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

Impacts of Biofuel Production

Case Studies: Mozambique, Argentina and Ukraine

FINAL REPORT

Universiteit Utrecht

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UNITED NATIONS
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Executive summary and recommendations

Executive summary

The objective of this study is to develop and demonstrate a methodological framework to enable an ex-ante assessment of the potential land availability for dedicated energy crops and the potential environmental and socio-economic impacts of large scale biofuel production. This research involves two methodological steps:

1. The assessment of the developments in land availability for dedicated bioenergy crops towards 2030, taking into account the development of other land functions on a national level. This is demonstrated for three case study countries: Mozambique, Argentina and Ukraine.
2. The assessment of the environmental and socio-economic impacts of large scale biofuel production, including greenhouse gas emissions, impacts on soil water and biodiversity, as well as legality, land rights, food security, economic viability, local prosperity, social well-being, labour conditions and gender. This was demonstrated for specific settings: Ethanol production from switchgrass and eucalyptus in the Gaza-Inhambane and the Nampula region in Mozambique and ethanol production form switchgrass and biodiesel from soy in Santiago del Estero and Buenos Aires in Argentina.[1]

The studied impacts follow the recommendations made by the *Biofuels Screening Toolkit* produced for the GEF under the same project[2]. The methodological concepts developed in the Biofuel screening toolkit, have been translated to a methodological framework to quantify the environmental and socio-economic impacts of biofuel production on a regional level. This methodological framework is demonstrated for the three specific case studies but could also be applied to any bioenergy supply chain, any production scale level and any region in the world.

Land availability for energy crops

The key to this study is to assess how bioenergy potentials develop over time. Therefore a spatio-temporal land use change model was developed that enables spatially detailed assessment on under which conditions 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 size, Gross Domestic Product (GDP), food intake per capita and self-sufficiency ratio. The efficiency of the agricultural sector is a key factor for the land required to meet the total demand for food, animal products and materials. A scenario approach was used to explore potential long term developments in the productivity of the agricultural sector. The Business as Usual (BAU) scenario projects a future in which historical trends in yield levels and livestock productivity are continued, resulting in a low agricultural productivity. The progressive scenario assumes the implementation of improved agricultural management resulting in a high agricultural productivity. The land use changes for each year towards 2030 were modelled on high resolution by allocating land to a land use class based on the suitability for the specific land use classes. 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 and the maps of excluded areas for bioenergy production (such as forest areas), the land availability for bioenergy crops is determined for each year.

The spatially explicit assessment of the development in land availability for bioenergy crops over time, shows how much land could become available at which locations and under what conditions. The case studies show that there is decreasing or no land availability for bioenergy crops in the BAU scenario, i.e. when there is little improvement in agricultural productivity. However, in the progressive scenarios the case studies show that large amounts of land could become available for bioenergy crop production if the increase in productivity of the agricultural sector

1 For Ukraine, a detailed analysis of the environmental and socio-economic impacts was deemed not feasible due to the low availability of data especially on the local socio-economic conditions

2 See: http://www.unep.org/bioenergy/Activities/TheGlobalEnvironmentFacilityGEFProject/tabid/79435/Default.aspx.

Table ES1: Developments in land availability for bioenergy crops towards 2030 in the three case study countries for the Business as Usual and the Progressive scenario.

Case study country	unit	Land in use for agriculture 2010	Land in use for agriculture 2030 BAU	Land in use for agriculture 2030 PROG	Land availability for bioenergy crops 2010	Land availability for bioenergy crops 2030 BAU	Land availability for bioenergy crops 2030 PROG
Mozambique	Mha	14.3	21.9	6.2	8.7	7.7	16.4
Ukraine	Mha	47.2	51.2	15.1	0.01	0.3	32.1
Argentina[a]	Mha	90.6	97.7	57.9	0	0	32.0

a This is excluding the land that is already in use or expected to become in use for soy. As part of the soy complex is used for biodiesel, there is a biofuel production potential even in the BAU scenario in which no additional land becomes available.

(crop + livestock production) exceeds the increase in food demand. This requires a discontinuation of current trends in productivity in agricultural sectors in all three countries. Table ES1 shows the land availability in the case study countries in 2010 and in 2030 for the BAU and the progressive scenario.

Environmental and socio-economic impacts

The environmental and socio-economic impacts of bioenergy supply chains depend on the biophysical and socio-economic conditions of the production region, the characteristics of the supply chains (energy crop, conversion technologies, logistics, etc) and on the management of the agricultural project of energy crop cultivation and of the supply chain. Therefore, the impact assessments are performed for typical settings for specific regions, supply chains, scenarios and timeframes. The assessment on the development in land availability for energy crops was a key input for the assessment of the potential environmental and socio-economic impacts of large scale biofuel production. The environmental impacts included are GHG emissions, impacts on water, soil and biodiversity. The socio-economic impacts addressed are legality, land rights, food security, economic viability, local prosperity, social well-being, labour conditions and gender. For all impacts it was aimed for finding an appropriate quantitative method to analyse the potential impacts taking into account the state of the art methods and the availability of data. Many of the socio-economic impact are directly related to the design, the implementation and the management of the project (social well-being, labour conditions, and gender). Other impacts refer to compliance with (inter-) national law and regulations (land rights, labour conditions and legality). For those impacts, no ex-ante assessment of the impacts can be made but recommendations for best practice can be provided.
The environmental and socio-economic impacts of large scale biofuel production in Mozambique have been assessed for ethanol production from eucalyptus (EU) and switchgrass (SG) production at a scale level of 1400 MW in the Gaza-Inhambane region and the Nampula region for the Business as Usual (BAU) and the progressive (PROG) scenario. Table ES2 provides a summary of the selected environmental and socio-economic impacts for the selected settings.

In Argentina, the environmental and socio-economic impacts of large scale biofuel production have been assessed for ethanol production from switchgrass (SG) and biodiesel production from soy at a scale level of 4.67 PJ biodiesel/yr in the province of Buenos Aires and Santiago del Estero for the Business as Usual (BAU) and the progressive (PROG) scenario. Table ES3 provides a summary of the selected environmental and socio-economic impacts for the selected settings for these provinces.

Conclusions

The land use model developed in this study is an advanced tool to assess future land use dynamics and land availability for bioenergy crops. Applying a scenario approach on the key drivers of LUC and using a food first paradigm, allows for an evaluation of the biomass potentials that can be achieved without competition with food and feed, and for the identification of the required conditions to realize these potentials. As biomass yields, production costs, logistics, and environmental and socio-economic impacts are strongly related to location specific biophysical and socio-economic conditions, spatially explicit assessment of land availability for bioenergy crops is an important precondition for the design of bioenergy supply chains and logistics, for the assessment bioenergy production potentials and environmental and socio-economic impacts. The developed methodological framework addresses the key environmental and socio-economic concerns raised by several (inter-) national initiatives on the sustainability and certification of biomass production for energy i.e. GHG emissions, impacts on soil, water and biodiversity, legality, land rights, economic viability, local prosperity, social well-being, labour conditions, food security and gender. The developed approach enables the quantification of environmental and a socio-economic impact of large scale biomass production on a regional level. This allows for the selection of promising regions and supply chains and identifies the key concerns that need to be addressed when a project is implemented.

This *ex-ante* analysis of the land availability for and the environmental and socio-economic impacts of large scale energy crop production contributes to the identification of

Table ES2: Selected potential environmental and socio-economic impacts of the supply chains of ethanol from eucalyptus (EU) and switchgrass (SG) in the Gaza-Inhambane and Nampula region for the Business as Usual (BAU) and Progressive (PROG) scenario conditions.

Positive impact — *Neutral or minor impact* — *Negative impact*

			Gaza-Inhambane				Nampula			
			BAU		PROG		BAU		PROG	
		Unit	EU	SG	EU	SG	EU	SG	EU	SG
Land availability and suitability	**Scale up potential**									
	Total land in selected region	Km^2	37324	37324	37324	37324	9974	9974	9974	9974
	Total land availability	Km^2	8323	8323	16129	16129	837	837	3146	3146
	Total land availability	% of region	22	22	43	43	8	8	32	32
	Potential suitability of available land	% of max yield	31	31	34	34	63	63	62	62
	Land requirements to meet input	Km^2	2054	3008	1579	2373	826	826	1321	1885
	Suitability of best available land	% of max yield	41	39	53	50	63	63	64	62
	Total biomass production	Million Odt/ha/yr	2.2	2.3	2.2	2.3	1.4	1	2.2	2.3
	% of required capacity	%	100	100	100	100	62	45	100	100
	Impacts									
Environmental Impacts	**GHG Emission**									
	Life cycle	Kg CO_2-eq /$GJ_{biomass}$	2.3	3.9	2.2	3.8	2.2	3.7	2.2	3.7
	LUC related emissions	Kg CO_2-eq /$GJ_{biomass}$	11.9	35.2	-19.7	-14.7	10.6	29.8	-27.3	-23.0
	Total emissions	Kg CO_2-eq /$GJ_{biomass}$	14.1	39.1	-17.5	-10.9	12.9	33.5	-25.1	-19.3
	Total avoided emissions	Kg CO_2-eq /GJ_{EtOH}	58	32	90	84	59	38	97	91
	Soil									
	Soil Organic Carbon	Δ kg C /$GJ_{biomass}$	0.0	2.4	1.3	3.7	0.0	2.3	1.5	4.4
	Wind Erosion	Qualitative	-	0	+	++	-	0	+	++
	Water									
	Water use efficiency	$Odt_{biomass}$/ l water	0.7	0.7	0.9	0.9	0.8	0.9	0.8	0.9
	Water depletion	mm/season	426	-96	426	-96	523	-237	523	-237
	Biodiversity									
	MSA	ΔMSA x100 /$GJ_{biomass}$	-0.4	-0.5	-0.1	-0.1	-0.3	-0.3	-0.1	-0.1
Socio-economic Impacts	**Legality**		*No ex-ante analysis possible, recommendations to comply with national law are provided see 3.2.2.1 and Annex 3*							
	Land rights									
	Land right risk	Qualitative	+	+	+	+	-	-	+	+
	Food security									
	Food security	Qualitative	+/-	+/-	+	+	-	-	+	+
	Economic viability									
	Feedstock	€/$GJ_{biomass}$	2.44	3.05	1.29	1.54	1.84	2.01	1.03	1.31
	End product	€/GJ_{EtOH}	14.18	16.62	11.32	12.86	12.96	14.38	10.93	12.63
	Local Prosperity									
	Total jobs	X 1000 jobs	11.9	8.4	9.1	6.6	4.8	2.3	7.7	5.3
	Local labour	%	100	100	100	100	100	100	100	100
	Total investment	M€	260	297	208	230	157	127	208	226
	Total wages	M€	11.41	7.74	8.73	6.01	4.95	2.38	7.40	4.86
	Social well-being									
	Total no of people affected	X 1000 people	59	42	46	33	24	12	38	26
	Labour conditions		*No ex-ante analysis possible, recommendations to comply with (inter-) national law and best practice are provided*							
	Gender		*No ex-ante analysis possible, recommendations to comply with (inter-) national law and best practice are provided*							

Table ES3: Selected potential environmental and socio-economic impacts of switchgrass ethanol (SG) and soy biodiesel (SOY) production in Buenos Aires and Santiago del Estero for the Business as Usual (BAU) and Progressive (PROG) scenario conditions.

