of sizing is to meet subsequent step feedstock specifications and to improve handling. It has been noted that the moisture content of fresh biomass is about 50% and that drying is necessary to meet feedstock criteria at conversion plants: the gasification process, for instance requires feedstock with a moisture content of less than 8%. Biomass also needs to be densified to increase its energy density and to reduce logistical costs. Key technologies used for densification include baling, pelletising and torrefaction. Drying and sizing steps always precede densification, because of strict feedstock specifications.

7.2.2 Conversion

There are two main promising routes used to process biofuels from lignocellulosic feedstock: bio-chemical and thermo-chemical. In the bio-chemical route, enzymes and other micro-organisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol. The thermo-chemical pathway (so-called Biomass-to-Liquids (BtL) technology) employs gasification to produce a synthesis gas from which a wide range of long carbon chain biofuels, such as synthetic diesel or aviation fuel, can be derived.

7.2.3 Ethanol production from lignocellulosic biomass (next EtOH)

The production process of lignocellulosic biomass to ethanol consists of three stages, namely biomass pre-treatment, hydrolysis and fermentation. Chemical and physical pre-treatment breaks down cell structures and separates the lignin from cellulose and hemicellulose and thereby facilitates the hydrolysis (saccharification). Acid or enzymatic hydrolysis converts the cellulose and hemicellulose into fermentable monomeric and oligomeric sugars, with enzymatic hydrolysis using cellulases and hemicellulases being the preferred route. The lignin residue can be used for electricity generation. The sugars are fermented to ethanol, which is then purified and dehydrated.

7.2.4 Syngas based biofuels (BtL)

Synthetically derived liquid transport fuels are able to use almost any type of biomass, with little pre-treatment other than moisture control. Thermo-chemical conversion of biomass to biofuels generally involves higher temperatures and pressure than those needed for the biochemical route. It is based on either gasification or pyrolysis. Biomass feedstock is pre-treated to required specifications before being fed into a gasifier. The syngas produced is further cleaned by removing tars, particulates and gaseous contaminants before being fed to a Fischer Tropsch (FT) reactor where syngas interaction with catalysts results in the production of different types of fuels. The FT process is an established technology and is already applied on a large scale in order to produce liquid fuels from coal or natural gas.

7.2.5 Technology status

Next generation biofuels are not yet produced commercially, although a number of pilot and demonstration plants are underway mainly in North America, Europe and a few emerging countries. IEA Bioenergy Task 39 estimates that there are 66 pilot- and demonstration-sized projects being undertaken worldwide. About 50% of the facilities are operational, 25% is under construction or under commissioning, and the remaining 25% are planned projects. At the end of 2009, total annual production capacity in demonstration facilities (both routes) was around 60,000 tonnes of fuel, and if all planned projects are completed, the annual production capacity is estimated to be about 680,000 tonnes by 2012. Significant progress is being made in R&D and demonstration, and it is likely that commercial scale plants will be deployed over the next decade. However, a number of technological and cost barriers need to be overcome for the successful commercial deployment of next generation biofuel technologies.

7.2.6 Lignocellulosic biofuel production costs

Biofuel production costs include feedstock production costs (see section 7.1), pretreatment costs, transport costs, storage costs and conversion costs. The costs that are analysed here are very generic, in the sense that it is important to include spatial detail and biomass distribution detail to come up with more representative estimates. However, country specific information is also included, such as expected transport distances and truck transport limitations as well feedstock production costs. See Table 7-10. Technology cost estimates are also generic and represent state of the art knowledge in biomass pretreatment and conversion, which is expected to be applied in the respective countries in 2020 and 2030.

Table 7-10 Key assumptions for biomass transportation in selected countries

	Mozambique	**Brazil**	**Ukraine**	**Argentina/China**
Distance from farm to conversion plant (km)	100	200	50	120
Truck capacities (tons)	20	40	40	40

The next EtOH conversion technology route considered here involves use of physical and acid pretreatment followed by enzymatic saccharification of the remaining cellulose after which the resulting sugars undergo enzymatic fermentation to produce ethanol. A base capacity of 400 MWth input capacity is assumed at a load factor of 90% (see Table 7-11). Investment costs are expected to decline from 374 M$ in 2020 to 290 M$ in 2030 due to learning effects in conversion technology.

For BtL conversion, the technology route considered is a combination of circulating fluidised bed gasification and turbular fixed bed FT reactor. A base scale of 400 MWth is also assumed at a 90% load factor. Investment costs are expected to decline from 422 M$ in 2020 to 327 M$ in 2030 due to learning effects in conversion technology.

Table 7-11 Summary of biofuel conversion technology costs

Conversion factor	**Next EtOH**		**Fischer Tropsch CFB**	
	2020	**2030**	**2020**	**2030**
Base Scale (MWth LHV input)	400	400	400	400
Base Investment (M$)	374	290	327	327
Scale factor	0.7	0.7	0.78	0.78
Lifetime	25	25	25	25
Load factor	90%	90%	90%	90%
O&M (% of investment)	4%	4%	4%	4%
Efficiency fuel only (LHVwet)	40%	40%	45%	45%

7.2.7 Next generation ethanol production costs from eucalyptus

Figure 7-8 provides a comparison of next EtOH production costs from eucalyptus in Brazil and Mozambique. Conversion costs dominate overall costs, accounting for 48 to 53% of the production costs. The higher biomass feedstock production costs on marginal land are a major driver of costs in setting 57 (about 20% of overall costs in Mozambique less suitable land – 19.8 $/GJ) and setting 58 (Brazil less suitable land-19.4 $/GJ). EtOH is produced at marginally higher costs in Mozambique due to higher feedstock production costs and higher electricity charges. Future ethanol production costs are expected to fall in line with falling feedstock production costs and lower conversion costs (16.8 $/GJ in Mozambique and 16.2 $/GJ in Brazil). Truck transportation is also a significant factor in overall costs contributing up to 27%.

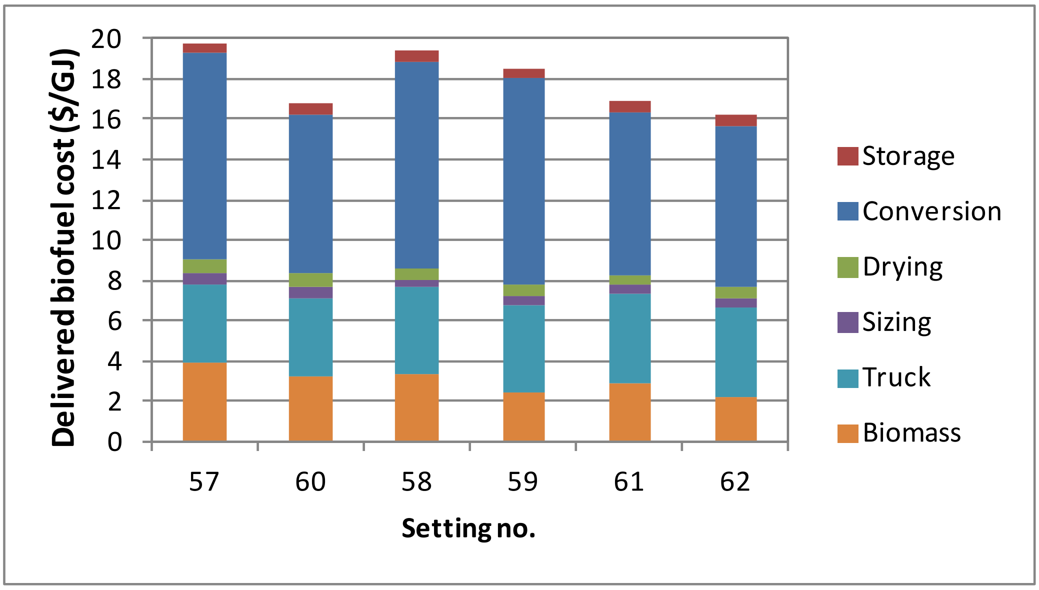

Figure 7-8 Eucalyptus to next EtOH production costs (Mozambique and Brazil)

7.2.8 BtL fuel production costs from poplar in Ukraine

BtL production in Ukraine is estimated to range from 13.9 to 17.8 $/GJ for the selected settings, with the latter representing production on more marginal land in the short term. There is a 16% difference in costs between the short term and long term, mainly attributed to learning effects in agricultural production and conversion technology. See Figure 7-9. Truck transport has a lower impact on overall costs (12-16%) due to the shorter distances assumed for Ukraine compared to other countries. Feedstock production costs and conversion costs are the main contributors to total costs, at 14-20% and 57-65% respectively.

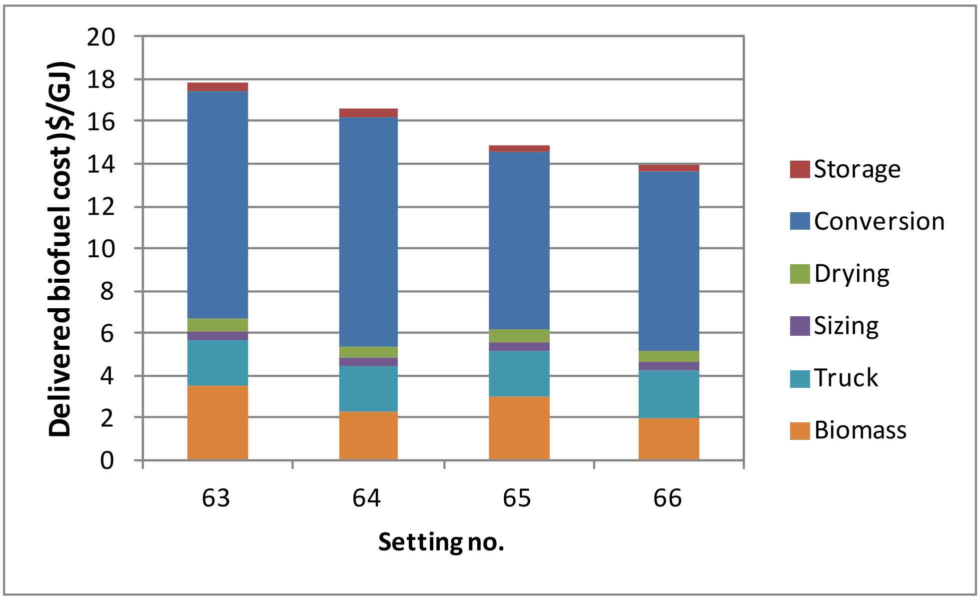

Figure 7-9 Poplar to synfuel production costs (Ukraine)

7.2.9 BtL and next ethanol fuel production costs from switchgrass in Argentina

A comparison of BtL and next ethanol production from switchgrass in Argentina shows that next ethanol production costs are marginally higher (18.5 – 21.0 $/GJ) compared to (18.3 – 20.8 $/GJ) for BtL. This is mainly attributed to the higher conversion efficiency for BtL, which offset the higher BtL investment costs. As shown in Figure 7-10, conversion costs are dominant in the overall costs (43-52%) while truck transport costs are also quite high at 23-29%. Storage of switchgrass bales and produced ethanol also contributes up to 10% of overall costs. Similarly, biomass production costs are also significant at 16%.

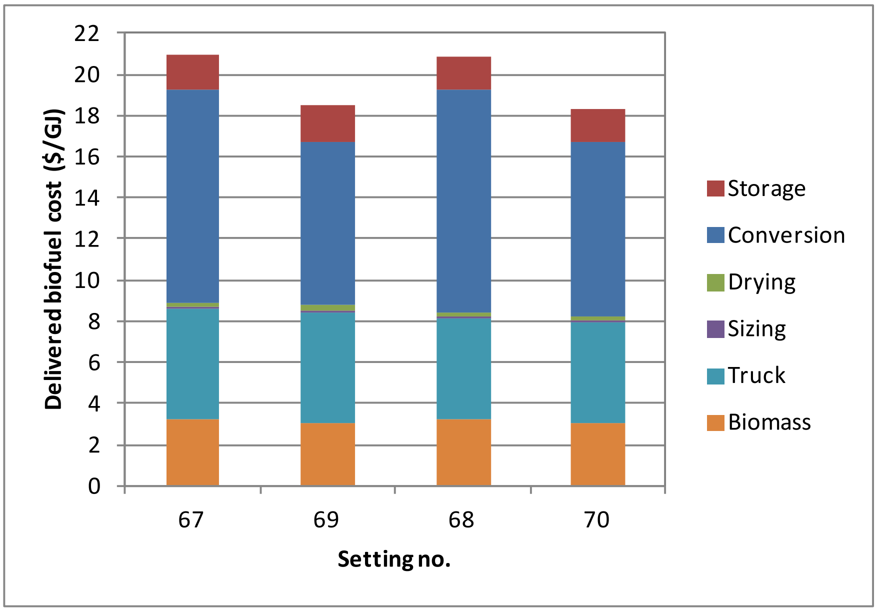

Figure 7-10 Switchgrass to next ethanol and synfuel production costs (Argentina)

7.2.10 Next generation ethanol fuel production costs from rice straw in China and wheat straw in Ukraine

Next generation bioethanol production from straw is estimated to cost between 20.1 and 26.1 $/GJ in China and Ukraine. Bioethanol production from wheat straw in Ukraine is cheaper at 20.1-23.4 $/GJ compared to that from rice straw in China (23.0 – 26.1 $/GJ). The differences between the two countries can be attributed to the large truck transport distances considered for China, which contribute 31-35% of the total costs compare to 20-23% for Ukraine. Contribution of conversion costs is comparable for the two countries at about 35-44%.

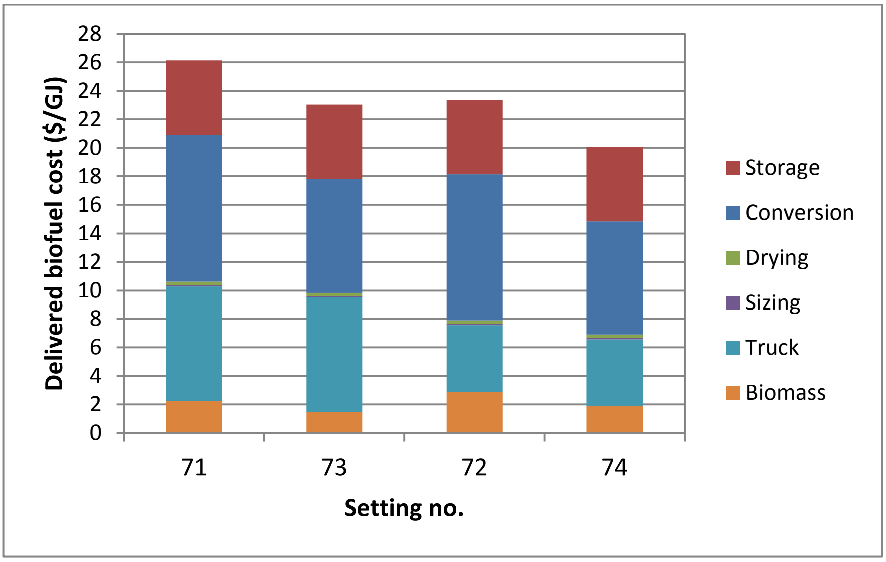

Figure 7-11 Straw to next ethanol production costs (China and Ukraine)

As shown in Figure 7-11, storage costs for straw bales and produced ethanol are also high, contributing between 20 to 26% of overall costs. Storage costs for other supply chains are very low, at about 2% of total costs. Feedstock (straw) costs are relatively low compared to other cost elements (and other supply chains) at about 6-26%.