Positive impact (green) ***Neutral or minor impact*** (yellow) ***Negative impact*** (red)

			Buenos Aires				Santiago del Estero			
			BAU		PROG		BAU		PROG	
	Impact	Unit	SG	SOY	SG	SOY	SG	SOY	SG	SOY
Land availability and suitability	**Scale up potential**									
	Total land in selected region	1000 Km^2	306	306	306	306	137	137	137	137
	Total land availability	1000 Km^2	5.2	5.2	85.4	85.4	2.4	2.4	34.5	34.5
	Total land availability	% of region	2	2	28	28	2	2	25	25
	Potential suitability of available land	% of max yield	49	32	56	45	5	1	22	8
	Land requirements to meet input	1000 Km^2	0.31	2.83	0.31	1.48	0.13	0.12	0.31	2.86
	Suitability of best available land	% of max yield	100	52	100	100	91	27	100	52
	Impacts									
Environmental Impacts	**GHG Emission**									
	Life cycle	Kg CO_2-eq /$GJ_{biomass}$	3.84	11.48	3.73	5.43	3.92	21.85	3.73	10.50
	LUC related emissions	Kg CO_2-eq /$GJ_{biomass}$	15.69	236.88	-15.56	0.00	15.33	624.47	-20.40	0.00
	Total emissions	Kg CO_2-eq /$GJ_{biomass}$	56	238	-18	24	56	587	-30	28
	Total avoided emissions	Kg CO_2-eq /$GJ_{Biofuel}$	-16	166	-90	-48	-16	515	-102	-44
	Soil									
	Soil Organic Carbon	Δ kg C /$GJ_{biomass}$	0.7	-9.5	1.8	0.0	1.3	-38.0	3.3	0.0
	Wind Erosion	Qualitative	0	--	++	-	0	--	++	-
	Water									
	Water use efficiency	$Odt_{biomass}$/ l water	1.93	0.47	1.93	0.91	1.29	0.23	1.43	0.44
	Water depletion	mm/season	-302	-216	-402	-180	-302	-216	-402	-180
	Biodiversity									
	MSA	ΔMSA x100 /$GJ_{biomass}$	-0.2	-2.3	-0.1	-0.5	-0.2	-4.3	-0.1	-1.0
Socio-economic Impacts	**Legality**		*No ex-ante analysis possible, recommendations to comply with national law and regulation are provided, see 3.3.2.1 and Annex 3.*							
	Land rights									
	Land right risk	Qualitative	+	+	+	+	-	-	+	+
	Food security									
	Food security	Qualitative	+	+	+	+	+-	+-	+	+
	Economic viability									
	Feedstock	€/$GJ_{biomass}$	2.44	13.75	1.96	6.27	2.62	26.47	1.96	12.06
	End product	€/$GJ_{biofuel}$	13.24	20.19	12.03	12.44	13.70	33.40	12.03	18.45
	Local Prosperity									
	Total jobs	Jobs	940	1417	940	738	384	59	940	1428
	Local labour	%	100	100	100	100	100	100	100	100
	Total investment	M€	74	113	67	70	28	4	67	103
	Total wages	M€	10	15	10	8	4	1	10	15
	Social well-being		*No ex-ante analysis possible, recommended to comply with (inter-) national law and regulations. Recommendations for best practices are provided, see 3.4.1.10*							
	Labour conditions		*No ex-ante analysis possible, recommended to comply with (inter-) national law and regulations.*							
	Gender		*No ex-ante analysis possible, recommended to comply with (inter-) national law and regulations. Recommendations for best practice are provided, see 3.4.1.12*							

go and no- go areas for energy crop production. This enables a sound planning of land use, sustainable investment in bioenergy production capacity, and infrastructure over time. It could also help investors and policymakers to make realistic estimations of the economic viability of a project and it provides the ability to define the preconditions to comply with sustainability criteria. This could help to prevent competition for land, reduce investment risks, avoid large scale project failures, minimise negative environmental and socio-economic impacts and optimize positive effects of large scale bioenergy production.

Recommendations

Based on the developed methodological framework and the findings of the research on the potential land availability and the potential environmental and socio-economic impacts of large scale biofuel production, recommendations can be articulated for different stakeholders at several levels and different stages of the planning and implantation of large scale biofuel production. The combined actions required form these different stakeholders should enable sound land use planning, sustainable implementation and management of large scale biofuel projects and monitoring of sustainable development. This concerns actions from:

- international organisations
- national government
- market parties

Recommendations for international organisations[3]

For the development of sustainable large scale biofuel production, sound land use planning is key. The methodological framework to assess potential LUC and the potential land availability for energy crop production, and the framework to assess the environmental and socio-economic impacts show that these assessments require high amounts of accurate (spatial) data. For most countries, this data is not available on a national level or is outdated or unreliable. The global datasets could definitely be improved in terms of accuracy, spatial resolution, consistency, classification, ground-truthing, updating and continuation. Therefore it is recommended that international organisations contribute to better data availability that is required to make proper land use planning and environmental and socio-economic impact analysis, including:

- Detailed (spatial) data on land cover, land use (especially degraded areas, pasture properties), soil properties, climate, hydrology, biodiversity hotpots and protected areas
- Statistical data on agriculture on low administrative level (NUTS 3 or NUTS 4) on crop production, (ha and yield), Pasture (ha, yield and head per ha), Livestock (head per type of animal), Production system of livestock.

Statistical data on socio-economic conditions on a low administrative level (NUTS 3 or NUTS 4) on Population, Regional GDP, Input/Output matrix, Total workforce and (un) employment, Education levels and facilities, Food security, Health figures and facilities, Access to infrastructure, electricity, water and sanitation.

Recommendations for governments

For the development of sustainable large scale biofuel production, sound land use planning is key. This should be done by the national government and should represent a long term vision on the sustainable development of the country. Therefore, national governments should:

- Make a long term land use planning for the entire country;
  - By mapping current land use and land cover, protected areas, vulnerable ecosystems, land use rights or land ownerships, community and customary land use rights.
  - By projecting LUC for the coming decades which involves developing projections of the developments in population growth, dietary intake, urbanisation, import and export rates, agricultural productivity, livestock productivity, and developments in infrastructure.
  - By developing a scenario approach to explore possible future developments taking uncertainties in key parameters into account such as the productivity of the agricultural sector.
  - By indicating all the areas that are required or are likely to become required and are desired to become required for several land use functions and designate areas for potential energy crop production.
- Define the key preconditions of the scenarios, identify a strategy to achieve the scenario conditions and develop policy measures to steer towards the desired direction of development.
- Assess and monitor environmental and socio-economic impacts to flag potentially important issues.
- Require an extensive project plan from potential investors including a quantitative description of how they will comply with all sustainability criteria and make this part of the land tenure procedure.

Recommendations for GEF

This report provides the methodological framework to make an ex ante assessment of the land availability and the potential environmental and socio-economic impacts. In order to assess if the proposed projects are able to produce biofuel sustainably, GEF may consider evaluating project proposals on the following sustainability aspects:

- The land that is planned to be used for the biofuel project: the suitability of the land, the availability, the

3 Including GEF, UNIDO, FAO, UNEP.

potential competition with other land use functions (excluding land currently in use as cropland, pasture, community land and conservation areas), the characteristics of the land (high carbon stocks, high biodiversity value and organic soils), the land tenure procedure, the community consultation process.
- The overall efficiency of the total supply chain.
- The avoided GHG emission over the total supply chain.
- The applied management: Preferably no intensively managed high input monoculture.
- The economic viability: Realistic crop choice, yield levels, rate of establishment, logistics and supply chains, cost, prices and assumptions on (inter-)national markets.
- The contribution of the project to the local prosperity; the amount of jobs, total investment in region/ outside the region
- The contribution of the project to the social well-being; such as education, health, food security, access to infrastructure/electricity/ water and sanitation/ fuel wood alternates etc.
- The practices related to labour conditions and gender should be all in line with (inter-) national laws and regulations and no discrimination based on gender, race, age, etc.

Recommendations for the market

Investors should make a thorough ex-ante assessment by keeping in mind compliance with national and international legislation and compliance with all sustainability issues on: i) the biophysical properties of the land that potentially obtained for the biofuel project, ii) the socio-economic conditions in the region, iii) the biomass feedstock that will be produced, and iv) the management that will be applied. The methodological framework for the ex-ante assessment of the potential environmental and socio-economic impacts provided here could help to the identification of the available and suitable land, the promising production locations and supply chains and the pre-conditions that are required. This is a first step to make a project proposal for a project that potentially could be certified for sustainable production by international certification bodies, and is a precondition to obtain land from the national government and apply for investors, funding and support.

In addition, the design, implementation and the management of the project should be in line with the sustainability criteria. Specific recommendations on how to comply with sustainability criteria are provided in the report 'Global Assessments and Guidelines for Sustainable Liquid Biofuel Production in Developing Countries' by Franke *et al.* (2012). Certification of the biofuel production chain provides access to markets and makes them eligible for premium prices.

1. Overall objectives

This study aims to analyse the impacts of scaling-up biofuel production and its implications on sustainable development. Dedicated bioenergy crops are assumed to be the main contributors to future bioenergy supplies (Smeets *et al.* 2007; Dornburg *et al.* 2010), and there are concerns over impacts of biofuel production caused by land use changes (LUC) related to land use for dedicated energy crops. The aim of this study is to analyse potential environmental and socio-economic impacts of large scale biofuel production in three different regions: Argentina, Mozambique and Ukraine.

The three countries are selected because of the relatively high availability of land for energy crop production and because they represent very different biophysical and socio-economic conditions, so as to be able to compare differences in supply chains and biophysical and socio-economic conditions. See map with selected countries in Figure 1.

The aim of the study is not to identify fixed geographical locations for biofuels development, but rather to ascertain the potential for large-scale biofuel developments.

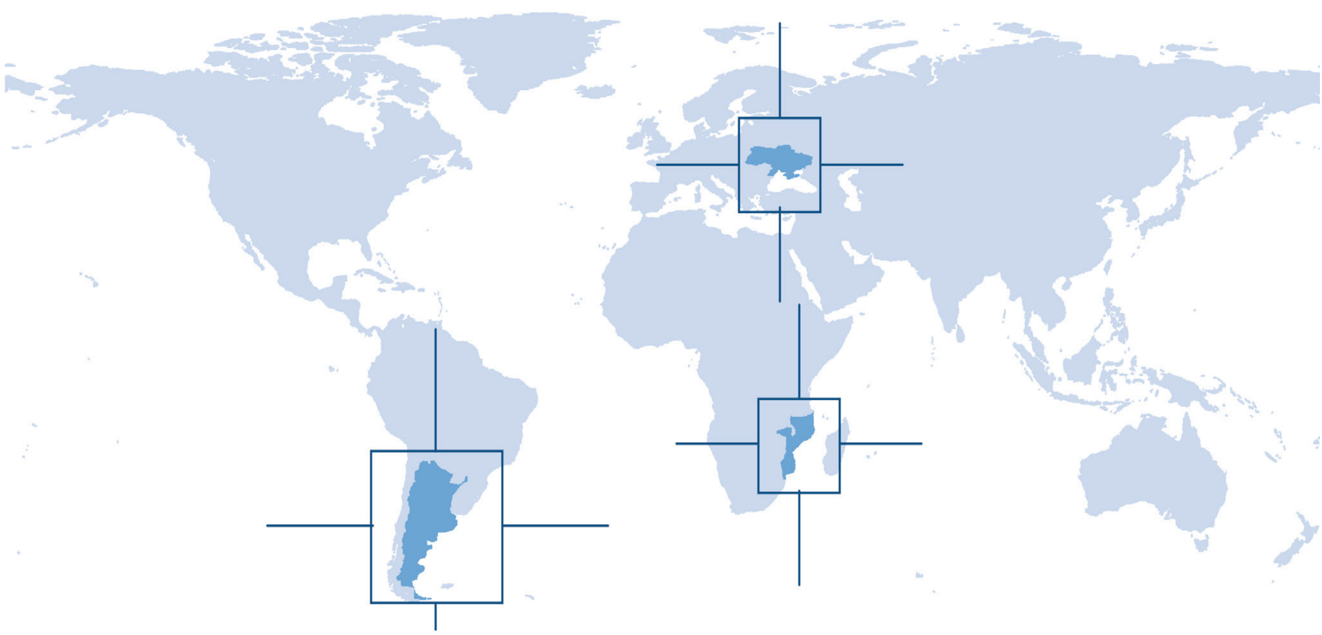
For the Case Studies the potential environmental and socio-economic impacts of large scale production of biofuels are assessed. To this end, two research steps are taken:

1. Assessment of the land availability for dedicated bioenergy crops up to 2030, taking into account the development of other land functions on a national level (for Mozambique, Argentina and Ukraine)
2. Environmental and socio-economic impacts of large scale biofuel production, including greenhouse gas emissions, impacts on soil water and biodiversity, as well as legality, land rights, food security, economic viability, local prosperity, social well-being, labour conditions and gender (for Mozambique and Argentina).

The studied impacts follow the recommendations made by the *Biofuels Screening Toolkit* produced for the GEF under the same project [4]. The methodological concepts developed in the Biofuel screening toolkit, have been translated to a

4 See: http://www.unep.org/bioenergy/Activities/TheGlobalEnvironmentFacilityGEFProject/tabid/79435/Default.aspx.

Figure 1: Selected case study countries: Mozambique, Argentina and Ukraine.



methodological framework to quantify the environmental and socio-economic impacts of biofuel production on a regional level. This methodological framework is demonstrated for three specific case studies but could also be applied to any bioenergy supply chain, any scale level and any region in the world.

The environmental and socio-economic impacts of bioenergy supply chains depend on the biophysical and socio-economic conditions of the production region, the characteristics of the supply chains (energy crop, conversion technologies, logistics, etc) and on the management of the agricultural project of energy crop cultivation and of the supply chain. Therefore, the environmental and socio-economic context, the supply chain and the management need to be defined in order to make an *ex-ante* assessment of the sustainability of the biomass supply. However, these conditions vary from place to place, change over time and are scenario dependent. Therefore, the impact assessments are performed for typical settings for specific regions, supply chains, scenarios and timeframes. The environmental and socio-economic impact analysis has only been performed for specific settings in Mozambique and Argentina for which extensive research and field work has been performed. This was also feasible due to combined efforts for several projects. For Ukraine, a detailed analysis of the environmental and socio-economic impacts was deemed not feasible due to the low availability of data especially on the local socio-economic conditions and due to language difficulties (region specific information is often not available in English), and the lack of additional resources for extensive field work.

The methodology and the results of the assessment of land availability for energy crops are described in chapter 2. The selected case study regions and the biomass supply chains are described in Annex 1 and a more detailed description of the methodology and the results of the lands availability assessment are found in Annex 2. Chapter 3 highlights the environmental and socio-economic impact assessment of the selected biomass supply chains in the case study regions in Mozambique and Argentina. In Annex 3 more information on the applied methods to assess the environmental impacts (i.e. the greenhouse gas emissions, the impact on soil water and biodiversity) and socio-economic impacts (i.e. legality, land rights, food security, economic viability, local prosperity, social well-being, labour conditions and gender) and more in depth results of these analyses are provided. Chapter 4 provides the overall conclusions of the assessment.

The study was commissioned by UNIDO, under the Global Environmental Facility's (GEF) targeted research project *"Global Assessments and Guidelines for Sustainable Liquid Biofuels Production in Developing Countries"*. UNIDO place particular emphasis on linking the development of agriculture and energy sectors by encouraging the use of agro-resources and wastes to generate renewable energy, to achieve the high potential deployment levels of biomass for energy, and to avoid competition between food, feed and fuels by balancing the increased production of biomass for energy by improvements in agricultural management (Dornburg, van Vuuren et al. 2010; Wicke, Vuuren et al. 2012). Promoting sustainable agriculture is therefore an overarching objective, which fits in with UNIDO's multi-objective and cross-sectoral planning, including through working together with agricultural, industrial, energy and environmental professionals and government representatives to design multi-objective projects. As large scale deployment of biomass for bioenergy could contribute to GHG emission reduction, energy security and rural development, biomass is expected to play an important role in future energy supply (IPCC 2011; GEA 2012). Dedicated bioenergy crops are considered to become the main contributors to future bioenergy supplies if higher deployment levels are achieved (WWI 2006; Smeets, Faaij et al. 2007; Dornburg, van Vuuren et al. 2010). As a rapid increase in the deployment of biomass for energy is expected, this study focuses is on the impacts of large scale bioenergy production.

2. Land availability for energy crops

2.1 Methods

Large scale deployment of biomass for bioenergy could contribute to GHG emission reduction, energy security , rural development and restoration of degraded lands (Dornburg *et al.* 2010; IPCC 2011). Dedicated bioenergy crops are considered to become the main contributors to future bioenergy supplies (WWI 2006; Smeets *et al.* 2007; Dornburg *et al.* 2010) if higher deployment levels are achieved. However, an increased implementation of dedicated bioenergy crop production could have significant adverse socio-economic and environmental impacts such as deforestation, loss of carbon sinks, biodiversity and other ecosystem functions and services, increased competition for land and higher food prices (IPCC 2011; Wicke *et al.* 2012). Many of these impacts are related to land use change (LUC) (Wicke *et al.* 2012). It is therefore of key interest to assess how much land can be made available for bioenergy production, without competing for land for other uses, such as food, feed and materials production, and to avoid indirect land use change (iLUC)[5].

2.1.1 Objective

In recent years, an increasing number of studies have been published on bioenergy potentials on a global (e.g. Berndes *et al.* 2003; Hoogwijk *et al.* 2005; Smeets *et al.* 2007; Dornburg *et al.* 2010), European (e.g. Ericsson and Nilsson 2006; EEA 2007; Fischer *et al.* 2007; de Wit and Faaij 2010), national (e.g. Faaij *et al.* 1998; van den Broek *et al.* 2001; Walsh *et al.* 2003; Sang and Zhu 2011) and regional level (e.g. van Dam *et al.* 2009a). However, most of these studies have assessed biomass potentials on a spatially aggregated level. The disadvantage of such studies is that they provide only limited information on the location of the land available for bioenergy crops. Potential yield levels and environmental and socio-economic impacts of energy crop production are strongly related to the physical and socio-economic conditions of a location (van Dam *et al.* 2009a; 2009b; Van der Hilst *et al.* 2010; Beringer *et al.* 2011; 2011); therefore, it is important to assess where land is (or could become) available for bioenergy production.

5 iLUC occurs when crops or land that would have otherwise been used for producing food or animal feed are used for growing biofuels, displacing agriculture to new areas, where indirect emissions can occur, for example as a result of deforestation to accommodate new agricultural areas.

LUC result from complex interactions between human and biophysical driving forces that act over a wide range of temporal and spatial scales (Verburg *et al.* 1999). Several methodologies and models have been developed to simulate and explore LUC (Veldkamp and Lambin 2001). These models differ in terms of scale (e.g. regional, global), process (e.g. deforestation, urbanisation), discipline (e.g. economic, environmental), approach (e.g. extrapolating historical trends, driving forces) and complexity (e.g. methods, resolution).

The objective of this study is to develop a new modelling framework to assess the development in land availability for bioenergy crops on a detailed spatial level, taking into account the dynamics of several other land use functions and the uncertainties in drivers of LUC. This model is especially developed to assess the land availability for bioenergy crops and therefore provides opportunities to assess how iLUC effects are to be avoided. The technical characteristics of the model are described in Verstegen *et al.* (2011). More information on how the model is applied for the case study countries is described in Annex 2.

2.1.2 Scenario approach

It is of key interest to assess how competition for land and related effects of iLUC can be avoided; therefore, the modelling of the land availability for energy crop production needs to take into account the land required for other land use functions. Land use requirements for crop and livestock production depend on the developments in food demand and agricultural productivity. Consequently, land use is dynamic over time. This study includes the demand for food, feed and materials (including wood) which results in a claim on land for crop production and grazing area as well as in deforestation. In order to project the dynamics in these land use functions over time, future developments regarding the main drivers for LUC need to be identified and quantified.

The main LUC drivers are the developments in the demand for food, feed and materials and the productivity of the

Table 1: Key scenario paremeters for the Business as Usual scenario and the Progressive scenario for Mozambique, Argentina and Ukraine.

Scenario Characteristic	Business as Usual Scenario	Progressive Scenario
Population	Based on outlooks of UNDP	
Diet	Development in caloric intake and composition based on outlooks of FAO	
SSR	Development in self sufficiency and exports based on FAO	
Farming practices	Continuation of trend towards more commercial farming.	Abandonment of subsistence farming and shifting cultivation, increased shift towards large scale commercial farming.
Technology adoption	Continuation of current trends in input levels.	Increased adoption rate of improved seeds, fertilizers, agro-chemicals, knowledge, machinery and irrigation.
Agricultural productivity	A modest increase in yield and cropping intensity in line with historical trends.	High increase in crop yields and cropping intensity.
Livestock sector	Modest shift towards mixed systems and modest increase in conversion efficiencies.	Shift towards high productive farms. Increased feed conversion efficiencies in both pastoral and mixed systems.
Deforestation [a]	No additional policies, regulation and enforcement. Continuation of current trends in deforestation.	Additional policies, regulation and enforcement to prevent further deforestation
Bioenergy implementation	Abandoned agricultural land is used for bioethanol crops.	

a For Ukraine and Argentina the deforestation as a result from agricultural expansion is modelled. For Mozambique, in addition to the deforestation as a result from agricultural expansion, the deforestation resulting from illegal logging and fuel wood consumption is modelled.

agricultural sector. The demand for domestically produced food and feed is related to developments in population size, GDP, food intake per capita and self-sufficiency ratio (SSR, i.e. the extent to which domestic supply meets domestic demand) (FAO 2003). The amount of land required to meet the total demand for food, animal products and materials depends on the efficiency of the agricultural sector.

Since it is uncertain how LUC drivers evolve and the prediction of land use developments is problematic (Verburg *et al.* 2004), a scenario approach was used to explore potential long-term developments in LUC driving forces. A storyline describes a demographic, social, economic, technological, environmental, and policy future for one scenario. The storylines were formulated in close cooperation with different stakeholders in the countries in a process in which the driving forces, key uncertainties are identified. An outlook is made towards 2030 in order to explore long term effects of different directions of development. The storylines approach will allow policy makers (and the GEF) to evaluate the feasibility and performance of various policy measures across the different sustainability aspects for different biofuels scenarios and production pathways. Two divergent storylines were developed: a Business as Usual (BAU) scenario and a Progressive scenario. The divergent storylines were used to explore possible developments in technological, institutional and societal changes which result in changes in productivity in the agricultural sector. In Table 1, the key parameters and the differences between the BAU and the Progressive scenario for the three selected countries are depicted.

2.1.3 Land use change modelling

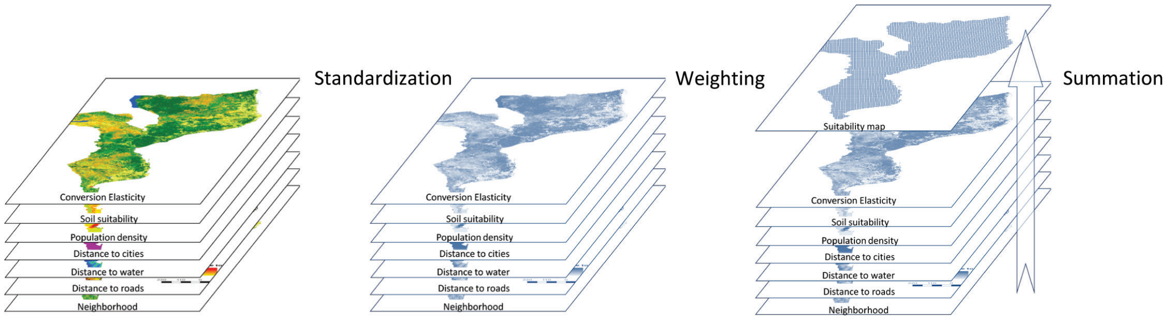
Due to variations in agro-ecological conditions, the yields of crops, pasture and wood are spatially highly heterogeneous. Therefore, the total amount of land required to meet the demand for food, wood and animal products is directly related to the location of the specific land use class. Several studies on LUC have developed methodologies for land use allocation.

In this study, the land in use for agriculture, pasture and forest are modelled dynamically[6]. In the modelling framework the allocation of land to land uses classes is based on the suitability of the location for a specific land use class which is defined by a combination of several selected spatially explicit suitability factors. Typical suitability factors for land use allocation are the agro-ecological suitability, the accessibility, the land conversion elasticity and the neighbourhood characteristics (Rounsevell *et al.* 2006; Verburg *et al.* 2006; Overmars *et al.* 2007; Verburg *et al.* 2008; Verburg and Overmars 2009; Britz *et al.* 2011). The number, kind and importance of suitability factors differ per land use type. In order to differentiate the importance of the suitability factors, weights are assigned to the individual suitability factors.

For each land use class, a suitability map was constructed based on the spatially weighted summation of a specific set of individual suitability factors (See Figure 2). The characteristic of the suitability factors for land use allocation for each land

6 In the case study countries (strong) urbanisation is expected. However, this is not modelled in the spatio-temporal land use model as the amount of land occupied by urban areas is relatively small (±2%) and will therefore not affect the land availability for energy crops.