Figure 7-12 summarises the biofuel production cost by country for both next ethanol and BtL pathways. The BtL route results in biofuel production costs of between 13.9 -20.8 $/GJ. Bioethanol production costs range between 16.2-26.1$/GJ.

Production costs are much lower in Ukraine, due to the lower input costs reflected especially through the use of cheaper organic manure instead of chemical fertilisers in the production of poplar. However, the cost of fuel produced from wheat straw is high due to the higher logistical costs such as storage and truck transportation. As shown in Figure 7-12 and Figure 7-13, biofuel production costs in China are relatively higher than other countries due to the long transportation distances of low energy density rice straw. Truck transportation contributes about 8 $/GJ to the overall fuel production costs in China. This demonstrates the need for reducing the energy density of agricultural residues by densification of straw early in the chain to reduce the logistical costs.

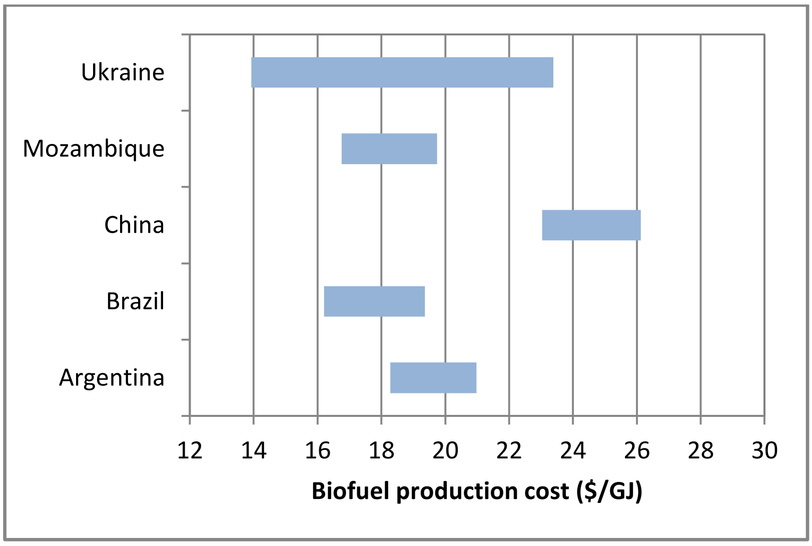

Figure 7-12 Biofuel production costs by country

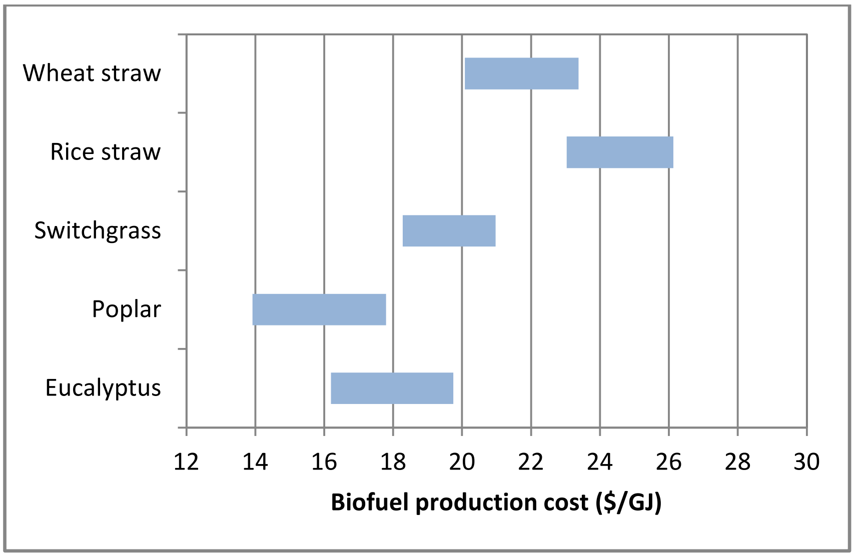

Figure 7-13 Biofuel production costs by feedstock type

Sensitivity analysis

Biofuel production costs depend on a number of factors as already shown by the differences among countries and feedstocks. For feedstock production, the feedstock productivity is important and developments in plant selection and breeding leading to experience/technological learning has a significant impact on future feedstock production costs. At the conversion stage, the capital investment cost and associated cost of capital are the key determinants of the biofuel production cost levels. It is expected that future capital investment costs will decrease with technological learning and scaling up of production facilities. A sensitivity analysis shown in Figure 7-14 was performed to assess the impact of technological learning, interest rates, conversion efficiency and feedstock production inputs.

Table 7-12 Selected variation in parameter used in sensitivity analysis

Parameter	Variation
Technological learning in conversion facilities (progress ratio)	0.88 - 0.98
Interest rate	4%-12%
Conversion efficiency improvements	- EtOH from 39% to 47% - BtL from 45% to 53%
Variation in feedstock production costs	Labour increase to 319% in 2030; land rent by 50%; fertiliser by 300%; agrochemicals by 121%

The sensitivity analysis show large variations in fuel production from wheat straw (14.0-17.6 $/GJ) and rice straw (16.6-30.3 $/GJ). These supply chains are influenced by the future conversion efficiency improvements, which result in lower feedstock requirements and lead to corresponding decrease in logistical costs, especially long distance transport and long term storage of feedstock. All the supply chains are heavily influenced by conversion costs and the lower cost range reflects cheap cost of capital (i.e. 4%) and faster technological learning (progress ration of 0.88). Overall, biofuel production costs vary by 67% from 10.0 to 30.3 $/GJ. The production costs of next ethanol varies over a much wider range from 12.0-30.3 $/GJ, while BtL production costs range are marginally lower at 10.0-24.0 $/GJ.

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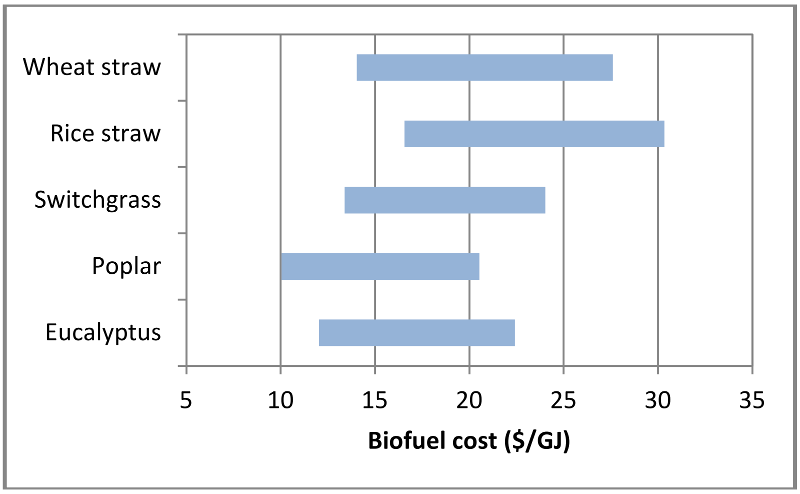

Figure 7-14 Range in biofuel costs by feedstock type

For comparison, recent state of the art analysis estimate that second generation production costs for bioethanol range from 13-30 US$/GJ, while BtL derived fuels are estimated to cost 16-30 US$/GJ. See Appendix 3.

7.3 Potential development of second generation biofuels in developing countries

It is clear from recent investigations and this analysis that significant volumes of next generation biofuels can be produced at competitive costs in various developing countries. A key pre-requisite is that several technological hurdles be overcome and that a large, stable supply of lignocellulosic biomass be guaranteed. Other important pre-conditions for ensuring competitive biofuel production and supply include rationalisation of agricultural production in developing countries (which will be essential for realising significant feedstock volumes), as well as the availability of efficient logistics (which are needed to ensure competitive biomass supply).

Initial focus on feedstock production

Given the status of the technology and investment requirements to establish processing plants, it is unlikely that second generation biofuels production can be achieved in developing countries in the coming decade. However, developing countries can already develop a biofuel feedstock production industry, which could be the basis for a strong biofuel industry when the technology matures. Investment in feedstock production could offer an option for developing countries to profit from the growing biomass market for second-generation biofuel production outside their borders, provided that transport infrastructure is suitably developed.

Need for developing capacity, improvement in infrastructure

Profits could be invested in the rural sector to improve infrastructure and the overall economic situation, and at the same time to develop skills for feedstock cultivation and handling. However, there are still risks that small landholders' interests are ignored when large investments are undertaken by foreign companies and this concern needs to be carefully addressed through sound policy regulations. Furthermore, only certain feedstocks with high energy density (e.g. woody biomass), are suited for long-distance transportation. Poor infrastructure in many developing countries and little experience with biomass production and supply form significant barriers for feedstock trade and can prevent international trade in many cases.

Need for cooperative RD&D and technology transfer

As a next step, cooperation on R&D at a scientific level would be needed in many emerging and developing countries to build capacity for second-generation biofuel production. Besides exchange of knowledge and capacity building, technology access is ensured through cooperation, an important factor to implement a sound second-generation biofuel industry in the future. During the transition to second generation biofuel commercialisation in developing countries, cooperative RD& D could stimulate technology transfer and generate important experience. Skills development and adaptation of technology – especially the local fabrication of part of the facilities, training of personnel on requisite techniques for equipment operation and maintenance and the emergence of private sector participation are important prerequisites for commercialisation of second generation biofuel technologies.

Investment strategies

For developing economies, where project finance for the capital intensive industries is a major barrier to investment, it makes practical sense to develop the biofuels sector using the backbone of already existing industries. This goes a long way on reducing the overall investment costs of project. A typical example is found in first generation biofuels - the establishment of annexed ethanol distilleries on existing sugar mills. An autonomous distillery would costs significantly more as there is still need to invest in sugar processing plant. Similar piggybacking relationship with for example the coal or oil sector could result in valuable synergies that can bring costs to competitive levels in the medium term.

8 Fuel and vehicle compatibility

8.1 Introduction

Many countries have created or are in the process of creating national biofuel targets or blending mandates as part of their strategy to de-carbonize the transport sector and decrease oil dependency. Identifying the 'right' biofuel blending mandate or target in a given country context depends on a range of factors including: sustainability concerns (such as biodiversity loss, water competition, food security and GHG balances) biofuel feedstock availability, cost competitiveness, and infrastructure and vehicle fleet composition. Although finding clarity within sustainability concerns is one of the most critical steps in the national planning process, there is also a great importance when it comes to how to implement a blending policy with regard to compatibility with fuel infrastructure and vehicles. If these compatibility implementation challenges are not analysed during the national planning process, the potential impacts of these mandates can be detrimental and lead to unnecessary spending from the consumer, private sector and government. Recognising this importance, this report will address key compatibility barriers for developing countries that are hoping to achieve blending mandates or targets in the present or in the medium-term. The key issues identified will be then used to formulate recommendations for decision-makers in regards to the sustainable development of biofuel mandates and blending targets.

The purpose of this section is to highlight the challenges related to fuel/vehicle compatibility in an effort to provide recommendations for decision-makers in regards to the sustainable development of biofuel mandates and blending targets. This chapter contains not only a look at compatibility issues related to fleets, but also at external constraints and "bottlenecks" that should be taken into consideration in a national planning process to define targets such as: infrastructure requirements of different blends, supply demands, and effective policy measures. Through defining these barriers, developing country governments can better understand how to effectively resolve certain challenges and how to identify what an appropriate blend level is for their current light-duty passenger vehicle fleet.[28]

For policy purposes, the definitions are as follows:

Biofuels: fuel produced directly or indirectly from biomass such as fuel wood; plants; grains; charcoal; bioethanol; biodiesel; biogas (methane); or biohydrogen (UN-Energy, 2010).

Biofuel blend mandate: a regulation that defines the proportion of biofuel that must be used in (road-) transport fuel (at the point of distribution) (IEA, 2011).

Biofuel blend target: a graduated future target for the level of biofuel that is blended at the point of distribution or the total volume of biofuels produced.

Blend wall: a term to define the point where there is a limitation on increasing a biofuel blend to a higher blend level. This term can be used to explain compatibility limitations due to both physical compatibility and supply constraints.

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[28] Although it is important to analyze the total fleet compatibility, including heavy-duty vehicles, light-duty vehicle, light-duty truck, etc. this paper will concentrate solely on light-duty passenger vehicles.

8.2 Key questions and concerns for decision makers

For developing countries that are considering putting in place national blending mandates for biofuels, a critical look at the capability of the current and future fleet to utilise certain fuel blends is important to the sustainability of the sector. For countries that have already instituted a blending mandate, increasing further the biofuel ratio in the fuel blends and/or target to utilise a higher volume of biofuels in the transport sector might be a policy consideration. In these cases, the issues related to compatibility are still important to analyse. A list of questions decision-makers should address before considering the establishment of a blending mandate and/or altering an existing one can be found in Table 8-1.

Table 8-1 Key questions and concerns for decision makers

Fuel/ Vehicle Compatibility Questions for Developing Countries	
No existing blending mandate	**Existing blending mandate**
Specific compatibility related questions: ➢ What is the make-up of the current vehicle fleet? ➢ What are the compatibility concerns for the existing fleet? What blend levels in mass market fuels (both for bioethanol and biodiesel) can the current fleet utilise? ➢ What refining, blending, storage and distribution infrastructures are necessary for different blends and fuels? What infrastructure already exists? ➢ Does the biofuel introduction require a mass market fuel or a dedicated fleet? Beyond compatibility: ➢ What are the supply constraints of the market regarding both domestic production and imports of biofuels? ➢ What is the cumulative economic cost of introducing the blending mandate? ➢ What policies can support the blending mandate? What vehicle emission regulations/current standards are currently in place? ➢ What is the current consumer confidence in biofuels?	Specific compatibility related questions: ➢ What is the future fleet projection (passenger cars/ heavy duty)? Will the future fleet be compatible with a higher blend? What will be the future of vehicle emission regulations/ other policies? ➢ Is the existing infrastructure compatible with a higher biofuels blend? If not, what physical changes need to be made? Beyond compatibility: ➢ What is the current sustainable supply of biofuels that is consumed? What is the additional volume that can be produced and utilised by the transport sector? ➢ What are the economic costs of increasing a blending mandate? ➢ What policies can support this transition? ➢ What is the current consumer awareness about compatibility with their own vehicles?