Figure 2: The standardisation, weighting and summation of suitability factors for a specific land use class for a specific country.



use type for each case study country are further explained in (van der Hilst *et al.* 2012; Diogo *et al.* Forthcoming; Van der Hilst *et al.* Forthcoming)

Areas that are not suitable (e.g. steep slopes) or not allowed (e.g. conservation areas) to be converted to agricultural land were excluded. Based on a specific set of suitability factors, the excluded land, and the order of allocation, land is allocated to the different land use functions for each year. This results in a new land use map. Based on this land use map and a map of the areas that are excluded, the land availability for bioenergy crops is determined.

In order to enable the modelling of the LUC dynamics, a spatio-temporal land use model has been developed based on the building blocks of the PCRaster Phyton framework (Karssenberg *et al.* 2010; PCRaster 2010)[7]. The major advantage of this model framework is its ability to deal with stochastic input data[8]. This enables spatio-temporal Monte Carlo (MC) runs that evaluate uncertainty propagation[9]. An overview of the modelling framework is provided in Annex 2.

2.1.4 Biomass potentials

Due to variations in agro-ecological conditions, the yields (and related production costs) of energy crops are spatially highly heterogeneous. In order to calculate the development in the total biomass production potential spatially explicitly, the map of land availability of a specific year is combined with the crop suitability map and the maximum attainable yield given the level of management in that specific year. The equations for these calculations are provided in Annex 2.

2.1.5 Regional land availability assessment

As the environmental and socio-economic impacts of bioenergy supply chains depend on the biophysical and socio-economic conditions of the production region, the characteristics of the supply chains (energy crop, conversion technologies, logistics, etc) and on the management of the agricultural project of energy crop cultivation and the supply chain, the impact assessments are performed for typical settings for specific regions, supply chains, scenarios and timeframes.

The methods to make an ex-ante environmental and socio-economic impact analysis in order to assess the sustainability of potential large scale biomass production chains are demonstrated for specific settings in Mozambique and Argentina. For Ukraine, a detailed analysis of the environmental and socio-economic impacts was deemed not feasible due to the low availability of data especially on the local socio-economic conditions, and due to language difficulties, and the lack of additional resources for extensive field work. The settings in Mozambique and Argentina are differentiated for two selected regions, two selected energy supply chains and the two scenarios. The settings have a time horizon of 2020 in order to allow sufficient time for potential technological development (e.g yield improvements and second generation biofuels) but also to limit the uncertainties related to projections for the long term future (e.g.2030 and beyond). In addition, as currently the bioenergy production sector develops quite rapidly, an impact assessment for the mid-term future could serve as input for more informed and sustainable choices and policy measures of today. Also, the impacts are assessed using the current situation as a reference, this is more realistic for the mid-term future (2020) than for the long term future (2030).

7 PCRaster Is a collection of software targeted at the development and deployment of environmental models scripted in Phyton. It is frequently used for the assessment of processes in e.g. geography, hydrology and ecology. It includes a rich set of model building blocks and analytical functions for manipulating raster GIS maps. The PCRaster model construction framework offers a combined interface for spatio-temporal modeling and uncertainty analysis and includes a visualization tool for stochastic data (Karssenberg, 2010).

8 In stochastic modeling, a model input is defined by a probability distribution of all possible values. For each of the stochastic variables the error model (e.g. normal, uniform) and the standard deviation or the range is determined (see Verstegen et al, 2011).

9 For a Monte Carlo analysis the model is run a large number of times, each time drawing a realization from the input probability distribution(s). For spatial models this results in different spatial patterns for the different model realizations, i.e. model runs or samples (Verstegen et al, 2011). This provides information about the probability of land use change for each grid cell given the uncertainty in the input variables.

In Mozambique, the Gaza-Inhambane and Nampula region were selected and in Argentina the provinces Buenos Aires and Santiago del Estero were selected. In Annex 2, the regions are described in detail. In the land availability assessment a special focus is on the selected regions. It is assessed how much land becomes available in 2020 the BAU and the progressive scenario, what is the suitability of the land for selected bioenergy crops, how much biomass can be produced on this land and what type of land cover is replaced by the energy crops.

2.2 Results

The spatially explicit assessment of the development in land availability for bioenergy crops over time, shows how much land could become available at which locations and under what conditions. The case studies show that there is decreasing or no land availability for bioenergy crops in the BAU scenario, i.e. when there is little improvement in agricultural productivity. However, in the progressive scenarios the case studies show that large amounts of land could become available for bioenergy crop production if the increase in productivity of the agricultural sector (crop + livestock production) exceeds the increase in food demand. This requires a discontinuation of current trends in productivity in agricultural sectors in all three countries. Table 2 shows the land availability in the case study countries in 2010 and in 2030 for the BAU and the progressive scenario.

The results of the individual case study countries are discussed in the following sections. More information and results are found in Annex 2. Include

2.2.1 Mozambique

2.2.1.1 Land use change dynamics

The modelled developments in land use in Mozambique in the timeframe 2005-2030 for the BAU and the progressive scenario are depicted in Figure 3. It shows the land use in the reference year 2005 (time step 1, same for both scenarios), 2015 (time step 11), and 2030 (time step 26). In the maps of 2015 and 2030, it is apparent that cropland, mosaic cropland-pasture[10], mosaic cropland-grassland[11] and pasture areas are expanding in the BAU scenario, whereas these land use types are contracting in the Progressive scenario. In the BAU scenario, the shift towards pure or mosaic cropland and pastures is most profound close to main cities and in proximity to the road network. The expansion of agricultural land use is mainly at the expense of forest (76%) and shrubland (21%). In the Progressive scenario there is a shift from the more extensive mosaic cropland towards specialised cropland close to the main cities and in proximity to the road network. Extensive mosaic cropland and pastures are progressively abandoned due to the intensification of crop and livestock production. This is most apparent in the remote semi-arid and less populated areas in south-west (Gaza Province) and north-west (Tete province) of Mozambique. Another important difference between the scenarios is the development in autonomous deforestation, in addition to forest converted to agricultural land uses. In the BAU scenario, deforestation is most apparent along the main road network. The expansion of the deforested areas is most profound in the first ten time steps. Due to the assumed regeneration of forest, the expansion of deforestation slows down in the BAU scenario. In the Progressive scenario, it is assumed that deforestation can be prevented from 2011 onwards, and the effects of deforestation are no longer visible after 2020.

10 The mosaic cropland-pasture land use category is a mixed land use class consisting of 20-70 % cropland and 30-80% pasture (ESA, 2011). In the land use assessment it is assumed that the mix is uniform for the entire country and is set at 50% cropland and 50% pasture.

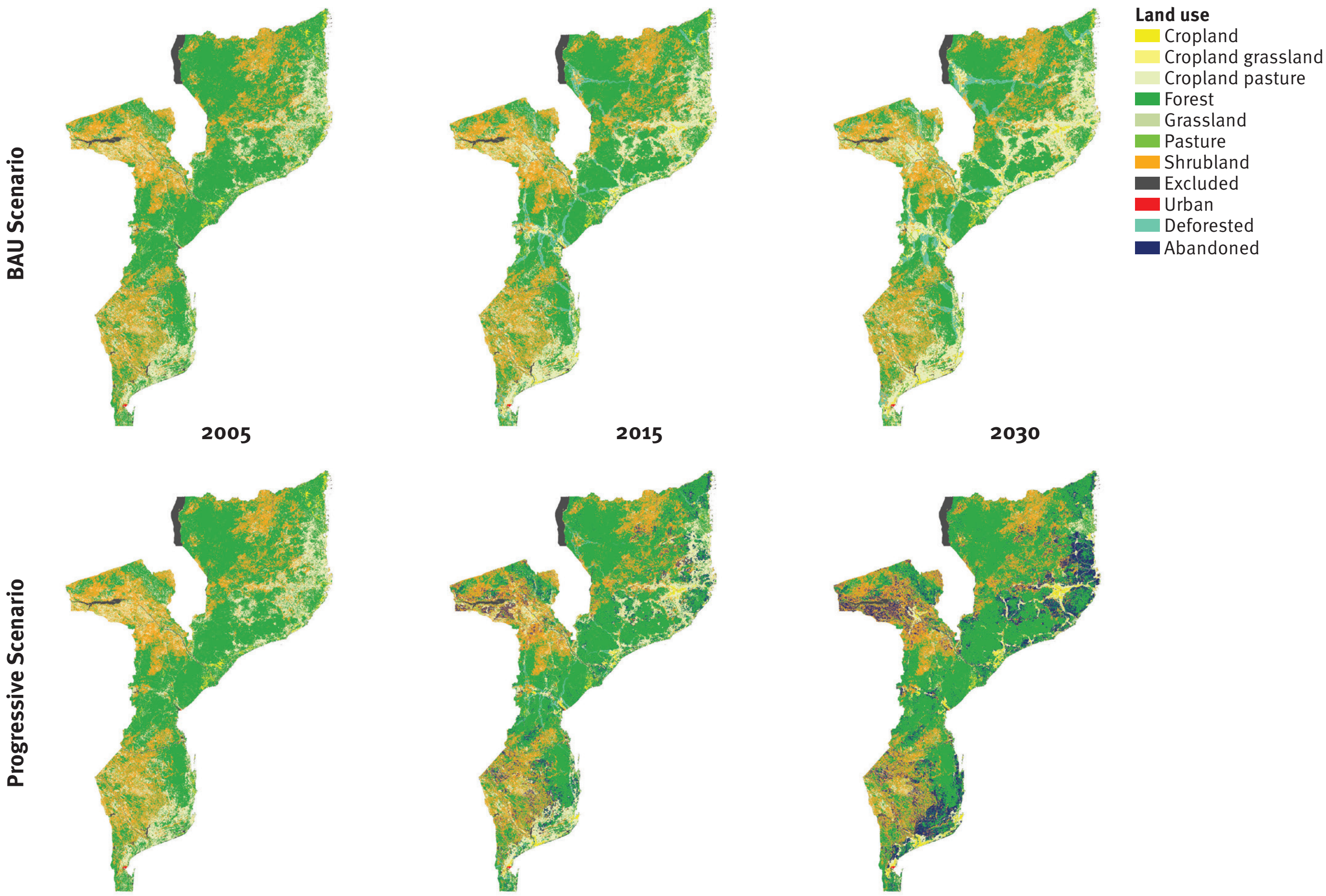
11 The mosaic cropland-grassland land use category is a mixed land use class consisting of 20-70 % cropland and 30-80% grassland /shrubland which is not used for grazing. In the land use assessment it is assumed that the mix is uniform for the entire country and is set at 50% cropland and 50% grassland/ shrubland.

Table 2: Developments in land availabilility for bioenergy crops towards 2030 in the three case study countries for the Business as Usual and the Progressive scenario.

Case study country	unit	Land in use for agriculture			Land availability for bioenergy crops		
		2010	2030		2010	2030	
			BAU	PROG		BAU	PROG
Mozambique	Mha	14.3	21.9	6.2	8.7	7.7	16.4
Ukraine	Mha	47.2	51.2	15.1	0.01	0.3	32.1
Argentina[a]	Mha	90.6	97.7	57.9	0	0	32.0

[a] This is excluding the land that is already in use or expected to become in use for soy. As part of the soy complex is used for biodiesel, there is a biofuel production potential even in the BAU scenario in which no additional land becomes available.

Figure 3: Land use dynamics in Mozambique up to 2030 for the Business as Usual (upper maps) and Progressive scenarios (bottom maps).