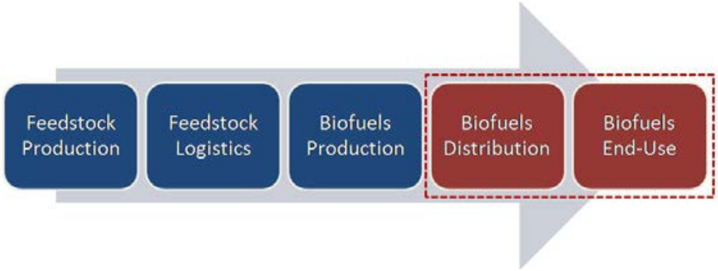
The key questions show that in order to find a suitable biofuel blending mandate/target that can be implemented successfully certain considerations need to be made. At the outset, there should be an inventory conducted of the current fleet make-up to help inform decision making. This is because certain vehicles may be able to adopt higher blends more than others. For example, if a country's current fleet is comprised of older vehicles (sometimes referred to as "legacy vehicles") that may present a bottleneck as those vehicles are not adapted to higher blends. A key question is: Will the existing fleet be able to utilise the blend of biofuel without affecting the durability and performance of the fleet? Questions related to the capacity and compatibility of existing infrastructure are also key.

For instance, decision makers must ask: is the current infrastructure compatible with the mandate or target?

Even though compatibility considerations might be a narrow issue, there are still questions to consider in the planning process beyond just physical compatibility itself. Some issues that might affect the successful implementation of a blending mandate might be for example: having supply constraints, having the mandate as an economic burden for the consumer or retailer, or introducing supporting policies that are ineffectual.

8.3 Supply chain compatibility

As evident from the key questions, decision makers should assess compatibility not only in the vehicles/ fleets themselves (end-use), but also along the supply chain, beginning at the point of distribution (see Figure 8-1).

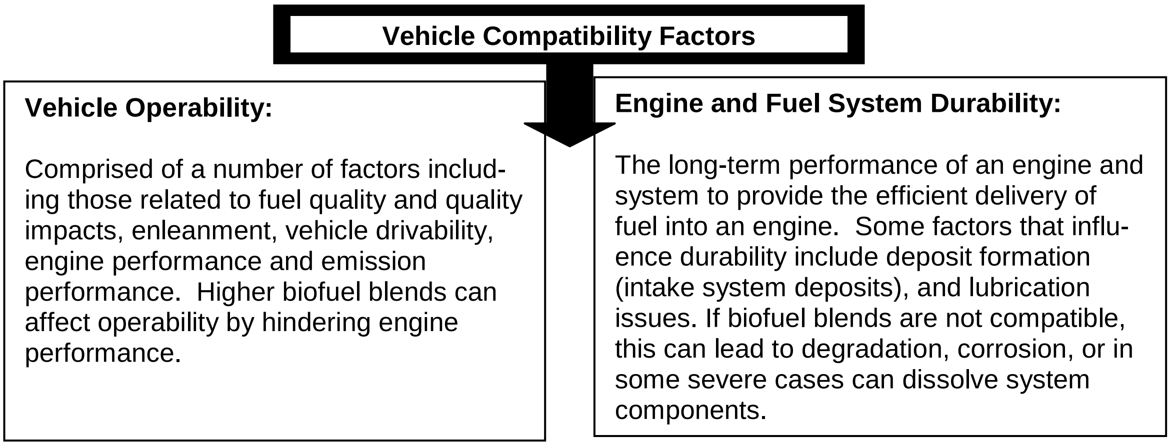


Source: Adapted from U.S. Department of Energy, Energy Efficiency and Renewable Energy Program 2011.

Figure 8-1 Biofuel compatibility along the supply chain

At the *biofuels distribution point*, physical compatibility with distribution materials might begin to become a problem. Materials used in equipment such as storage tanks, piping, trucks and distribution/dispensing materials might be affected or damaged if they are in contact with blend levels that are too high. These materials should all be equipped and warranted by manufacturers for those blend levels.

At the *end-use* the compatibility concerns are heightened as there are many challenges that might emerge from utilising biofuel blends in vehicles/fleets that are not compatible. Problems can occur that affect vehicle durability and operability if proper fuel blends are not used. *Vehicle compatibility*, in the context of this report, refers to the adaptability of a vehicle to utilise and combust biofuel blends while maintaining long-term durability and operability as warranted by the vehicle manufacturer. The factors in vehicle compatibility are depicted in Figure 8-2. (Department of Sustainability, Environment, Water, Population and Communities, Government of Australia, 2011).



Vehicle Compatibility Factors

Vehicle Operability:

Comprised of a number of factors including those related to fuel quality and quality impacts, enleanment, vehicle drivability, engine performance and emission performance. Higher biofuel blends can affect operability by hindering engine performance.

Engine and Fuel System Durability:

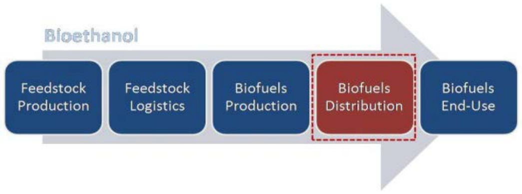
The long-term performance of an engine and system to provide the efficient delivery of fuel into an engine. Some factors that influence durability include deposit formation (intake system deposits), and lubrication issues. If biofuel blends are not compatible, this can lead to degradation, corrosion, or in some severe cases can dissolve system components.

Figure 8-2 Vehicle compatibility factors

8.4 Compatibility challenges with bioethanol

In considering the appropriate blend level of bioethanol for a particular fleet, certain compatibility barriers have to be taken into consideration. If a country is developing a biofuel mandate for the first time, there must be an assessment of the current fleet and infrastructure before a mandate and/or target is set. Additionally, current infrastructure compatibility needs to be considered if a country is increasing a bioethanol blend level. The following will be a discussion of the main compatibility concerns associated with bioethanol blends at various levels.

8.4.1 Bioethanol – compatibility challenges in distribution

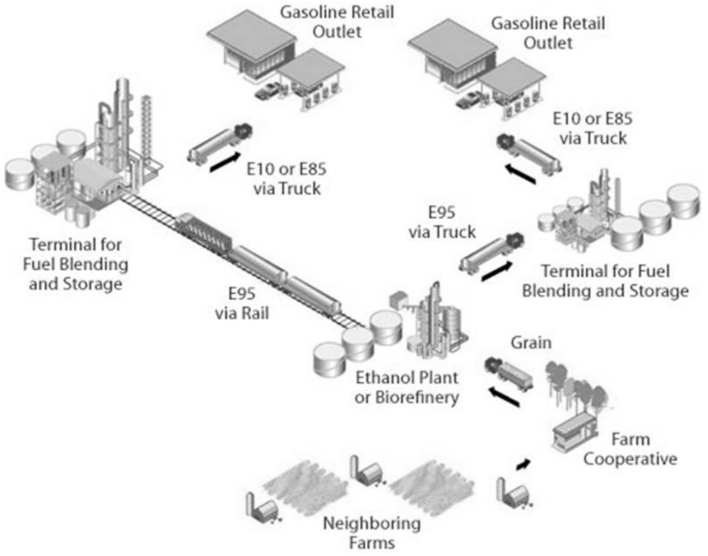


There are unique challenges that are specific to developing efficient infrastructure and distribution systems for bioethanol, whether bioethanol blends are low level blends (E5-10), intermediate/medium (E15-E20), or higher blends (E20 – E100) (US Department of Energy, 2011). Infrastructure needs for various bioethanol blend levels will vary according to the blend level. A schematic graphic of two types of bioethanol distribution system can be found in Figure 8-3.

Both distribution systems of bioethanol, (1) through dedicated pipelines and (2) through the use of trucks and road, have their own challenges with regard to compatibility. Because bioethanol has solvent and corrosive properties, dedicated pipelines and equipment in trucks have to be properly equipped with materials that are warranted to withstand certain percentages of bioethanol. In developed biofuel markets, lower blends, such as E5-10, pose little compatibility challenges in distribution. However, for blends higher than

E10, issues related to corrosion and wear start to become a problem. In developing countries, or countries without a current biofuel industry, E5 is assumed to be the blend wall (Rimmer, 2011).

As bioethanol blends increase, there have been concerns regarding the compatibility of older storage tanks (that were originally made to support lower blends such as E5-10) to support higher blends of bioethanol. Although there is not a lot of substantial research in this area, there is evidence to assume that higher blends of bioethanol will damage incompatible tank systems. More corrosive than lower blends, these higher blends can not only damage tank systems, but can cause bioethanol to leak into the groundwater. This can pose numerous health and environmental risks. In the case of the United States, storage systems for bioethanol are able to store an E10 mixture, and government authorities now warn that this might not be compatible with E15 or higher; thus, distributors would have to retrofit existing systems to ensure public health and the environment are not harmed (Government Accountability Office, 2009).



Source: US Department of Agriculture, 2007

Figure 8-3 Schematic distribution of bioethanol

One response to these challenges is retrofitting existing distribution systems to be compatible with the level of bioethanol used. This could be an option if a country decides to increase its bioethanol target or mandate. However, in some cases, the economic burden on retailers may be significant. For instance, retrofitting retail stations to distribute higher blends (E10 +) costs somewhere between 100,000 to 200,000 USD per station (Rimmer, 2011). In addition when moving to higher bioethanol blending, fuel infrastructures must sell in parallel two petrol grades: a protection grade for non-compatible fleet and the new grade (Lahaussois, 2011).

Policy Options for Compatible Bioethanol Distribution Systems

Some countries have demonstrated that there can be a policy response if retrofitting distribution systems is necessary. Policies can enable the conditions for higher bioethanol blends to be distributed and lower the costs on retailers (see box below). However, some of these policies then come at a financial cost to the government, or relayed back to the consumer (Hart Energy, 2012). A full assessment should be done to find the most appropriate solution.

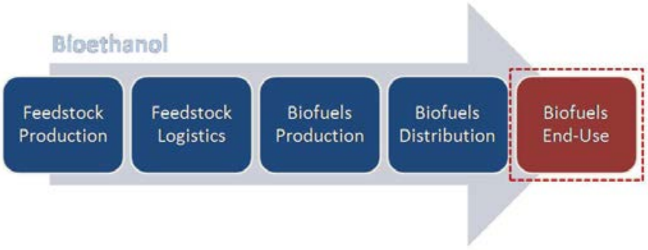
Policies needed to facilitate the necessary transformation of fuel infrastructure changes: State centered policy incentives for upgrading to E85 – Illinois, USA

Enacted in 2005, the 'Governor's Opportunity Returns' is a fund that was set up to help stations cover the costs of installing E85 pumps. The fund operates by setting aside $500,000 in matching grants to help gas stations buy the equipment they need to sell E85. The effort provides an incentive to create new E85 fueling sites throughout the state. As part of this initiative, the Illinois Department of Commerce and Economic Opportunity (DCEO) E85 program provides up to 50% of the total cost of converting an existing facility to E85 operation or constructing a new fueling facility. Grants are available to qualifying individuals or companies operating retail gasoline stations, with grants up to $2,000 for converting a site and up to $40,000 for building a new facility.

Source: National Renewable Energy Laboratory, 2007.

For developing countries that are initiating a bioethanol mandate, there are still peripheral concerns to consider with regard to compatibility of distribution systems. The availability and reliability of basic infrastructure such as roads and rail systems is one of these considerations. Without this basic infrastructure biofuel markets will not be sustainable or be able to reach end-users.

8.4.2 Bioethanol – compatibility challenges in vehicles



An extensive literature review suggests that low levels of bioethanol blends (i.e. under E10), have little impact on vehicle compatibility in most light-duty passenger vehicles as levels of ethanol are too low to cause significant impacts (Ministry of Transport NZ, 2006). However, when introducing mid-level blends (i.e. E15-E20), compatibility issues have been documented with problems occurring particularly in older vehicles (and legacy vehicles). Often these vehicles have no manufacturer's warranty to assure compatibility and long-term performance with higher biofuel blending. Higher blends (E20-E100) require dedicated vehicle technology and can only be used in certified flex-fuel-vehicles (FFV).

Compatibility Challenges with Mid-level to High-level Bioethanol Blends

For currently available bioethanol blends that range from E15- E100, the compatibility issues that need to be addressed to ensure that vehicles maintain their full performance are variable. It is worth noting that these compatibility challenges are most often related to anhydrous bioethanol, which is the most common mixture of bioethanol found in the market. Anhydrous bioethanol (ethanol) has a concentration of between 93-96% ethanol to water and is distilled through a dehydration step. In contrast hydrous ethanol has a purity of at least 99% and can be produced through simple distillation processes. At the time of writing there are few available studies that test the performance of hydrous ethanol and compare it to anhydrous (Brewster et al., 2007).

There is evidence that suggests that mid-level blending levels can affect fuel system durability if not warranted by the vehicle manufacturer. Some of these impacts include the increased presence of fuel system deposits in non-compatible engines, which can ultimately cause fuel blockages in the system. For engines that were equipped with carburettor engines and steel fuel tanks, using mid to high level bioethanol blends might impact the fuel system by disrupting the air/fuel ratio; this can be the case for most vehicle engines that are made before 1986, which can represent a substantial share of the existing fleet in many developing countries. Seals may also be affected. Corrosion of both fuel tanks and fuel lines from bioethanol can be seen, and this system disruption can ultimately block the delivery of efficient fuel supply. The presence of water that is found in bioethanol can also make an engine run ineffectively (Consumer News, 2010).

Mid to high-level bioethanol blending levels have been shown to also affect the vapour pressure (V/L) in automobile engines. As a result incompatible vehicles might run the risk of forming a vapour lock, causing engines to stall and preventing the fuel from moving efficiently to the engine (Grabner Instruments, 2010). Studies have shown that as the ethanol content in bioethanol increases to 7%, vapour pressure increases. This is a critical point, as most developing countries begin their bioethanol programs with lower ethanol blends, and then progressively move to higher blends. Upwards of 7%, the vapour pressure decreases, with the most dramatic decrease occurring in mid-level bioethanol blends from around E70-E100 (see Figure 8-4).