2.2.1.2 Land availability for energy crops

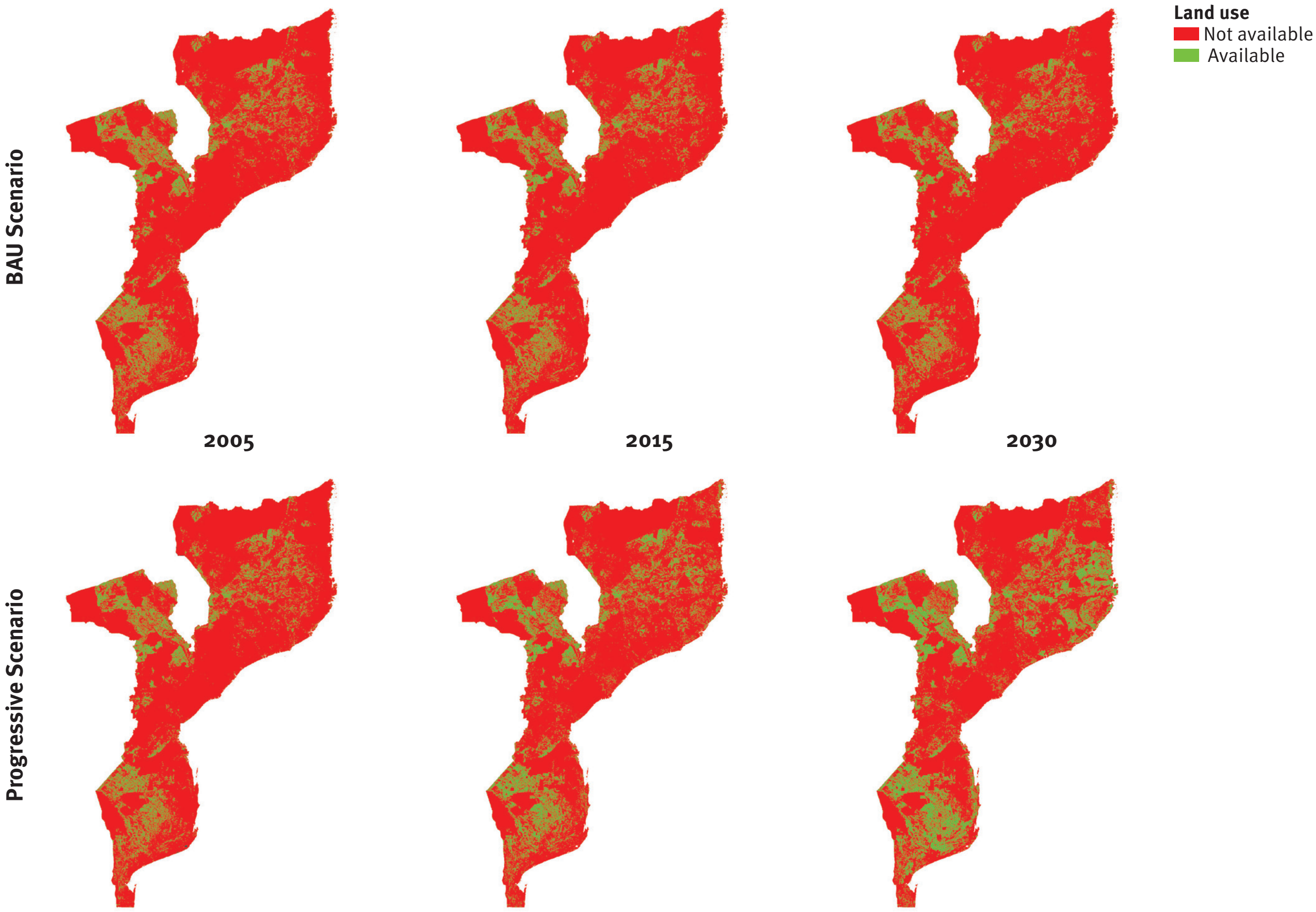
The developments in land availability for biofuels over the timeframe 2005-2030 are presented Figure 4. The red areas indicate areas that are not available for bioenergy crops. These areas have been excluded because they are used for other land use functions, such as cropland, pasture, forest and urban areas, or because they are not suitable (e.g. regularly flooded areas or steep slopes). In the BAU scenario in 2015 and 2030, the available land area decreases as land required for pasture and crops expands. As the expansion of cropland and pasture areas occurs mainly in the densely populated areas close to the main cities and road network, the land available for bioenergy is decreasing most rapidly in these areas (e.g. along the main north-south road and the Beira corridor). The areas which remain available for bioenergy crops are the more remote and less productive areas: in the central northern parts (Cabo Delgado, Niassa and Nampula provinces; mainly moderately to marginally productive), the north-western parts (Tete province; mainly marginally to non-productive) and south-western parts (Gaza province; mainly marginally to non-productive). In the Progressive scenario, the area required for crop and livestock production decreases over time. Mainly areas with an initially high proportion of mixed cropland-grazing become available. These areas are mostly situated in the South-East (Inhambane province; moderately to very productive), North-East (Nampula province; marginally to very productive) and North-West (Tete province; marginally to non-productive).

In the BAU scenario, land availability decreases over time from 9.1 Mha in 2005 to 7.7 Mha in 2030. For the Progressive scenario, the land availability for bioenergy crop production increases from 9.1 to 16.4 Mha.

2.2.1.3 Biomass potentials

Based on the time and spatially explicit calculations of land availability and suitability and the technical characteristics of the biomass supply chain, the development in potential of torrefied pellets and sugarcane ethanol production is calculated. For eucalyptus pellets the total potential is quite large (3200 PJ in 2030 in the progressive scenario), especially compared to the potential of sugarcane ethanol (866 PJ in 2030 in the progressive scenario). This is due to two main reasons: First, sugarcane is already converted to ethanol in which energy is lost, whereas pellets are still about to be converted to power and heat. And second, much more land

Figure 4: Land availability for bioenergy crops in 2005, 2015 and 2030 for the Business as Usual and the Progressive scenarios (based on deterministic runs). Red areas indicate the areas that are not available, whereas the green areas are the areas available for bioenergy crop production.



is suitable for eucalyptus cultivation than for sugarcane cultivation.

2.2.1.4 Regional land availability for selected settings in Mozambique

The modelling of land use shows and increasing land availability in the progressive scenario and decreasing land availability in the BAU scenario. Based on the findings of the land availability assessment, two areas were selected to make an environmental and socio-economic impact assessment. The Gaza-Inhambane and the Nampula region were selected based on the clustered land availability in these regions. The two areas were selected because they are quite different in terms of biophysical and socio-economic conditions such as current land use, land availability, climate, soil, population density, available infrastructure, employment etc. The boundaries of the selected areas are harmonised with administrative borders of districts and *localidades* (2rd and 3thorder administrative units).

The selected region in the central south of Mozambique is in the border area of Gaza and Inhambane province (see Annex 1 section A1.1.3.1 and blue delineated area in Figure 5). In this region there is a lot of land already available in 2010 and also in the BAU scenario a lot of land remains available as agriculture is not expanding much in these areas (Figure 5). In the progressive scenario large amounts of agricultural land becomes available for bioenergy crops due to the intensification of the agricultural sector. The amount of land that is available for bioenergy crops will double by 2030 and the majority of the available land is that which was previously in use as agricultural land. The average suitability of the available land increases as more suitable land becomes available over time. When the most suitable areas are selected even less land is required (see Table 3). The detailed figures on land availability, suitability and requirements in Gaza-Inhambane region are provided in Annex 2.

The other selected area in Mozambique is in the southern part of Nampula province (see Annex 1, section A1.1.3.1 and blue delineated area in Figure 6). In this region, little land is currently available as most of the land is in use for agricultural practices or is covered with forest. In the BAU scenario, the land availability decreases as agricultural land expands over time. The suitability of the land that is available is however high and is expected to remain constant over time in the BAU scenario. The current land availability is not sufficient to meet the input requirements of a large scale conversion plant. In the progressive scenario, land will become available in the selected area in Nampula due to intensification of

Figure 5: Land availability for bioenergy crops (in blue) in the selected area in Gaza and Inhambane provinces in 2020 in the Business as Usual scenario (left) and in the Progressive scenario (right).

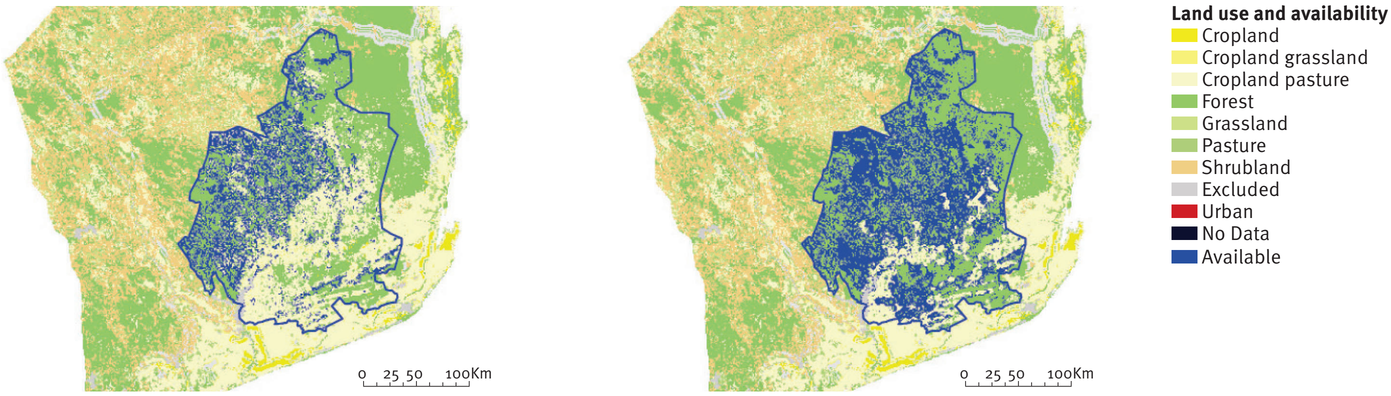
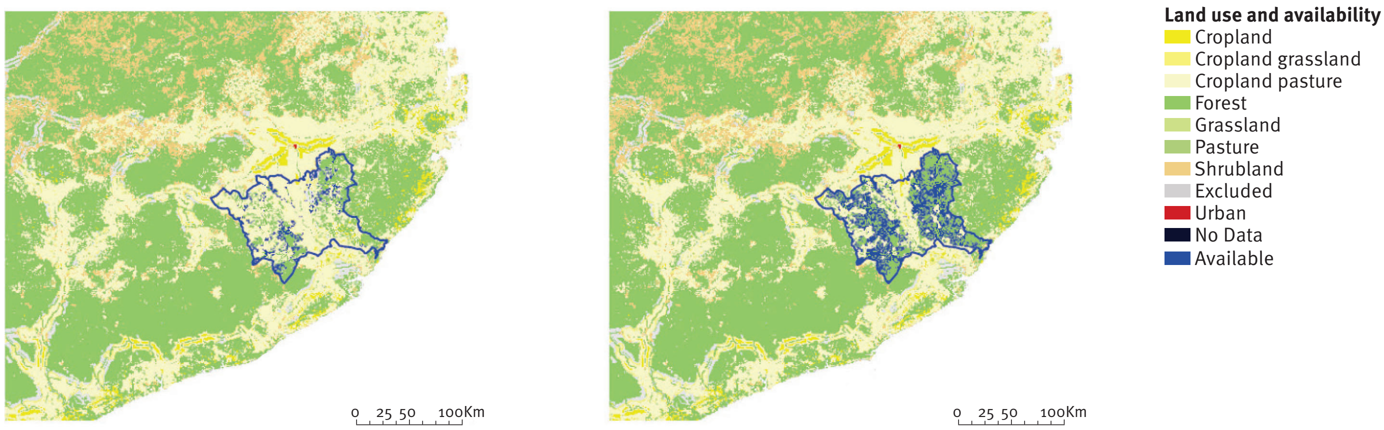


Figure 6: Land availability for bioenergy crops (in blue) in the selected area within Nampula province in 2020 in the Business as Usual scenario (left) and in the Progressive scenario (right). The left hand side map shows little land availability in 2020 in the BAU scenario. The right hand map shows a high increase in the land availability in the progressive scenario in 2020.



the agricultural sector (see Figure 6). The land availability will increase with a factor 4 by 2030. The proportion of the available land required to meet the input requirements of the conversion plant decreases rapidly due to the increased land availability and the expected increase in energy crop yields. If the most suitable areas are selected, even less land is required (see Table 3).The detailed figures on land availability, suitability and requirements in Nampula region are provided in Annex 2.

It is assumed that the project is implemented on in the best suitable area of the available land (former shrubland for the BAU scenario and mosaic cropland-pasture on the progressive scenario), the average suitability of the best suitable area is higher than the average suitability of all available land in the region.

In Annex 2, the selected settings for which the environmental and socio-economic impact assessment is conducted are described. The settings are differentiated for the two scenarios (BAU and Progressive), the two selected regions (Gaza-Inhambane and Nampula), the two selected energy crops (eucalyptus and switchgrass), and are all assumed to have the same end product (Ethanol), the same plantation type (large scale plantation) and the same management style (state of the art). See Table 3.

Based on regional assessment of the land that is and could become available in the two regions under the two scenario conditions, the selected setting differ in terms of replaced land use, average suitability, and required area to meet input requirements of the conversion facility. The key characteristics of the 8 different settings including the results of the land availability assessment are provided in Table 3. For these eight selected settings a full first order impact assessment will be performed addressing the key sustainability issues.

The selected supply chains are second generation ethanol from Eucalyptus and from switchgrass. The supply chains are described in Annex 1. For both supply chains, a large scale ethanol conversion facility is assumed. The supply chains are normalised to the same biomass capacity referred to the input of 1400 $MW_{th\,LHV}$. Given the feedstock to product ratio and the losses during the supply chain assumed, 2.2 Mton Eucalyptus feedstock and 2.3 Mton Switchgrass is required annually.

Table 3: Overview of the different settings in Mozambique included in the environmental and socio-economic impact assessment. The settings are differentiated for region, scenario and energy crop and concequently for suitability of the land in use, and the required area to meet the input requirements of the conversion plant.

Setting	Selected region	Scenario	Feedstock	Reference land use[a]	Required area (km²)[b]	Average suitability [c]	Potential Feedstock production [d]
1	Gaza-Inhambane	BAU	Eucalyptus	Shrubland	2046	41%	100%
2	Gaza-Inhambane	BAU	Switchgrass	Shrubland	3013	39%	100%
3	Gaza-Inhambane	PROG	Eucalyptus	Agricultural land	1336	55%	100%
4	Gaza-Inhambane	PROG	Switchgrass	Agricultural land	1470	54%	100%
5	Nampula	BAU	Eucalyptus	Shrubland	826	63%	62%
6	Nampula	BAU	Switchgrass	Shrubland	826	63%	46%
7	Nampula	PROG	Eucalyptus	Agricultural land	1317	64%	100%
8	Nampula	PROG	Switchgrass	Agricultural land	1871	62%	100%

a The current use of the land that (according to the land use modelling from 2005 towards 2030) is assumed to become available for energy crop in 2020.
b The amount of land that is required to meet the input requirements given that only the best suitable land of the indicated reference land use is used for the implementation of the project.
c The average suitability of the required land given that only the best suitable land of the indicated reference land use is used for the implementation of the project
d The extent to which the potential feedstock production in the region can meet the input requirements of the project size given the availability and the suitability of the land.

Considering the large scale of the plantation, it is likely that it will take some years to establish the entire project. However, in this impact assessment, the potential environmental and socio-economic impacts area assessed ex ante for an established and running project. The timeframe and the development in impacts during the establishing phase are not included. For example: clearance of the total area before planting and the environmental and socio-economic impacts of clearing and planting are included. But the rate of clearing and planting (amount of hectares per year) is not considered and how that would affect socio-economic and environmental impacts, is not addressed in this study.

2.2.2 Argentina

2.2.2.1 Land use change dynamics

The allocation of food production systems and land requirements to meet the demand for food crops and grass were modelled in yearly time steps from 2010 to 2030[12]. The modelled land use is depicted for the year 2010, 2020 and 2030 in Figure 7. In the BAU scenario, the currently observed trends of land-use change are maintained during the considered timeframe: 1) mixed production systems are gradually substituted by pure agricultural systems in the provinces of Buenos Aires and La Pampa; 2) the share of soy in the agricultural rotation schemes increases in the provinces of Buenos Aires, Santa Fe and Cordoba; 3) pastoral systems for livestock production keep expanding at the expense of nature areas, particularly in areas previously covered with forest in Chaco eco-region.

12 For Argentina, the selected reference year is 2010 as the land use maps of Globcover for 2009 were yet available when the assessment was made. In contrast, the reference year for Mozambique is 2005 as the land use maps of 2005-2006 of Globcover were the most recent maps available when the assessment was made for Mozambique.

In the progressive scenario, meat production increasingly shifts towards the intensive landless systems and increased feed conversion efficiencies. This results in lower land requirements for livestock production in grazing systems, despite the increase on the demand for animal products. The decrease in area required for livestock production also implies that the conversion of nature areas to pastoral grazing systems as observed in the BAU scenario does not occur in the progressive scenario. Moreover, the increase in attainable crop yields implies that the total area of land devoted to agriculture and mixed rotation systems remains fairly constant during the considered timeframe, even though there is an increase in the use of food and feed crops.

2.2.2.2 Land availability for energy crops

Since technological developments in crop production and particularly in livestock production are modest in the BAU, the increase in demand for food commodities implies that the land required to meet the increasing food demand keeps expanding and therefore no surplus land becomes available for dedicated biofuel production (see Figure 8). In the progressive scenario, the developments in livestock and crop productivity exceed the increase in demand for food. Consequently, around 32.6 Mha could become available for dedicated biofuel production by 2030. The decrease in area required for livestock production also implies that the conversion of nature areas to pastoral grazing systems as observed in the BAU scenario does not occur in the progressive scenario.

The largest share of surplus land that could become available for biofuel production is currently used for livestock production in pastoral systems (82.3%), followed by mixed production systems (15.0%) and agriculture (2.7%). A large part of surplus land is located in the south-east part of

Figure 7: Land use dynamics in Argentina up to 2030 for the Business as Usual (upper maps) and Progressive scenarios (bottom maps). The mixed rotations (1,2) land use classes comprise 50% livestock and 50% crop rotations. The agricultural rotations (3,4) comprise 100% crop rotations. The number (1,2,3,4) indicate the typical rotations for specific regions. The static areas are the areas that are assumed to be excluded from any change and include e.g. inland water bodies, regularly flooded areas, urban areas, consolidated bare areas.

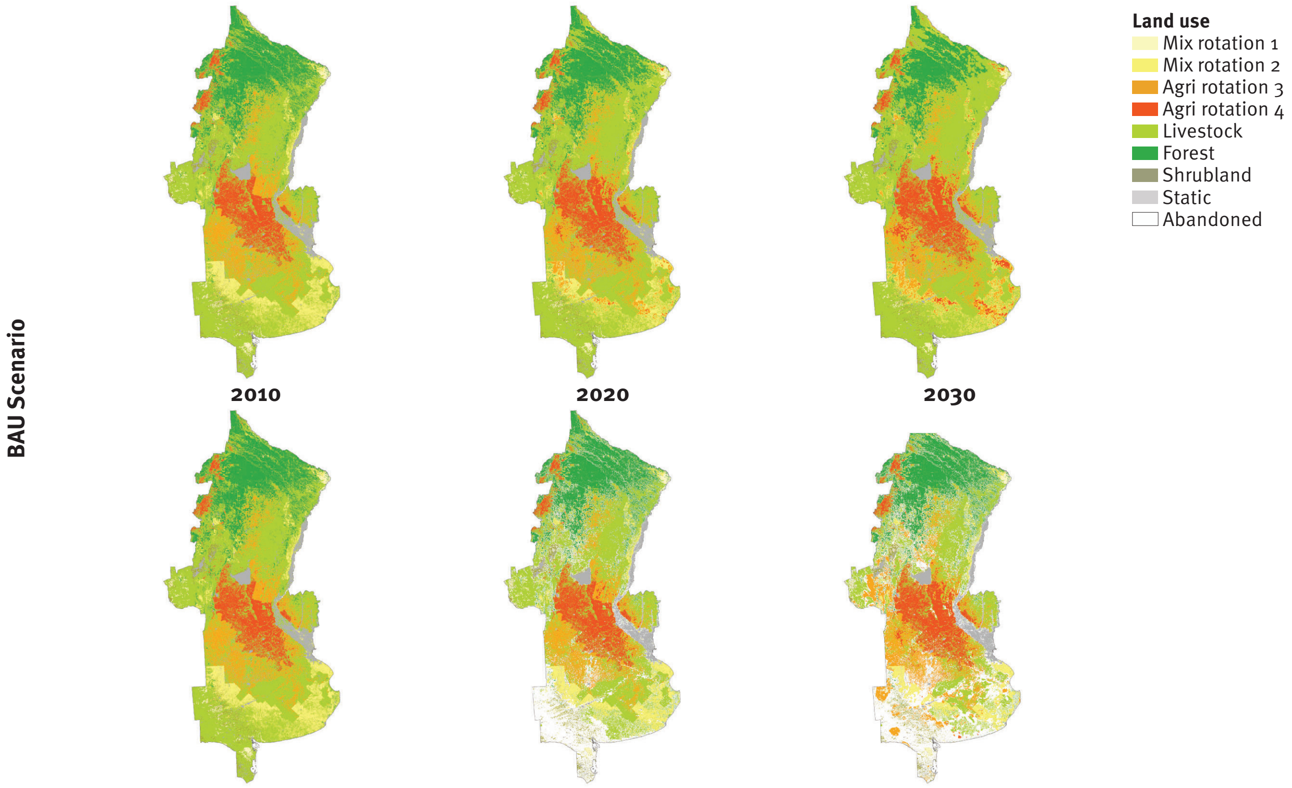
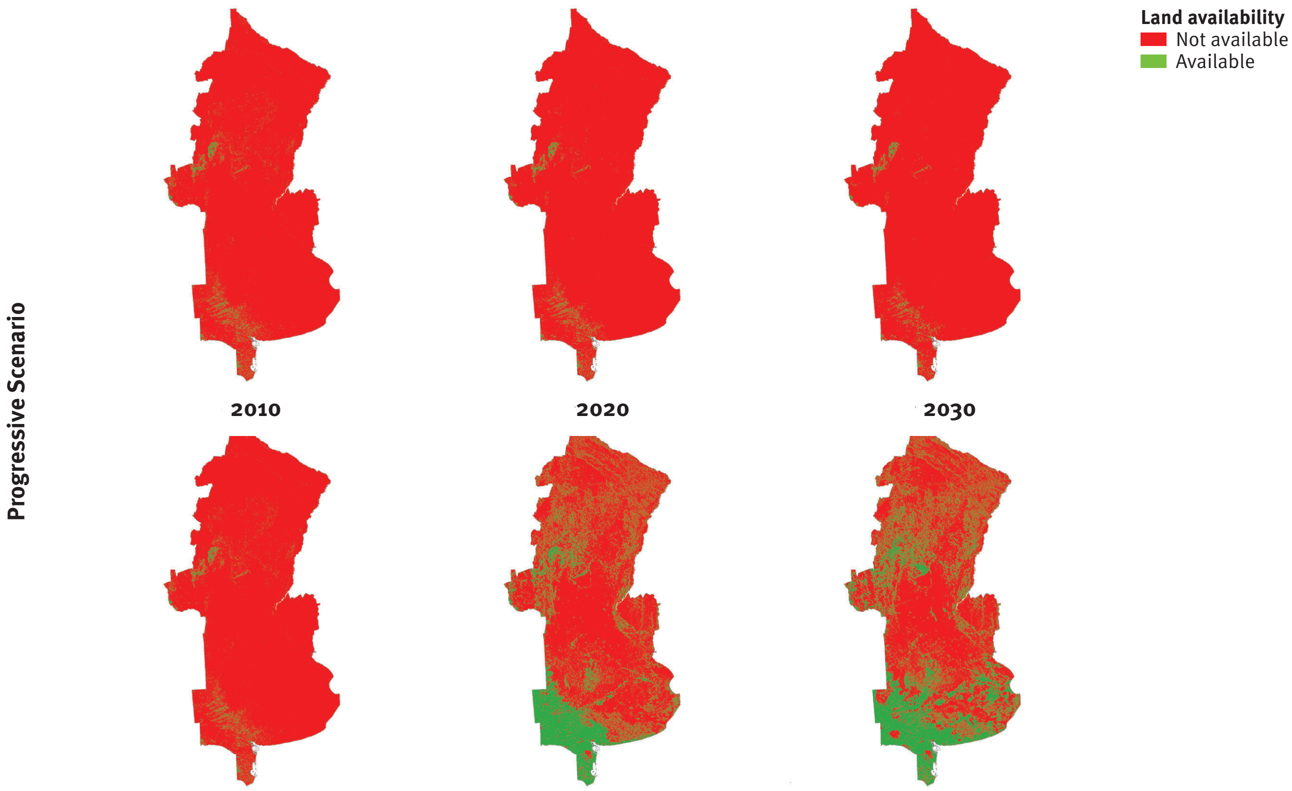


Figure 8: Land availability for bioenergy crops in 2010, 2020 and 2030 in Argentina for the Business as Usual and the Progressive scenario. Red areas indicate the areas that are not available, whereas the green areas are the areas available for bioenergy crop production.