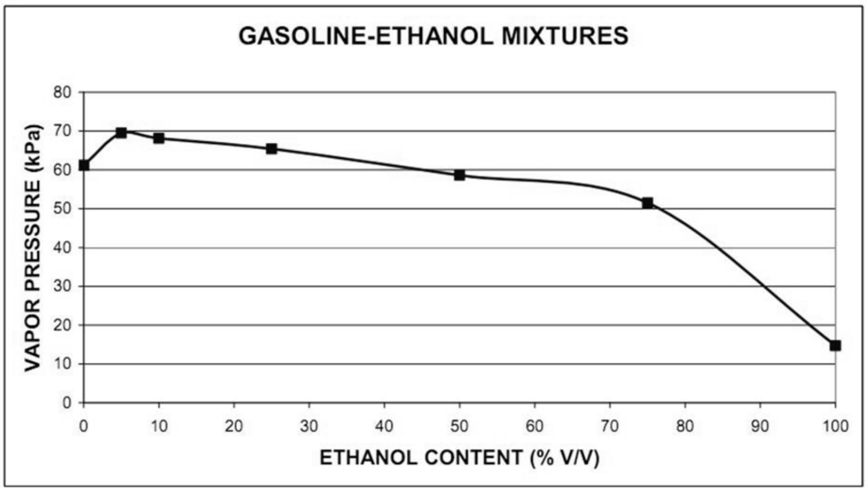


Figure 8-4 Vapor pressure in various levels of bioethanol (source: Ford Motor Company, 2007)

Another impact of mid to high-level bioethanol blends is the susceptibility for phase separation or partial phase separation. Phase separation occurs when water molecules separate from hydrocarbons in gasoline, and most likely it is a result of lower temperatures or quality standards. This can cause the bioethanol/water mixture to reside below the gasoline at the bottom of the vehicle fuel tank, causing a vehicle to potentially break down. A summary of the risks and issues that are related to compatibility of engines and mid to high blend bioethanol can be found in Table 8-2 (Sah, 2007).

Table 8-2 Properties of bioethanol and associated implications

	Properties of Bioethanol and Associated Implications
Hydrogen Bonding/Vapor Pressure	This property means that pure ethanol has a very low vapor pressure compared to gasoline. But it also means the vapor pressure of a mixture can be higher than the gasoline alone. Where the peak vapor pressure occurs depends on the base gasoline vapor pressure and ethanol concentration. Vapor pressure directly affects the evaporation rate and potential hydrocarbon emissions.
Hydrogen Bonding/Water Attraction	Easy hydrogen bonding makes ethanol attract water. The presence of water, in turn, increases the risk that certain metals will corrode. This becomes a problem when fuel remains in storage (including vehicle fuel tanks) and handling systems for a long time.
Oxygen Atom	Ethanol mixed with gasoline makes the air-to-fuel ratio leaner than with gasoline alone. Controlling the air-to-fuel ratio is critical to the combustion process and engine performance. Performance problems include hesitation, stumbling, vapor lock, and other impacts on driveability. Pre-ignition also can occur, causing engine knock and potential damage.
Oxygen Atom	Manufacturers calibrate the oxygen sensors (generally used in modern vehicle technologies but not in off-road equipment) to recognise specific levels of oxygen in the exhaust stream. If a mixture is outside the calibration range, the sensor will send inaccurate signals to the air-to-fuel feedback and on-board diagnostic systems. This could cause improper air-to-fuel ratios as well as an increased risk of causing one of the dashboard's warning lights (MIL) to illuminate.
Higher Combustion Temperature	Excessive combustion temperatures can cause engine damage.
Higher Latent Heat of Vaporization	This can delay catalyst "light-off," which is period of time before the catalyst warms up and can increase exhaust emissions of HC, CO, and NOx.
Higher Electrical Conductivity	This property increases galvanic corrosion of metals.
Permeability	Ethanol readily permeates at significant rates through elastomers, plastics, and other materials used widely for hoses, o-rings, and other fuel system parts.
Solvency	Under certain conditions, the presence of ethanol can cause certain additives to precipitate out of solution, leaving the engine unprotected from gummy deposits. Deposits can increase emissions, lower fuel economy and increase driveability problems.

Blends E20 and higher do not comprise much of the global bioethanol market. These fuels though, can be safely combusted in dedicated fleets called Flex-Fuel Vehicles (FFVs). Any conventional vehicle will be unable to run on these fuels. FFVs vehicles are equipped to utilise bioethanol blends that range from E0-E100 as they contain specific engine control modules that identify what percent blend is being utilised, and adjust the vehicle system automatically to that blend (US Environmental Protection Agency, 2011). It should be noted that FFVs vary from country to country in terms of their compatibility. In the United States, for example, FFVs are compatible with E0-E85. In Brazil, however, the case is different as dedicated FFVs are able to run on 100% hydrous ethanol as well (i.e. FFVs are compatible with E0-E100) (Hart Energy, 2012).

Policy Options for Bioethanol Compatible Vehicles

As discussed, not all light-duty passenger vehicles are compatible with medium or high level bioethanol blends. Often times, older vehicles and/or legacy vehicles will experience long term durability and operability impacts and must also continue to have access to a protection grade. This protection grade is a fuel that must be on the market (at fuelling stations) in parallel to new blending levels to allow non-compatible fleets access to the old fuel (Lahaussois, 2012). If these older vehicles constitute a majority of a country's fleet this can pose a problem in the sustainability of a bioethanol mandate. This is often the case in developing countries (with the exception of Brazil) where a large percent of the vehicle fleet is comprised of older vehicles.

There are policy options, however, that can influence the renewal of the national fleet so that more vehicles on the road are newer, and might be more compatible with the blend level that is chosen. On the supply side, import regulations should be made consistent and harmonise with the blend mandate. For example, Algeria has an import regulation on vehicles that states that second-hand vehicles must be less than three years old. This is the case for Tunisia as well (UNEP, 2009).

Harmonising policies is an important part of ensuring that a mandate will be successful and sustainable. Apart from the import regulation example given, some economies such as Brazil have illustrated that coordinated policies can also introduce compatible FFV vehicles onto the market through tax incentives (see box below).

Market Support to Encourage Uptake of FFV, an Example from Brazil:

Brazil has a progressive biofuels for transport policy and is the second largest producer of bioethanol in the world. In 2001, after seeing the opportunity to further bolster the bioethanol market, make future fleet compatible with higher blends and respond to shifting ethanol supply, Brazil introduced a preferential tax treatment for the sales of flex-fuel vehicles. Each flex-fuel vehicle would be sold with a 14% sales tax, as compared to a 16% sales tax on non-bioethanol vehicles. This and decisive support from the OEMs has led to a substantial growth of FFVs in the country. In terms of passenger vehicles, fleet estimate models predict that in Brazil the proportion of gasoline (only) vehicles and bioethanol (only) vehicles will decrease in the medium-term. The fleet changes will really occur in a significant increase in flex-fuel vehicles which will represent 78.2% of the total feet by 2020 (table below).

Fleet by Fuel (% Total Fleet) in 2009 and 2020

	Gasoline	Flex-Fuel	Diesel	Bioethanol	Automotive Natural Gas (NGV)
2009	49.8	35.1	4.5	5.3	5.3
2020	14.6	78.2	4.5	0.4	2.4

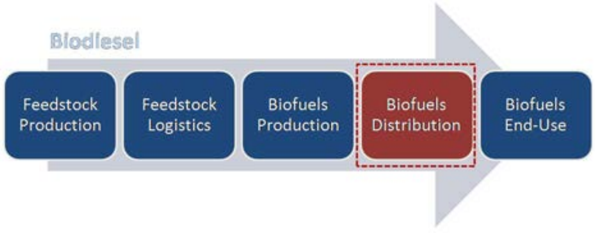
This growth of these vehicles provides some lessons on the ability of the auto industry to adapt and scale-up production on FFVs and the consumer willingness to accept a somewhat “new” technology.

Source: Losekann, 2010.

8.5 Compatibility challenges with biodiesel

Although globally biodiesel production is small relative to bioethanol feedstock production, biodiesel production (Fatty-Acid Methyl Ester (FAME)) is still expected to be an important energy crop in developing countries. For countries that are creating mandates for biodiesel, similar compatibility challenges found in bioethanol exist. These are both related to distribution compatibility and vehicle compatibility.

8.5.1 Biodiesel – compatibility challenges in distribution

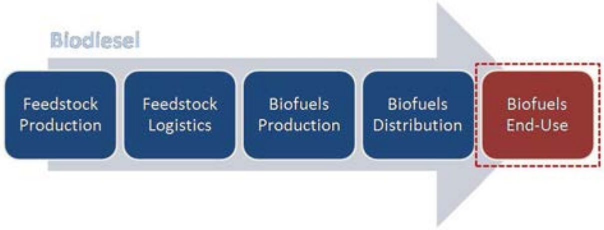


Biodiesel blending (FAME) can be done in one of three ways, depending on the type of feedstock and location of physical infrastructure: (1) splash blended at the end use stage in a storage tank (2) blended by a distribution company and sold as a final blend product, or (3) blended at the petroleum terminal. (The last method is the recommended one as it presents the most assurance to customers that the blending is complete.) Depending on the method of blending and different infrastructure needs, infrastructure adjustments will need to be made to make systems compatible (National Renewable Energy Laboratory, 2009).

A literature review suggests that there is a need for additional research concerning the long term storage compatibility of different biodiesel blend levels in storage systems. Unlike bioethanol, research on the compatibility of distribution systems for biodiesel blends is nominal. At all levels however, there is some evidence that precautions need to be taken to ensure that storage materials during the distribution phase are compatible. For example, a mitigation step that has been illustrated is that at all blend levels, the addition of a synthetic oxidant, along with consistent monitoring of biodiesel in storage and tanks should occur to ensure that oxidation stability levels are kept at optimal levels. This is an issue related to fuel quality. If not it could have corrosive effects and also create conditions for microorganisms, which might end up affecting fuel quality and eventually fuel system durability (National Renewable Energy Laboratory, 2009).

Compatibility at petroleum terminals and facilities will be a big challenge for the long term sustainability of biodiesel. Evaluations of the terminals are important for independent retailers to conduct, and regulations and certain certification might have to be approved to maintain quality standards. Some equipment might have to go through retrofitting, depending on the level of biodiesel that is being distributed at the pump (the higher the blend level, the greater compatibility issues will be present at the terminal). Some equipment use components include seals, hoses, tanks and piping that are in terminal facilities. In order to retrofit these materials they might have to be made from compatible materials such as: stainless steel, aluminum, fluorinated polyethylene, fluorinated polypropylene, teflon, and fiberglass (Bulktransporter Magazine, 2007).

8.5.2 Biodiesel – compatibility challenges in vehicles



Low Level Biodiesel Blends and Compatibility in Vehicles

Biodiesel blends, most commonly blended with petroleum diesel, pose less material compatibility issues than bioethanol blends. However, this is very contingent to the quality of FAME used. For instance, heavily oxidized FAME can have very detrimental impacts on diesel engines. Biodiesel blends should meet prescribed quality standards, set by national regulation, before going to the end-user (Lahaussois, 2012).

For light-duty passenger vehicles, low level blend levels are considered to fall within the range of B5-B7. Fuel and injection system manufacturers have previously made statements that in the United States, B5 is recognized as being the maximum blend level; in the European Union (EU) it is B7. Both of these levels are compliant with an ASTM and EN 590 standard for the US and EU respectively. In this case, B5 could be considered a safe blend level for a low FAME blend in a mass market fuel. If the blend level is higher (greater than B5) there might be a need for a protection grade at the pump for non-compatible vehicles (Lahaussois, 2012).

Mid-High Level Biodiesel Blends and Vehicle Compatibility

Passenger vehicles that utilise blends of B7 and higher have been shown to experience technical compatibility problems in durability tests performed by private auto manufacturers. These field tests reveal the possible dangers higher blends have on unmodified engines. For FAME blends that are used in captive fleets with dedicated engines (e.g. B30), there are specific maintenance and operational instructions to ensure performance. A list of common operational risks from the utilisation of high blend biodiesel in non-modified vehicles is summarised in Table 8-3.

Table 8-3 Vehicle compatibility risks with high level biodiesel blends

Operational Equipment	Risk
Fuel filters	Clogging caused by contaminants, sterile glycosides, microbes or under cold climate conditions (*not only restricted to high blends)
Fuel system parts – high pressure pump, injector	Sticking and corrosion after certain standstill periods
Injector	Nozzle coking and deposits of fuel that is accelerated through by-products of biodiesel
Piston rings and exhaust gas recirculation systems	Deposit formation
Engine (general)	Increase of engine oil dilution under low load operation, sludge formulation of engine oil

Source: Diesel Technology Forum, 2011

The most common problem seen in engines is that biodiesel blends might “clean out” vehicle fuel tanks and fuel systems. As diesel sometimes forms sediments that accumulate in engine storage systems, biodiesel blends have been shown to have properties that dissolve these sediments. Components such as seals, gaskets, adhesives, and parts made from natural or nitrile rubber can be affected. In that case, these engines would have to go through modification/retrofitting in order to sustainably utilise higher levels of biodiesel without causing engine problems (Schmidt, 2004). Degradation of FAME could also impact the operability or driveability of diesel vehicles.

Cold flow properties in biodiesel blends are one of the concerns that are commonly raised in the context of biodiesel /vehicle compatibility. In colder climates, there is a risk that biodiesel can freeze or gel in engines. As well fuel filter plugging could occur in low temperatures due to the specific cold flow properties of the FAME used that is typically related to feedstock used. For higher blends and climates that are above the freeze point, biodiesel can still be utilised, although additional blending infrastructure might be necessary, such as adding low-temperature flow additives (NREL, 2009).

Retrofitting for Biodiesel Blend Compatibility

For many developing countries, compatibility issues will become a considerable economic challenge if proper strategy is not put in place. Biodiesel vehicles that are not compatible with the mandated blend level might experience shorter operability lifetimes and pose an economic burden on households that operate an older vehicle. Retrofitting may be an option to maintain the performance of the vehicle. However, the costs of the retrofit might be substantial relative to household income or the cost of the vehicle itself. Additionally, retrofitting vehicles to be compatible with higher blends might not be possible in developing countries where some parts are unavailable. Thus, the option of retrofitting vehicles is not considered feasible in developing countries. Other policies that continually push the fleet make up to be more compatible, such as scrappage programs, where a car owner would receive a monetary incentive to turn in his/her old vehicle is one way of approaching the problem apart from retrofitting. Another can be to offer a protection grade for non-compatible vehicles until fleet renewal is compatible with the new FAME blending.

8.6 Beyond vehicle/fuel compatibility: other challenges that affect the implementation of mandates

Other issues besides vehicle/fuel compatibility influence the successful implementation of a national biofuel blending mandate. Many of these issues can be seen as external constraints and if considered before the development of mandates and targets, might prevent future economic losses. As previously discussed in the introduction, decision makers should consider these questions alongside compatibility questions. These considerations should aid in the development of appropriate mandates. These peripheral issues include (but are not limited to): the availability of sustainably sourced and produced biofuels, fuel quality, consumer awareness and use and industry engagement.

Availability of sustainably produced biofuel

The available supply of biofuels for transport should be determined from first conducting an assessment of domestic energy needs in the sector and available sustainable resources. These potentials, as well as the economic costs of importing biofuels, should be considered when determining the appropriate volume of biofuels that are feasible to enter the market and should guide the formulation of biofuel blending mandates. All of the assessments of potentials should take into account sustainable principles and criteria. A systematic process for conducting these assessments is advised using national planning tools such as the UN-Energy Bioenergy Decision Support Tool.

Biofuel quality

For countries that adopt blending targets and mandates there is a need to ensure that the quality of the biofuels and final fuels are meeting certain set standards. For mass market fuels, the use of internationally recognised standard such as CEN or ASTM is recommended to ensure vehicle manufacturers warranty. For end-users, these quality standards are an assurance that the biofuel that they are purchasing at the pump meets a certain quality standard and specifications that will not have negative effects on their engines (APEC, 2007).

Biodiesel fuel quality challenges are related to both fuel properties and biodiesel production processes and feedstock. These effects need to be monitored to ensure that quality standards are met. For example feedstock parameter properties, such as free fatty acid, insolubles, iodine value, phosphorus, stability and deposits, sulphur, and water are all necessary to monitor and specify in a standard. A study completed from Hart Energy Consulting reports that “biodiesel market problems often have less to do with the standards, and more with poor manufacturing practices and quality control resulting in biodiesel not complying to standards in place” (APEC, 2007). Therefore, for developing countries that are looking ahead to create national markets, monitoring approaches and systems for fuel quality standards need to be created and followed.

For bioethanol as well new guidelines and specifications could be aligned with other market standards. The Worldwide Fuel Charter Committee, for example, has released collective guidelines concerning the quality issues that are present in all bioethanol blends. The guideline document, representing the views of the automotive industry, outlines performance and measurement methods for various levels of bioethanol and is focused on the compliance of blenders and the quality of the blend (Auto Alliance, 2011).

Consumer awareness

Consumer awareness of new biofuel mandates should be undertaken by the government. Evidence has shown that often times, when a new blend level is introduced at the pump, consumers are unaware of which blend is compatible with their vehicle. If consumers are not aware of compatibility issues, this may lead to misfueling at the pump, or sometimes strong reactions against higher blends as consumers believe that it will affect their vehicles in the long term (without necessarily having sufficient information). This happened in Germany in early 2011 where consumers refused to buy the new petrol grade E10 despite having compatible vehicles. A combination of factors could explain the customers’ reticence such as lack of communication about vehicles’ compatibility or impact of the new fuel on the vehicles (Lahaussois, 2011).

Industry engagement

It is apparent that engaging and communicating with industry is critical when developing a biofuel mandate. Retailers, blenders, distributors and car manufacturers (OEMs) need to be not only made aware of new regulations, but invited and involved in the development process. As well, biofuel producers should also be involved in the dialogue as processes in their production could have an impact on the quality of FAME (and ultimately end use fuel) produced. Below is an outline of some challenges that industry faces when biofuel blending mandates are developed. It is important for decision makers to be aware of these challenges and find solutions to resolve them together. Table 8-4 shows an outline of challenges to industry when biofuel blending mandates are developed.

Table 8-4 Outline of challenges to industry when biofuel blending mandates are developed

Industry Party	Compatibility Challenge	Potential Policy Solution
OEMs	• New vehicles have to be warranted for new biofuel blend levels	• Provide longer lead times for regulation to be implemented in order for OEMs to have time to research and develop compatible vehicles (i.e. more than five years) • Provide incentives for OEMs to provide FFVs or those vehicles with higher biofuel blending compatibility
Retailers/ Distributors	• Higher blend levels have to be included at the pump, even though the demand for higher blends is low • Protection grade pumps need to be included at the retail station • Sometimes stations need to be retrofitted for higher blends	• Offer more lower fuel blends across a wide region, than concentrating higher blends in a few remote stations • Provide tax incentives/ cuts for retrofitting retailing stations

The following is an example of how a lack of industry dialogue affected the outcome of a blending mandate in Thailand.

Industry Engagement, Thailand

Thailand has instituted a mandatory blend of biofuels to be used in its national market. In 2007, the government made a concerted effort to push towards the uptake of E10, however, the effort failed because of the lack of the automotive industry to provide appropriate warranties on new vehicles. After this lesson, policy makers worked with major automobile dealers to agree to provide warranties to consumers for vehicles that would be compatible with the new *biodiesel* blending mandates. Through industry engagement both parties agreed on the warranties that would be developed for the future market.

Source: Biofuels Digest, 2010.

8.7 Conclusion: Informed, integrated policies are needed for biofuel mandates and targets

In the medium-term mandates are expected to increase as more countries become equipped to source and supply their own markets, or in some cases export to markets with biofuels. However, as this research has illustrated proposals to create or increase blending levels are constrained by the current fleet’s ability to utilise the blend mandated or constrained by the current infrastructure. If a country is not equipped with either (1) a compatible fleet, or (2) compatible infrastructure for distribution/ storage, then compatibility issues might impact the successful implementation of a mandate. Therefore, it is imperative to develop mandates that allow biofuel blends that are compatible with a majority of the fleet, or create innovative policies that structure appropriate conditions to turn over old fleets in order to make new generations of fleets more compatible whilst ensuring in the meantime that non-compatible fleet have access to a protection grade. This encompasses both demand side policies (such as consumer incentives) and supply side strategies such as import regulations on non-compatible vehicles.

The research suggests that for developing countries that are interested in developing a bioethanol blending mandate, ***a safe level of blending is below E10*** (assuming there is not a high prevalence of FFVs) (Mass, 2011). This would assume that a blend level of E5 is suitable as an “entry” blend level, as bioethanol blends move incrementally from E5 to E10 to E15, etc. For developing countries that are considering an increase in bioethanol blend levels, it is imperative that a thorough assessment of the current fleet and infrastructure is done. From an economic and compatibility standpoint, diversifying the availability of lower blends might be more constructive than increasing the total national blend level (see Figure 8-5). With a mandate of E15, for example, only a few retail stations would supply it as only newer vehicles would be compatible. Thus, the demand is too low for it to be economical. Instead, it might make more sense to introduce lower blend levels and increase the availability of the supply throughout the country. This also implies that there are protection grades at the fuelling stations.

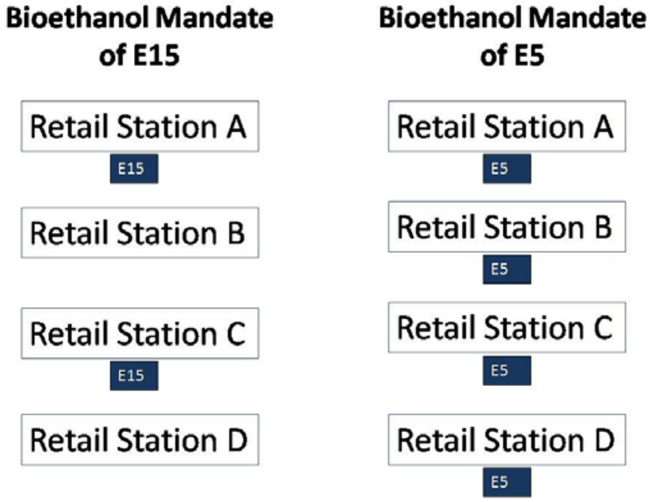


Figure 8-5 Blending concept

For countries that are considering the introduction of biodiesel mandates, research has shown that the ***blend wall for developing countries is B5 to B7*** (Rimmer, 2011). B7 can be seen as the maximum blending level if high quality standards are used (Lahaussois, 2011).

Without comprehensive and integrated planning, many compatibility challenges might emerge with current vehicle fleets and infrastructure. It is important that future policies, mandates, targets, etc. are harmonised with other cross-cutting policies for transport. For example, in some cases, emission standards between OEMs and retailers/ biofuel companies are different. The same can be said for fuel efficiency and quality standards. Fuel quality and vehicle emissions standards should always progress together as specific vehicle emission regulation will dictate specific after treatment systems that will require a specific fuel quality standard to ensure the correct performance of the vehicle technology to meet the emission regulations (Lahussois, 2011). This often times will set the maximum biofuels content that is allowed in mass market fuel to be used by a certain segment of the vehicle fleet. Therefore, the national planning process should create blending policies that are consistent with other policies that affect similar stakeholders and industry.

On a national planning level, compatibility is just one of many factors decision makers must consider when developing appropriate biofuel blending mandates and targets. The compatibility of a specific decision framework is presented below and the following steps are recommended for developing countries that are interested in creating mandates for biofuels or who are looking to alter/increase their existing blend level. Each of the steps requires reliable data and research, and input from various stakeholders in order to develop a comprehensive assessment (Figure 8-6).

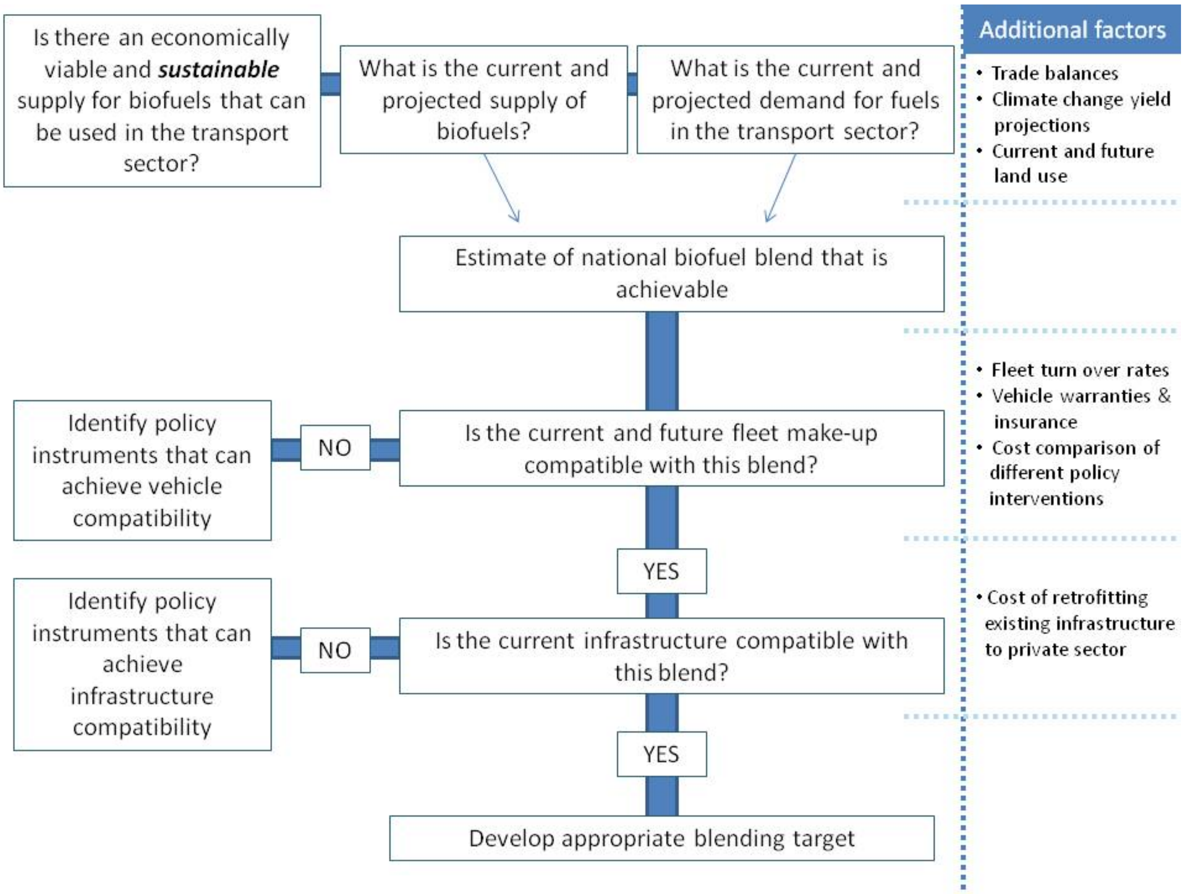


Figure 8-6 Decision tree for biofuel blending

9 Stationary applications

9.1 Introduction

Biofuels as energy carriers for transport are of interest to many countries (IEA 2011), and global trade in liquid biofuel is increasing (IEA Bioenergy 2011). Still, in many developing countries, the majority of bioenergy is used for **non-transport** services, especially cooking, electricity generation and (process) heat. To allow for a comparison of stationary and transport application, this section evaluates the possibilities to use liquid biofuels for **stationary** use in selected rural settings in terms of costs and environmental impacts.

9.2 Settings for stationary biofuel applications

The two main stationary biofuel applications settings of interest are village-based electricity generation and small-scale cooking, both based on straight vegetable oil (SVO).

As this study analysed just one setting which produces SVO from Jatropha, and such settings are typical for rural electrification schemes[29], the biofuel provision from this setting is used, even if currently no real-world SVO project in Tanzania is in operation (GIZ 2011). The only change from the setting is that instead of using a transport distance of 450 km for the field to the mill and from the SVO mill to the consumer, a transport distance of **10 km** is assumed for both, reflecting the village-based production and use of SVO.

In the comparison, SVO is used either as a transport fuel for busses or truck, as a fuel for village-sized diesel generators, or as a cooking fuel for stoves. The respective reference systems are fossil-based diesel (for transport and electricity[30]), and LPG for cooking.

As Tanzania imports practically all fossil-based oil products, this setting also indicates the potential benefits of substituting domestic biofuels for imports. As a sensitivity case, electricity from the grid is assumed instead of diesel generation.

Data for the Tanzanian electricity and oil system are based on IEA statistics. The data for the local diesel generator were derived from ETA (2003), Gül (2004) and WB (2009), for the LPG stoves from Afrane/Ntiamoah (2011) and Gaul (2011).

Data for the SVO diesel-generator were based on Gmünder et al. (2010) and Gaul (2011), for SVO stoves the data came from Gaul (2011) and Wagutu (2010).

The scenarios for the comparison of stationary biofuel applications were defined so that they imply the **same SVO consumption,** but SVO delivers different energy services.

Table 9-1 shows the key scenarios assumptions.

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[29] see Achten (2010), Duarte, (2010), FAO/IFAD (2010), Gaul (2011), Gmünder (2010), GTZ (2010), Kerkhof (2008), Kimming (2011), Raswant (2011), Wagutu (2010), Wijgerse (2008), Wiskerke (2008).

[30] A discussion of rural electrification is beyond this study, but it is noteworthy that more and more emerging economies deploy renewable energy options to provide electricity in off-grid rural settings, see IEA (2010). Until now, those schemes have mostly relied on hydro and solar PV, so the role of bioenergy so far has been small.