Buenos Aires province and in La Pampa provinces, where the biophysical suitability for conventional crops is low. This result is in line with historical trends of agricultural land abandonment in the less suitable areas of La Pampa province (Carballo, 2011) and with the findings of Van Dam *et al*. (2009a), which had also identified the province of La Pampa as a promising region in terms of land availability for the deployment of large-scale biofuel feedstock. To some extent, land could also become available in the northern regions of the study area, but here the patterns appear to be more scattered. The most productive regions in the centre of the country are allocated for food crop production and thus are not available for cultivation of dedicated energy crops.

2.2.2.3 Biomass potentials

According to the dynamic simulation of future land-use following BAU scenario assumptions, no surplus land is expected to become available for biofuel production by 2030 and therefore, there is no potential for biofuel produced from switchgrass in this scenario. Biodiesel production is nevertheless expected from the existing soy complex for feed production, through conversion of oil resulting as a by-product of soy meal production that is not required to fulfil the expected demand for soy oil. Hence, taking into account the expected demand for soybean exports, soy meal and soy oil, the technical and economic potential for soybean-based biodiesel by 2030 is 81PJ. According to the progressive scenario, an increase on the demand for soy (8.5 million ton) is expected in this scenario, due to the increase of soy meal in the feed composition for livestock production, which could provide an additional potential of 60 PJ, thus leading to a potential of 141 PJ as a by-product of feed production.

In addition in 2030, 32 Mha of surplus land could become available for dedicated soybean cultivation (44 million ton) leading to potential production of 309 PJ and thus leading to a technical potential of 450 PJ soy-based biodiesel. No land is available for switchgrass in BAU scenario. In the progressive scenario, a production volume of 170 million ton could be attained in the available surplus land in progressive scenario, leading to a technical potential of 1.4 EJ switchgrass-based ethanol production.

2.2.2.4 Regional land availability for selected settings in Argentina

In Buenos Aires, there is some land available for energy crops in 2010 and these decreases over time in the BAU scenario. In this scenario only shrubland is available for bioenergy crops. In the progressive scenario, abandoned agricultural land becomes available. This is mainly located in the south west of Buenos Aires province (see Figure 9).

In Santiago del Estero, little land is available in the BAU scenario and the land that is available is not suitable for energy crop production. In the progressive scenario, large areas of land become available. However, the availability is relatively scattered throughout the province (see Figure 10). In the progressive scenario, the average suitability of the available land increases as more suitable land becomes available over time. It is assumed that only the land that is available and suitable can be used for bioenergy crops and that the best suitable areas will be used. In Table 4 the land availability, the land suitability and the land requirements are depicted for the switchgrass and soy in the two regions and for the two scenarios.

Figure 9: Land availability (in blue) in Buenos Aires in 2020 in the Business as Usual scenario (left) and in the Progressive scenario (right).

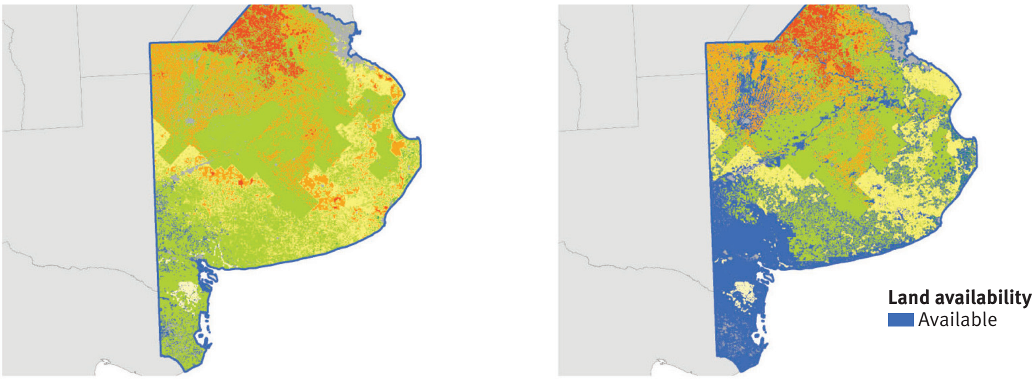


Figure 10: Land availability (in blue) in Santigo del Estero in 2020 in the Business as Usual scenario (left) and in the Progressive scenario (right).

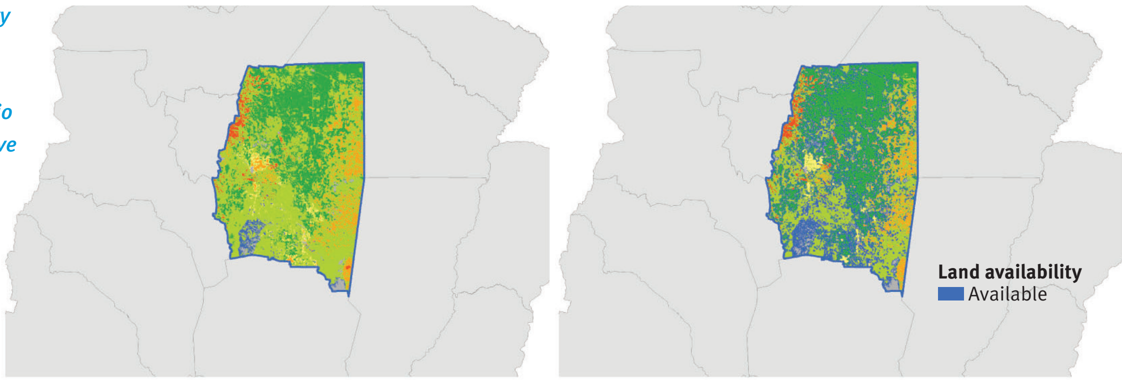


Table 4: Overview of the different settings in Argentina included in the environmental and socio-economic impact assessment. The settings are differentiated for region, scenario and energy crop and concequently for suitability of the land in use and the required area to meet the input requirements of the conversion plant.

Setting	Selected region	Scenario	Feedstock	Reference land use [a]	Required area (km^2) [b]	Average suitability [c]	Potential Feedstock production [d]
1	Buenos AIres	BAU	Switchgrass	Shrubland	313	100%	100%
2	Buenos AIres	BAU	Soy	Shrubland	2835	52%	100%
3	Buenos AIres	PROG	Switchgrass	Agricultural land	313	100%	100%
4	Buenos AIres	PROG	Soy	Agricultural land	1475	100%	100%
5	Santiago del Estero	BAU	Switchgrass	Shrubland	128	91%	37%
6	Santiago del Estero	BAU	Soy	Shrubland	117	27%	2%
7	Santiago del Estero	PROG	Switchgrass	Agricultural land	313	100%	100%
8	Santiago del Estero	PROG	Soy	Agricultural land	2856	52%	100%

a The current use of the land that (according to the land use modelling from 2010 towards 2030) is assumed to become available for energy crop in 2020.
b The amount of land that is required to meet the input requirements given that only the best suitable land of the indicated reference land use is used for the implementation of the project.
c The average suitability of the required land given that only the best suitable land of the indicated reference land use is used for the implementation of the project
d The extent to which the potential feedstock production in the region can meet the input requirements of the project size given the availability and the suitability of the land.

The settings for which the environmental and socio-economic impact assessment are conduced are differentiated for the two scenarios (BAU and Progressive), the two selected regions (Buenos Aires and Santiago del Estero), the two selected energy crops (switchgrass and soy), and the two end products ethanol from switchgrass and diesel from soy. It is assumed that for both switchgrass and soy are cultivated in large scale plantations and that state of the art management is applied. The supply chains are defined for the same biofuel production levels in $PJ_{biofuel}$ per year, unless land availability limits the biomass production. In that case the impacts are assessed for the all land that is available for energy crops even though this is not sufficient to meet the input requirements of the conversion plant. The output level of the soy biodiesel plant is set at 108 000 tons of biodiesel which equals 4.67 PJ biodiesel/yr. This is in line with the current average biodiesel plant size(Hilbert *et al.* 2012). For the ethanol supply chain the same output level 4.67 PJ ethanol /yr is assumed. Soy oil is just one of the outputs of soy bean processing: 81.6% of the mass of soy bean is used for soy meal production. The impacts of soybean cultivation and transport are allocated to biodiesel based on the energetic value (only 36% of the energy content of soy is used for the production of biodiesel). Allocation based on energetic value is in line with the renewable energy directive of the EC (2009).

Based on regional assessment of the land that is and could become available in the two regions under the two scenario conditions, the selected setting differ in terms of replaced land use, average suitability, and required area to meet input requirements of the conversion facility. The key characteristics of the 8 different settings including the results of the land availability assessment are provided in Table 4. For these eight selected settings a full first order impact assessment will be performed addressing the key sustainability issues.

2.2.3 Ukraine

2.2.3.1 Land use change dynamics

The current agricultural productivity in Ukraine is very modest and has seen little development over the last decade (de Wit *et al.* 2011a). Due to little expected changes in population numbers and dietary intake, the change in domestic demand for food and feed is relatively limited. In both scenarios, the growth rate of the land area for crops exceeds the growth rate of pastures and there is a tendency towards more dedicated cropland and pasture land, at the expense of mosaic cropland-pasture. This is the result of the intensification of the livestock sector which the productivity is currently very low. The modelled LUC dynamics in Ukraine for the timeframe 2010-2030 are depicted in Figure 11.

In the BAU scenario, cropland expands at the expense of mosaic cropland-pasture in areas with a high agro-ecological suitability and which are currently already popular agricultural areas (have high land rent). This is a clearly visible in the central west region (Ternopil, Vinnytsia, Cherkasy and Kiev oblast). Expansion of agricultural land is mostly at the expense of grassland and shrubland, and sometimes at the expense of forest especially the patches that are surrounded by agricultural land and are located in very suitable areas. Non-agricultural land is often first converted to pasture and subsequently to cropland-pasture and cropland. In the BAU scenario little land is available for bioenergy crops as all current agricultural land is required to meet the future food and feed production demand.

In the progressive scenario, agricultural land is rapidly abandoned due to the high productivity increase. Land is primarily abandoned in the areas which are less suitable for agricultural production such as the north and north-western

Figure 11: Land use dynamics in Ukriane up to 2030 for the Business as Usual (left maps) and the Progressive scenarios (right maps).