Table 9-1 Scenario definitions for the stationary biofuel applications in Tanzania

Scenario	**electricity**	**cooking**	**transport**
REF local	1 kWh local diesel	2 kWh from LPG stove	12 km diesel bus
REF grid	1 kWh grid	2 kWh from LPG stove	12 km diesel bus
SVO-el	1 kWh local SVO	2 kWh from LPG stove	12 km diesel bus
SVO-cook	1 kWh local diesel	2 kWh from SVO stove	12 km bus diesel
SVO-bus	1 kWh local diesel	2 kWh from LPG stove	12 km bus SVO

Source: Oeko-Institut assumptions; local electricity distribution excluded

The **reference** scenario assumes that 1 kWh of electricity is produced locally from a small-scale diesel generator, but costs of the local distribution systems are excluded.[31] For cooking 2 kWh of process heat from LPG is assumed, reflecting that energy needs for cooking are typically higher in rural villages. For transport, a diesel-run minibus is assumed which can transport (on average) 5 people plus the driver[32]. The **sensitivity** case to the reference scenario assumes that electricity is coming from the Tanzanian grid, all other assumptions are equal to the reference.

The three **SVO scenarios** assume that the Jatropha-based SVO is used for different services:

- In **SVO-el**, the diesel generator is run on SVO, while cooking uses LPG, and the bus is run on diesel (as in the reference).
- In **SVO-cook**, SVO is used for cooking (instead of LPG), while the local generator and the bus run on diesel (as in the reference),
- In **SVO-bus**, the bus is run on SVO, while the local generator is run on diesel and cooking uses LPG (as in the reference).

The scenarios deliver the same energy services to the local village, and the SVO scenarios use the same amount of (locally produced) SVO.

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[31] The configuration of local grids is not possible for generic settings. The scope of the analysis made here is on the effects of using SVO for different energy services. Thus, the exclusion of the local distribution grid does not affect the differences between scenario results (see Gmünder 2010).

[32] The transport distance is chosen so that the minibus running on SVO consumes the same amount of SVO as in the other SVO scenarios.

9.3 Costs and employment of stationary biofuel applications

The compilation of cost and efficiency data for the stationary biofuel applications in the village setting used the SVO fuel cost data calculated in this study (see section 4). For the reference systems, data from GIZ (2011) for the 2010 diesel prices in Tanzania were used and own estimates on LPG prices were used based on studies in West Africa.

The results of the cost and employment analysis are shown in Table 9-2. The results for the cost analysis are shown in Figure 9-1.

Table 9-2 Scenario results for Tanzania – costs and employment (year 2010)

	annual costs [€$_{2010}$]		**employment effects [jobs x 10^{-6}]**	
Scenario	**@ 8%**	**@ 12%**	**direct**	**Total**
reference	1.08	1.08	0	6
sensitivity	0.87	0.91	0	15
SVO-el	0.99	0.99	149	169
SVO-cook	0.86	0.87	149	169
SVO-trans	0.99	0.99	149	169

Source: Oeko-Institut calculation with GEMIS 4.7; el = electricity; SVO = straight vegetable oil from low-input Jatropha cultivation on marginal land

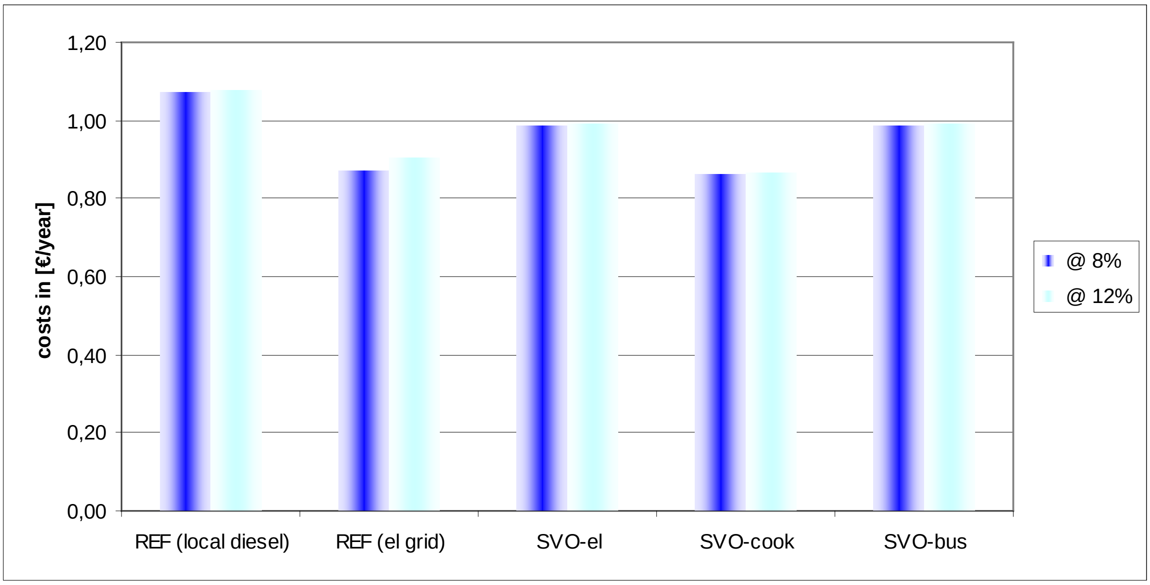

Figure 9-1 Scenario results for Tanzania – annual costs (year 2010)

The annual costs for delivering 1 kWh of electricity, 2 kWh of cooking heat and 12 km of bus service vary only slightly between the scenarios. The SVO cases would reduce the costs compared to the reference by 8% for electricity and bus, and by 20% for cooking, and these result are independent from the interest rate assumed for capital. Interestingly, the SVO cooking case would also be slightly less costly that the sensitivity case in which electricity would come from the Tanzanian grid (excluding local distribution).

With regard to employment, the SVO cases show a very significant increase over the reference and the sensitivity case, both for direct and for total jobs. The direct employment does not vary between the SVO scenarios as they consume the same amount of SVO.

9.4 Environmental effects of stationary biofuel applications

In addition to the cost and employment analysis, the comparison of key environmental effects of the scenarios is given in Table 9-3. The results for CO_2eq and CO_2 are shown in Figure 9-2.

Table 9-3 Scenario results for Tanzania – GHG emissions (year 2010)

Scenario	**CO_2eq [g]**	**CO_2 [g]**	**CH_4 [g]**	**N_2O [g]**
REF (local diesel)	3,285	3,180	3.0	0.10
REF (el grid)	2,522	2,410	3.4	0.09
SVO-el	2,170	2,088	2.1	0.10
SVO-cook	2,313	2,231	2.1	0.10
SVO-bus	2,157	2,076	2.1	0.10

Source: Oeko-Institut calculation with GEMIS 4.7; el = electricity; SVO = straight vegetable oil from low-input Jatropha cultivation on marginal land

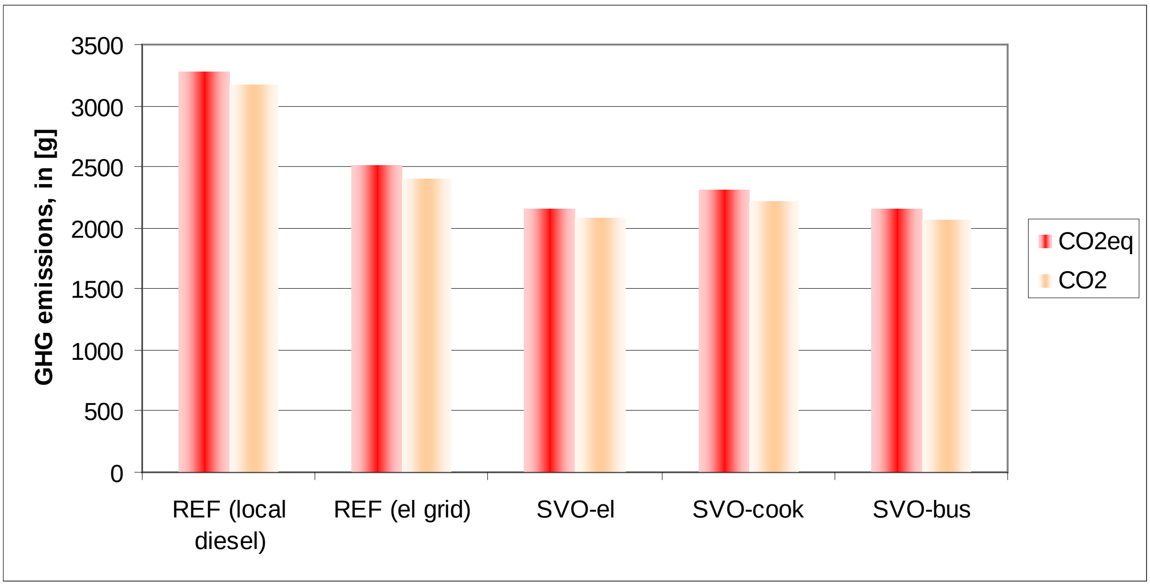

Figure 9-2 Scenario results for Tanzania – GHG emissions (year 2010)

All SVO cases reduce **all** GHG emissions compared to both the reference and the sensitivity scenario. The reductions in terms of CO_2eq against the reference scenario are 34% for the SVO-el and the SVO-bus cases, and 30% for the SVO-cook case. Interestingly, the SVO cases also reduce the CH_4 (by 30%) and N_2O (by 2%) emissions against the reference.

A similar analysis was carried out for the emissions of air pollutants from the scenarios, the results are given in Table 9-4. The results for the air emissions are shown in Figure 9-3.

Table 9-4 Scenario results for Tanzania – air emissions (year 2010)

Scenario [emissions in g]	**SO_2eq**	**SO_2**	**NO_x**	**PM_{10}**
REF (local diesel)	27.0	11.1	22.8	5.6
REF (el grid)	12.3	6.8	7.8	1.6
SVO-el	21.7	6.5	21.8	5.3
SVO-cook	24.8	9.4	22.1	5.5
SVO-bus	21.8	6.5	22.0	5.4

Source: Oeko-Institut calculation with GEMIS 4.7; el = electricity; SVO = straight vegetable oil from low-input Jatropha cultivation on marginal land

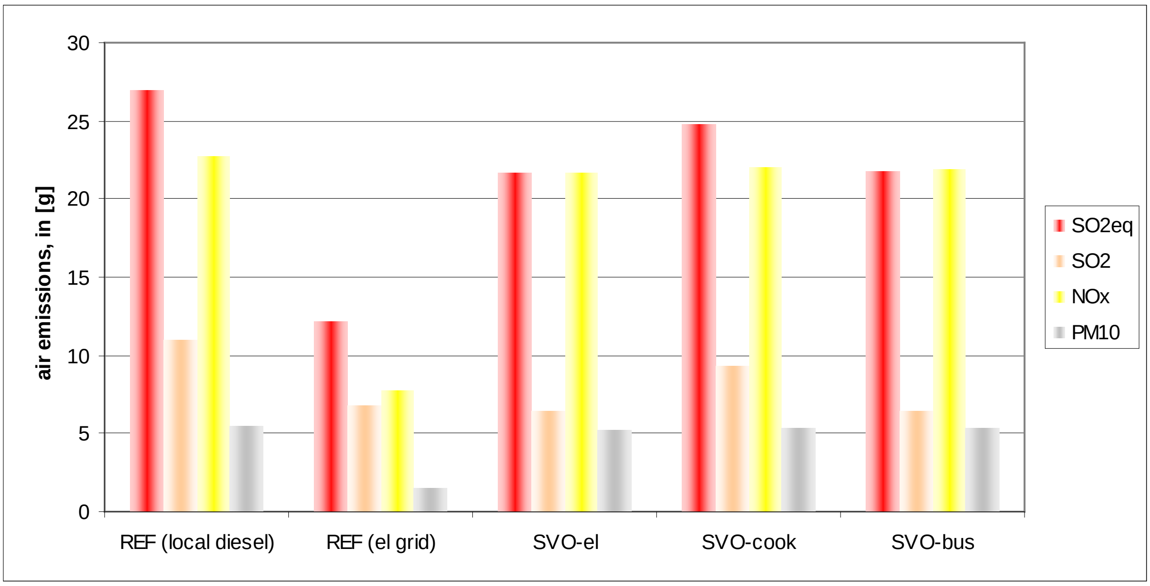

Figure 9-3 Scenario results for Tanzania – air emissions (year 2010)

Compared to the reference, **all** SVO scenarios reduce **all** air emissions though differently: The SVO-el and SVO-bus scenarios achieve a 20% reduction of SO_2eq, a 41% reduction of SO_2, a 5% reduction of NO_X and a 5% (SVO-el) and 3% (SVO-bus) reduction for PM_{10}.

The SVO-cook scenario shows a 8% reduction of SO_2eq, a 15% reduction of SO_2, a 3% reduction of NO_X and a 2% reduction for PM_{10}.

From the air emission point of view, the SVO-el and SVO-bus scenarios perform similar, with a slight benefit for the **SVO-el case**.

Box: Black carbon from biomass burning

Besides the GHG emissions usually considered (CO_2, CH_4, N_2O), there is a discussion on “black carbon” (BC) as another emission which changes the radiative balance of Earth’s atmosphere[33]: BC consists of very fine particles which can both reflect and absorb light, change the albedo of surfaces, and cloud formation. With a comparatively short atmospheric residence time, the radiative balance of BC might increase warming in the time horizon of a few years up to a decade, which is not included in the 100-year time horizon of typical global warming potential scenarios. Still, as BC is mainly an issue of incomplete combustion of solid fuels, the role of emissions from forest fires, open burning of agricultural and forest residues, and from wood stoves can have a significant near-term climate implication. As BC is also considered a health threat, reducing BC has positive trade-offs beyond climate change.

Given the uncertainty and variation in data for both radiative impacts, and emission factors, this study does not analyse BC explicitly. The emissions of fine particulates (PM_{10}) are a proxy indicator for BC formation, though. Reducing PM_{10} will also reduce BC, and its respective impacts the radiative forcing balance.

9.5 Recommendations in the context of GEF activities

The findings of the exemplary analysis of stationary applications of liquid biofuels indicates that village-based, decentralized rural electrification might be more effective in reducing emissions that transport applications so that this option should be explored and possibly implemented where energy access is a key issue of sustainable development.

There are more options to use liquid biofuels in stationary applications (e.g., EtOH-based gelfuels for cooking), and also to convert both biogenic residues and bioenergy crops into biogas (and biomethane) which could be used for clean cooking, and electricity generation.

It is recommended to consider alternative uses of liquid biofuels during the evaluation of GEF project proposals, and to extend the available information on decentralized stationary uses of biofuels for more settings to substantiate the exemplary findings presented here.

Furthermore, there might be opportunities to “modernise” provision of biomass-based energy services – especially traditional use in stoves – using liquid biofuels to replace firewood and charcoal, which could reduce pressure of forests, and respective negative impacts. These options should be explored in more detail, taking into account the cost and investment implications, and potential benefits on health.

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[33] For a comprehensive summary of current knowledge on BC see: UNEP (United Nations Environment Programme)/WMO (World Meteorological Organization) 2011: Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers; Nairobi/Geneva http://www.unep.org/dewa/Portals/67/pdf/BlackCarbon_SDM.pdf

10 Scale up and integration

The research for this chapter is still on-going and will be finalised in July 2012. In this chapter the potential and sustainable implementation of a large scale bioenergy sector is assessed. The following countries are included:

- Mozambique
- Ukraine
- Argentina

For each country, the energy profile, the relevant biofuel policies, the availability and use of land for biofuels and the related biofuel potential, the potential share of biofuels in the energy mix and the barriers to biofuel development specific to the country will be discussed. Utrecht University has closely cooperated with counterparts in the countries.

The key step in this study is to assess how bioenergy potentials develop over time. Therefore a spatio-temporal land use change model is developed that enables spatially detailed assessment on when and where land is or could become available for bioenergy production while taking into account both the developments in other land use functions, such as land for food, livestock and material production, and the uncertainties in the key determinant factors of land use change. The developments in the main drivers for agricultural land use, demand for food, animal products and materials were assessed based on the projected developments in population, diet, GDP and self-sufficiency ratio see Figure 10-1.

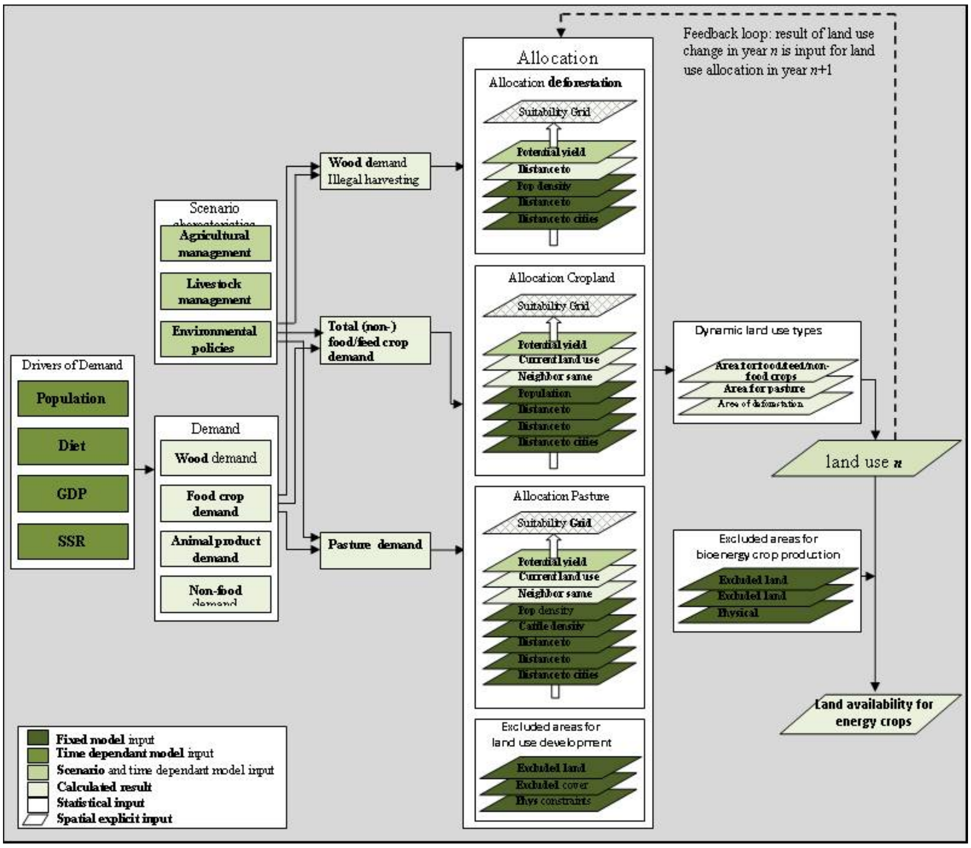

Figure 10-1 Overview of the model and parameters for the availability of land for energy crop production (van der Hilst)

A scenario approach was used to explore potential long term developments in the drivers of land use change. The Business as Usual (BAU) scenario projects a future in which historical trends in policies and technological adoption are continued. The progressive scenario represent a discontinuation of historical trends: it assumes a technology adoption and a policy context in which there is more emphasis for sustainable development. The scenarios were formulated in close cooperation with different stakeholders in the countries.

The land use changes in the timeframe 2005-2030 were modelled for each year on a 1km2 grid cell size level by allocating land to a land use class based on the suitability for the specific land use classes. The suitability of land was defined by a spatial weighted summation of a specific set of suitability factors (i.e. the vicinity of the same land use class; the productivity; the distance to road, water and main cities; population and cattle density; conversion elasticity; and the distance to forest edge). Areas that are not suitable (such as steep slopes) or not allowed (such as conservation areas) to be converted to agricultural land, were excluded. Based on the allocation of land use classes, the land availability for bioenergy crops was determined for each year. Local counterparts have assisted in collecting data input for the model and verifying the model output. The different GIS maps that are typically included in the allocation process are shown in Figure 10-2.

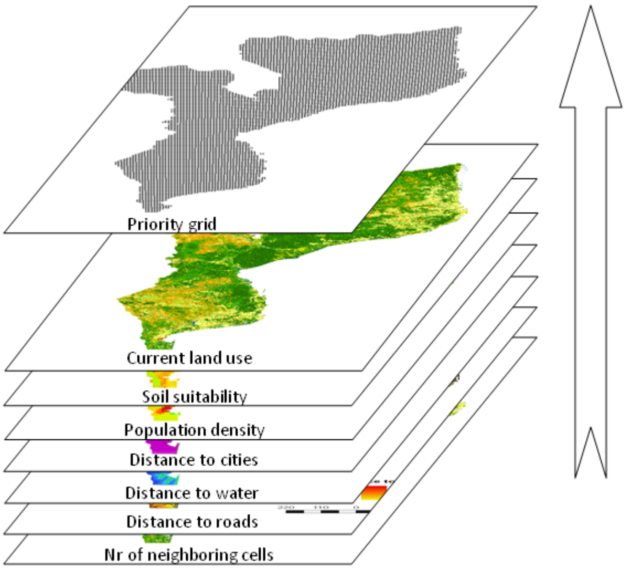

Figure 10-2 Methodology of spatial weighted summation of suitability factors for allocation of land use types.

11 Recommendations for GEF policy

11.1 Summary

The *Global Environment facility (GEF)* needs to set clear policies and priorities for future work and investments in biofuel related projects while providing guidance to countries that are keen to engage themselves in this sector. UN agencies in collaboration with scientific institutions worldwide address issues such as life-cycle energy and greenhouse gas assessments, economics, social/food security and pricing as well as overall environmental impacts, fuel and vehicle compatibility plus stationary applications, scale-up impacts and next generation biofuels. The results of this *GEF Targeted Research Project* are summarised in this report and its associated databases. The overall goal was to identify and assess sustainable systems for the production of liquid biofuels both for transport and stationary applications worldwide.

11.2 Specific recommendations

Life cycle energy and greenhouse gas (GHG) assessment

Future activities related to biofuel projects

- The calculation of life cycle GHG emissions for 74 biofuel settings reveals that every pathway emits less GHGs than the replaced fossil fuel, provided that direct and indirect land use changes can be avoided. Given this, biofuel projects can contribute to climate change mitigation and thus should be part of the GEF-5 climate change strategy. The 74 settings cover a broad portfolio of biofuel pathways. As all show GHG reductions, GEF can tailor biofuel projects to the national circumstances and the specific needs of recipient countries.
- As has been shown in chapter 3.1 and 3.2, biofuel GHG results strongly vary subject to yields, co-product use and production management. Therefore, GEF should strive for the best biofuel pathway design within the specific objectives and circumstances of a biofuel project. Furthermore, GEF should support capacity building with regard to these influences and raise awareness on the correlation between an improved GHG balance and a more efficient (and thus often cheaper) biofuel production.
- Among the different feedstocks, high yielding perennial crops have significant potential for GHG reduction. Also the use of agricultural residues such as straw is highly recommended as it is produced independently from agricultural land and therefore does not cause land use changes nor does it compete with food production. However, both types of feedstock are only accessible with second generation technologies that are often at an early stage of development. GEF should support awareness raising, capacity building and investment in pilot projects in order to enhance innovative technologies and make them available to developing countries.
- Biofuel production has many more impacts than GHG reductions. Therefore, it is recommended to pursue a broader perspective in project implementation that takes into account other GEF focal areas (e.g. biodiversity, land management). The implementation of multi-focal projects enhances the overall sustainability of biofuels but also can have further benefit with regard to GHG emission reductions. For ex-

ample, biofuels produced under the land degradation focal area can foster carbon sequestration which further improves the GHG results.

Use of the GEF Biofuel Greenhouse Gas Calculator

- The biofuel greenhouse gas calculator gives an overview on GHG results for a broad portfolio of biofuel pathways in developing countries and at the same time allows to perform own calculations. It is highly recommended that GEF requires the use of the calculator during project preparation phases and project evaluations in order to generate scientifically sound, harmonised and transparent calculations of GHG reductions in biofuel projects.
- For the successful implementation and dissemination of the tool and its further development it is recommended that GEF builds up competence and supports capacity building in the following areas: technical assistance to users of the calculator, handling review processes and result evaluation. Furthermore, GEF should monitor new developments related to biofuels and identify needs for updates. This concerns the pool of background data that needs constant updating and supplementation as much as the collection of project specific data.

Establishment of certification systems (focusing on GHG balancing)

- It is highly recommended that GEF introduces sustainability standards for biofuel projects and helps developing such standards at national level in order to provide a solid framework for the sustainability of biofuels. These standards should not only focus on greenhouse gas mitigation but take into account all relevant areas of sustainability.
- When it comes to GHG calculations within such standards and systems, the level of detail of the guidance should be adapted to the target groups (see chapter 3.3). If concrete calculations have to be done by market actors, a clear and transparent calculation methodology should be provided together with the related capacity building. The schemes assessed in chapter 3.3 can serve as appropriate examples. No matter how detailed guidance is, every method still gives ample room for interpretation and leads to differences in result. Therefore it is recommended that GEF supports the development calculation tools that are tailored to the sustainability schemes / systems as well as to the target groups and include a harmonised set of background data. The tool development should come with the related capacity building on GHG calculation.
- On this background, GEF should carefully observe the developments at international level since more and more big economies (e.g. USA, Europe) ask for feedstock certification with GHG balancing being part of the process. Since calculation methodologies are far from being harmonised, GEF has to weigh between two aspects: implementing a methodology to check whether required thresholds would be met by a certain project or adapting the methodology to national or project specific needs.

Economic viability of the production of liquid biofuels

The differences in the biofuel production costs for the different fuel production pathways indicate the importance of the specific settings that take the local circumstances into account. Local data collection and specific case studies are therefore key to more accurate modelling of the biofuel production costs, the profitability for a farmer (by means of NPV calculations) and the identification of alternatives. Costs are dynamic and long term costs should be considered indicative. Generally production costs are expected to decrease over time following continuous process improvements, technological learning and increasing scale of production. Possibilities for cost reduction can also be linked to local technology adaptation and strategies need to be developed to identify technology components that can be locally fabricated. The cost of alternative energy source (for example fossil diesel fuel for usage in a diesel generator in a remote village) determines the competitiveness of the biofuel feedstock and should be considered.

Appropriate policies need to be devised to make biofuels production more competitive and reduce investment risks. At the same time, it is necessary to ensure that key sustainability aspects are fully taken into account, when assessing biofuel supply. Studies have shown that inclusion of sustainability criteria has potential impacts on the amount of biofuels that can be produced as well as final delivered costs of the biofuels. A prerequisite is that sufficient data of high quality is available in the project proposals submitted to the GEF. Our report contains default values that facilitate an evaluation the compilation of results for other biofuels, if insufficient data is available, then the data for the 74 biofuels pathways and settings can be used as a benchmark.

If the NPV < 0, the net cash inflows over the total project lifetime are lower than the cost of financing the project and it should not be undertaken. When the NPV is close to zero, there is an expected no-profit no loss scenario, then the GEF could further research the financial viability by an extended Cost Benefit analysis, including other indicators such as, Internal Rate of Return (IRR), Benefit / Cost Ratio (BCR) and Pay Back Period (PBP), see Table 11-1 that includes all aspects of the economic analyses.

Table 11-1 Decision tool for GEF, based on economic analyses

Decision based on	**STOP**	**CHECK**	**GO**
NPV	The NPV is negative	The NPV is close to zero	The NPV is positive and compares well to other feedstocks in the region or the same feedstocks in other regions
Life cycle costs	The life cycle costs do not compare favourably to other feedstocks or countries	The life cycle costs are neutral compared to other feedstocks or countries	The life cycle costs compare favourably to other feedstocks or countries
Data quality	Generic public literature	Specific cost data is lacking	Specific regional setting data on costs, yields etc.
Sensitivity / risks affecting profitability	High risk of project negatively affecting by changing market conditions	Medium risk of project negatively affecting by changing market conditions	Robust performance, NPV and life cycle costs remain positive/competitive for varying conditions
Technical and organizational complexity	Relies on new, not well-established (unproven) technology, new infrastructure	Relies on new, but proven and commercialized technology and/or new infrastructure	Technical and industrial capabilities available

Global environmental impacts -other than GHG emissions

The “traffic light” thresholds suggested in this study were derived from life-cycle and material flow analyses for the settings selected, and are subject to significant uncertainty and variation, especially for the feedstock cultivation, and downstream conversion. There is a lack of empirical evidence and representative data for some of the life-cycles and settings, so that future activities should compile more comprehensive data on non-GHG emissions, and especially address regionalized water use.

A key requirement to successfully meet the environmental challenges on the project level is the availability of adequate spatially explicit data, especially high resolution maps. In that regard, enabling activities on GIS-based spatially explicit data are crucial for future GEF funding in the biofuels realm.

Priority for GEF project portfolios should consider that, in the subsequent decades, conventional agricultural practices are not adequate to meet climate change challenges. Thus, mitigation measures should be considered as “standard” requirements, and best practices for biofuel projects should be demonstrated by project developers.

Social standards, criteria and indicators

A key requirement to successfully meet the social challenges on the project level is the availability of adequate data. The evaluation and assessment of biofuel projects versus food security aspects requires data needs, analytical skills and access to modelling.

Usually, this goes beyond capacities and resources available to project developers or the GEF staff reviewing projects. Therefore, GEF is dependent on the responsibility of countries and governments to analyse the characteristic of their own country and provide the necessary data sets.

Priority for GEF project portfolios should consider countries with analysed biofuel production impacts on prices and food security. GEF activities have to pay attention due to land tenure, labour conditions and gender issues. These impact categories influence human welfare and can avoid poverty and hunger. Due to increasing population and increasing demand for food the subsequent decades will be very decisive and the social security of biofuel producers will play an increasingly important role.

Evaluation of potential future (next generation) types of biofuels

Similar to first generation biofuel projects, projects submitted to the GEF for next generation biofuels should be based on detailed and transparent life cycle cost calculations. This report provides a generic analytical framework and data and can be used as benchmark. But given the spatial heterogeneity of agro-ecological conditions and state of infrastructure in most developing countries, it is important that the local context of each project is taken into account. Table 11-1 shows a decision tool for GEF based on economic analyses.

For the production of energy crops or residues up to the farm gate, all the key activities in the development of energy crop plantations and procurement of residues must be itemised and taken into account. Formula (II) in section 4.1 of the main report shows the equation that can be used for life cycle cost calculations. It is important to note that biomass costs are site specific and localised conditions (e.g. soil, water, climate, yields, terrain, accessibility, land and labour costs) need to be taken into account, as this can have a huge influence on the final biofuels costs. Specific crop production activities depend on the site quality and location which influences site preparation, choice of species, planting density, and rotations, required cultural management and soil amendments, degree of mechanisation, as well as transport and logistics and the market value of fossil alternatives.

For biomass energy supply chain calculations, it is important to have regional specific data (such as distribution of biomass, percentage of land under energy crops, infrastructure by type and quality, transport distance by mode) and conversion plant specifications (including location, scale, efficiency, load factors). The number of stages in a supply chain varies depending on the feedstock characteristics, pretreatment requirements and infrastructure, but a clearly defined chain with detailed logistical capacity indications (e.g. truck capacities, speed, operational costs per tonne-km; specifications for sizing, drying, densifying, conversion, transfers, storage) as well as relevant mass balance is necessary.

It is important in a developing country context to determine what processes are cost effective at small scale and can be carried out locally, and to identify the more capital intensive conversion processes that benefit from scaling effects and centralised processing. Biofuel conversion (especially for next generation biofuels) benefits from economies of scale and it is important to determine the optimal scale of production beyond which feedstock transportation costs become prohibitive. To ensure competitive delivery of biofuels, it is important to optimise the various chain elements against the required logistic capacity (i.e. volumes of biomass being handled), taking into account the supply operating windows and need for maintaining high equipment load factors. Examples of optimisation options include using large capacity trucks and ships, early densification of biomass, open air drying, improving effective use of equipment, maximizing the operating window and improving equipment load factors.

For next generation biofuels, the fuel conversion stages are especially capital intensive and thus it is critical that appropriate equipment is identified and costed (given the many potential conversion equipment combinations). It is also important to take note of the relevant equipment specific cost factors (lifetime, interest rate, etc.) and different cost type information (capital-related and installation, consumption-related and operation related). As next generation technologies are not yet mature, it may be necessary to incorporate aspects of time dependent technological learning and scaling up effects in the economic analysis. The establishment of next generation biofuels will entail technology transfer in developing countries and thus involve import dependency risk. However, there are also opportunities for utilization of agricultural and forestry by-products, developing of new supporting industries and skills.

Fostering fuel and vehicle compatibility

Biofuel and vehicle compatibility needs to be fostered by developing countries before blending policies are instituted. Although the GEF, through this research, can assist in providing information on compatibility for developing countries, it is recognised that fuel/vehicle compatibility is beyond the scope of GEF activities concerning Global Environmental Benefits (GEB). Therefore, these recommendations are best directed towards developing country governments.

Without comprehensive and integrated planning, many compatibility challenges might emerge with current vehicle fleets and infrastructure. Often times developing countries have fleet make-ups that are comprised of older and legacy vehicles, which can regularly experience problems if they utilise biofuels that are not at a compatible blend level. Also, existing infrastructure might not be ready and adapted to higher blends, and can pose economic risks if not retrofitted appropriately. Therefore, it is recommended that governments take various steps to determine what blend level is appropriate for biodiesel and bioethanol.

- Determine the economically sustainable supply of biofuels that can be utilised in the transport sector
- Estimate the achievable biofuel blend (contingent on supply and projected supply)
- Determine if the current fleet make-up is compatible with this blend level > if not, assess if there are policy instruments that can improve compatibility problems
- Determine if the current infrastructure is compatible with this blend level > if not, assess if there are policy instruments that can improve compatibility problems
- Structure appropriate blend level(s) and accompanying policy instruments

Liquid biofuels in non-transport applications

The exemplary analysis of stationary applications of liquid biofuels indicates that village-based, decentralized rural electrification can be more effective than transport applications in reducing GHG and non-GHG emissions, without negative cost and employment impacts. Therefore, stationary biofuel options should be explored further and possibly implemented where energy access is a key issue of sustainable development. In this, applications such as EtOH-based gelfuels for cooking and conversion of biogenic residues and bioenergy crops into biogas could offer additional options for clean cooking, and electricity generation, and biogas production could be integrated in many biofuel production systems which would help reducing CH_4 leakage (e.g. in palm oil mills).

It is recommended to consider alternative uses of liquid biofuels during the evaluation of GEF project proposals, and to extend the available information on decentralized stationary uses of biofuels to more settings.

Furthermore, there might be opportunities to “modernise” provision of biomass-based energy services – especially traditional use in stoves – using liquid biofuels to replace firewood and charcoal, which could reduce pressure of forests, and respective negative impacts. These options should be explored in more detail, taking into account the cost and investment implications, and potential benefits on health, including effects on black carbon emissions.

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Annex: Definition of Biofuel Supply Chain System Components

HARVESTING

Efficient feedstock harvesting methods must match the unique requirements of each biomass source and site conditions. A wide range of new technology is being developed for harvesting short rotation woody crops (SRWC). Common felling methods include manual (chainsaws), feller-bunchers/ feller-bundlers, feller chippers, and swath cutters. Feller-bundlers and feller chippers convert the biomass into chips or bundles respectively, and significantly reduce biomass extraction costs. Other variations include the harvester forwarder, feller chipper, feller chipper forwarder, feller forwarder, feller skidder, harvester-multi-stem, tree puller, etc. For developing countries, manual motorised systems may be preferred due to availability of low cost labour.

Forwarding

Harvested biomass needs to be hauled to designated landing sites around the fields to enable roadside processing, storage or further transportation to central facilities. Forwarding or primary biomass transportation can be accomplished in many ways. The most basic form involves hand crews physically carrying material out of the stand when the extraction distance is relatively short. This is clearly very labour-intensive work and presents numerous safety and health issues. An alternative approach is to use a forwarder (a self-loading off-road truck) to drive through the stand collecting biomass from piles and transport piles to roadside where it is dumped or unloaded with a crane. Piled biomass could also be removed with a biomass bundler, which collects and compresses material into composite residue “logs” (CRLs) that are significantly more compact than loose woody biomass. The CRL’s can be transported on standard forwarders.

TRANSPORTATION

To determine the costs of transportation, transport requirements are related to the spatial distribution of biomass in each region, as well as subsequent transport to processing units and conversion plant. For first transport distance estimation, it is assumed that the distribution of biomass over an area is constant and that the biomass is transported over a marginal transport distance, represented by the radius of a circle in which the biomass is spread with the given distribution density (Dornburg et al. 2001). First transport from the field to local processing centres is by truck. Truck transport from the first processing units to the processing facility is “dedicated”, meaning that the trucks return empty. The main transportation modes are mainly road and rail. Long distance transportation is normally done by train and ships, but road truck transport can also be used. Truck transportation is the most expensive (and is advisable to limit to a few hundred kilometres. Water transportation is also possible along the coast where transfers are required to ports with facilities for sea going ships. International shipping is by the bulk carriers and tankers, and these can be chartered and dedicated also.

BIOMASS PRE-TREATMENT OPTIONS

Pretreatment of biomass is necessary to improve logistic efficiency. It includes sizing, drying and densification. Hence, an important logistical question is to identify combination(s) of pre-treatment options which can best upgrade biomass properties for optimal logistics. The following pretreatment options are normally considered.

Sizing:

The purpose of sizing is to meet subsequent step feedstock specifications and to improve handling. Appropriate technologies for sizing have to be selected; typically a Chipper or roll crusher is used for chipping logs to 30mm while a hammermill can be used to grind the chips to less than 10mm. A bales chipper can also be used when dealing with bundles or bales. Sometimes, a harvest chipper can also be employed, where chipping is done in the field during harvesting. It is important to note that chips decompose easily and moisture content increases in storage. Hence chips should be dried quickly or chipped as late as possible in the chain, otherwise biomass dry matter losses can lead to poor supply chain efficiency and costly biomass delivery.

Drying:

Moisture content of fresh biomass is about 50% and drying is necessary to meet feedstock criteria at conversion plant: e.g. gasification requires feedstock with moisture content of less than 8%. In addition, drying also helps in reducing decomposition risks, fire and health hazards as well as reducing biomass weight (not volume) – and thus reducing logistic costs. To allow efficient drying, it must always preceded by sizing step, so as to expose greater biomass surface area. Usually, part of dried biomass can be used in the drying process, reducing the fossil energy requirements. Various drying technologies can be used e.g. the Rotary Drum dryer.

Densification:

Since untreated biomass is bulky, moist, fibrous, perishable and leads to expensive logistics, it is necessary to densify it. Densified biomass has high energy density, it is water resistant, easily crushed, does not rot and this results in cheaper logistics. Key technologies used for densification include baling, pelletising, briquetting, torrefaction and pyrolysis. Drying and sizing steps always precede densification, because of strict feedstock specifications. An important consideration for densification is the choice between small scale decentralised facilities and large scale centralised facilities. The former is suited to developing country conditions where small scale systems dominate, but the latter offers economies of scale which may be important in driving costs down.

(a)Pelletisation:

Pellets are made by compressing and extruding heated (pulverised) biomass. The high pressure melts the lignin and binds the biomass (otherwise a binder added). Pelletisation produces biomass with a consistent quality and size, with better thermal efficiency and higher energy density. The most common pellet technologies used include the Pellet press, the Piston Press, the Extruder and the Roller Press.

(b)Torrefaction:

Torrefaction is a thermochemical treatment of biomass at 200-320 °C (under atmospheric conditions and in the absence of oxygen) to give a dry, blackened material “bio-coal” final product. The process liberates water, volatile organic compounds (VOC’s), and hemicellulose (HC) from the cellulose and lignin. The VOC’s and HC are combusted to generate 80% of the torrefaction process heat. The remaining and warm lignin can act as a binder when the torrefied wood is pelletized. During torrefaction, biomass loses typically 20% of its mass (dry bone basis), and 10% of the energy content (in volatiles). Torrefied biomass can be densified (into briquettes or pellets) using conventional densification equipment, to further increase the density of the material and to improve its hydrophobic properties.

Torrefied biomass has a higher energy density (18 - 20 GJ/m3) which results in lower handling costs. It has more homogeneous composition and a wide variety of raw biomass feedstocks can be used to yield similar products. However, torrefied biomass is hydrophobic but this improves on densification. The process of torrefaction eliminates biological activity and thereby reduces the risk of fire and decomposition. It improves the grindability of biomass which leads to a reduction in energy demand for densification. Small scale and decentalised torrefaction is possible, which offers advantages for reducing logistical capacity early in the chain. Torrefied biomass can be used as a substitute coal in combustion or gasification feedstock.

(c) Pyrolysis:

Pyrolysis involves the thermochemical breakdown of organic material from 430-800 °C, under pressure and in the absence of oxygen. It produces gas and liquid products and leaves a carbon rich solid residue (char). The composition of products depended on pyrolysis method, characteristic of biomass and reaction parameters, e.g. extreme pyrolysis (carbonization) leaves mostly carbon as the residue (used in industrial charcoal production). Higher efficiency is achieved by the so-called “flash pyrolysis” where pulverised feedstock is quickly heated to between 350 and 500 °C for less than 2 seconds. The resulting “bio-oil” has a high bulk density (1200 kg/m3) and a heating value of 15-18 MJ/kg. Pyrolysis oil can be used as a fuel, but also as a feedstock for gasification. Because of its corrosive nature, pyrolysis oil requires special lining in carbon steel tanks for storage and transportation (and this increases handling costs by about 14%).

Torrefied biomass densification (torrefied and pelletised biomass, TOPs)

Torrefied biomass is a porous product with a low density. It is fragile, which makes it relatively easy to grind. However, decreased mechanical strength and increased dust formation, in addition to low volumetric density, makes further densification desirable. This is especially important when long distance transport is considered. In the ECN Laboratories, the mass density of torrefied biomass pellet has been measured at around 22 MJ/kg, whereas the energy density reaches up to 18 GJ/m3. Although this energy density is less than that of coal (20.4GJ/m3), it is 20% higher than commercial wood pellets. Thus, torrefaction in combination with pelletisation (TOPs) offers significant advantages when the biomass logistics are considered. With torrefied biomass, the pressure required for densification could be reduced by a factor of 2 at 225 oC, while the energy consumption of densification could be reduced by a factor of 2 compared to biomass pelletisation. Torrefaction can reduce power consumption required for size reduction by up to 70–90% compared to conventional biomass pelletisation. A simpler type of size reduction, such as cutting mills and jaw crushers, can be deployed instead of hammer mills which are used for the conventional pelletising process.

Impact of pre-treated biomass on gasification systems

Torrefied biomass has several advantages; prior to gasification, electricity consumption for milling decreases significantly. The fibrous structure and the tenancy of biomass are reduced by hemicellulose decomposition together with the depolymeristation of cellulose during the torrefaction reaction. The power consumption in size reduction is decreased 85% when the biomass is first torrefied. The energy consumption required for milling biomass into 100 mm decreases from 0.08kWe/kWth(dry) to 0.01–0.02kWe/kWth when torrefaction is applied. Moreover the capacity of the mill increases in proportion to the particle size. When the 0.2mm particle size is considered, the chipper capacity for torrefied willow is up to 6.5 times the capacity of untreated willow. For both torrefied pellets and conventional pellets, drying is not needed.

In the case of bio-oil, the pre-treatment section needs to be adjusted depending on the bio-oil characteristics. Sizing is not necessary anymore and the feeding system can be similar to the liquid fuel feeding systems for CFB gasification instead of those that are suitable for solid fuel feeding.

Storage

Storage is required wherever there is difference in scale in adjacent supply chain steps, or when biomass is supplied seasonally. The main biomass storage types include open air, outdoor covered, bunker, container and silo. Harvested biomass can be stored in the field (open air) for four to six weeks to facilitate natural and low cost drying. After storage in the field, the moisture content of biomass is expected to fall from about 50% to about 30-35%. Further storage is expected at the roadside for logs and bales, at the conversion unit and at other transfer points in the chain. Storage facilities differ for each fuel type, i.e. open-air piles are assumed for logs and bales while pellets are housed in silos of capacity 5000m3. Pyrolysis oil is stored in special lined carbon steel tanks, which are 14% more expensive than conventional steel tanks.