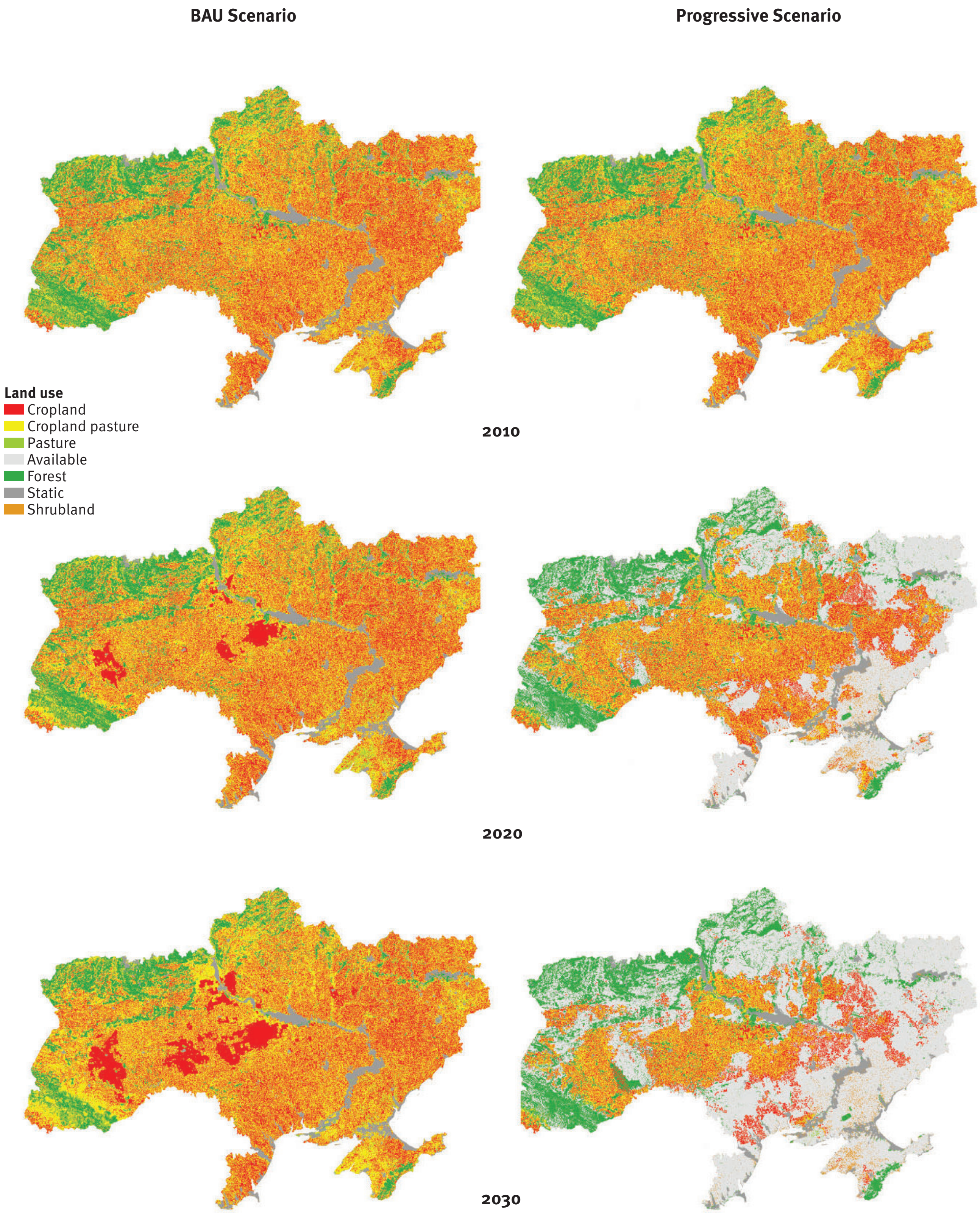
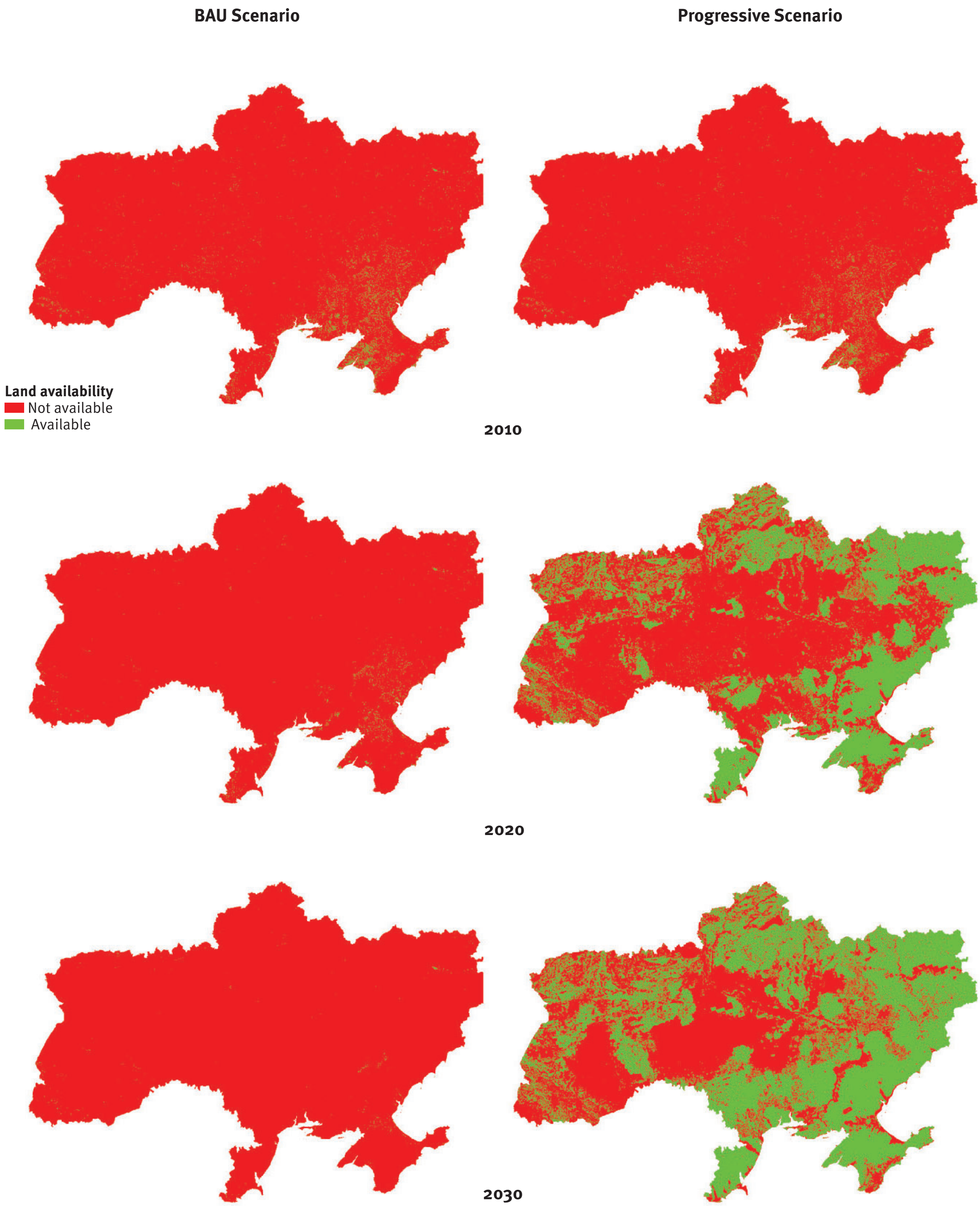


Figure 12: Land availability for bioenergy crops in 2010, 2020 and 2030 in Ukraine for the Business as Usual and the Progressive scenario. Red areas indicate the areas that are not available, whereas the green areas represent the areas that are available for bioenergy crop production.



areas, which are mainly marshy mosaic forest areas, the south west, which are the Carpathian Mountains (cropland), the eastern areas which are more industrialized, and the south, which receives little precipitation. Agricultural production concentrates in the central parts of Ukraine which are most suitable for both crops and pastures. In addition, these areas are currently popular for agricultural production, have relative high population density, are in the vicinity of large cities, have many villages, have access to railroads and have high unemployment rates. In the progressive scenario there is a trend towards more dedicated cropland and pasture at the cost of mosaic cropland-pasture. Therefore, cropland-pasture areas are abandoned more rapidly than pure cropland, and dedicated pastures areas even expand slightly. Although the conversion elasticity is in favour of converting abandoned agricultural land to pasture, pasture areas are expanding in other areas which are more favourable in terms of agro-ecological suitability, at the expense of shrubland.

2.2.3.2 Land availability for energy crops

In Figure 12, the land availability for energy crops is depicted for 2010, 2020 and 2030 for the BAU and progressive scenario. In the BAU scenario the land availability for energy crops is low and decreases over time. In the progressive scenario, the land availability for energy crops increases fast due to the rapidly contracting cropland and pasture land. The cropland and pastures remain concentrated in the high fertile and well accessible central part of Ukraine. As the less suitable areas are abandoned first, the suitability of the land that becomes available increases over time.

2.2.3.3 Biomass potentials

Based on the developments in land availability, the suitability of the land that becomes available for wheat and switchgrass cultivation, and the technical characteristics of the biofuel supply chain, the developments in biofuel production are assessed. Although the assumed conversion efficiency from wheat to ethanol is higher than from switchgrass to ethanol, the potential ethanol yield per hectare is higher for switchgrass due to the higher biomass yields (a maximum yield of 170 GJ/ha/yr for switchgrass and 100 GJ/ha/yr for wheat). In the progressive scenario, up to 5.0 EJ biomass could be produced on the available land (in 2030) compared to the potential wheat production 3.6 EJ (grain). As in the BAU scenario little land becomes available, potential annual production is low compared to the progressive scenario (±2 PJ for wheat and switchgrass in 2030).

2.2.3.4 Regional land availability for selected settings in Ukraine

The assessment of the regional land availability is performed as an input for the detailed regional analysis of the environmental and socio-economic impacts. For Ukraine, a detailed analysis of the environmental and socio-economic impacts was deemed not feasible due to the low availability of data especially on the local socio-economic conditions and due to language difficulties (region specific information is often not available in English and experts speak often solely Russian and/or Ukrainian), and the lack of additional resources for extensive field work.

Similar to the land use data for Mozambique and Argentina, the land use data for Ukraine is derived from Globcover. However, there is large spatial variability in the status of agricultural land. In some areas agricultural land is abandoned or degraded but maintain the status of agricultural land and in some areas there is intensive agricultural production. Although this is also true for Mozambique and Argentina these differences are more profound in Ukraine and could not be verified as there is no land use data available in Ukraine. The new land law and the land registration should provide more transparency on this, but this is still in progress (for some years now). For that reason the land use assessment is relatively uncertain. As all impacts of biofuel production are related to the change in land use, the uncertainty in the previous land use affects the ability to quantify these impacts to a large extent. In addition, limited climate data is available for Ukraine as there is no widespread network of weather stations. Spatial data on climate results from interpolation of climate data from weather stations inside and outside the boarders of Ukraine. As climate affects all environmental impacts (GHG emissions, soil, and water) inaccuracy in climate data will influence the ability to quantify the environmental impacts. The main shortcoming in data availability is the data on regional socio-economic conditions. This is often not available at all or not available in English. This was also confirmed by the reporting of SEC biomass, the local partner in Kiev Ukraine. Also a work visit of the authors of this report and longer working period of a Master student in Ukraine did not result in sufficient data. For these reasons, it was not feasible to conduct a full environmental and socio-economic impact analysis in this study. However, it is assumed that significant additional research efforts on data gathering and analysis could enable this type of analysis for Ukraine.

3. Environmental and socio-economic impacts

3.1 Methods

An impact analyses will be made to screen the environmental and socio-economic implications of large scale biomass production, following the state-of-the-art proposals for sustainability criteria for biomass production and use.

At several levels, initiatives for sustainability criteria, codes of conduct and protocols have been and are currently developed to deal with the sustainability issues of biomass for bioenergy production (Cramer *et al.* 2006; Fehrenbach *et al.* 2008; Gallagher 2008; ISO 2008; EC 2009; NEN 2009; ISCC 2010; RSB 2010; GBEP 2011). The expanding number of initiatives on certification systems and sustainability criteria differ (partially) in scope and type of criteria included but also on methodologies, data requirements and feasibility, partly due to conflicting values and objectives at stake (van Dam, Junginger et al. 2010, van Dam, Junginger 2011). Proliferation of standards could hamper general acceptance and implementation. Therefore, there is a strong need for a more coherent, harmonised and internationally acknowledged set of sustainability criteria (Scarlat, Dallemand 2011, van Dam, Junginger 2011). Currently there are several initiatives for harmonisation of sustainability standard for biofuels and bioenergy (ISO, 2008; Global Biopact, 2012). Sustainability criteria for biomass for bioenergy generally include principles related to environmental and social and economic impacts (Markevičius, Katinas et al. 2010).

In Table 5, the key environmental and socio-economic issues addressed by prominent sets of sustainability criteria for biofuel and bioenergy feedstock production are listed. The selection of sustainability issues is based on the inventory of Scarlat and Dallemand (2011) and van Dam *et al.* (2010) and complemented with the criteria drafted in Mozambique by the inter-ministerial biofuel commission (MICOA, 2012).oF[13] There are no specific official environmental or social sustainability criteria for biofuels in Argentina (Joseph 2012). Ukraine has no national sustainability criteria for biofuels, as they are not part of the European Union they don't have to comply with the EU RED. However, as Europe is a likely potential offset market for Ukraine compliance with the RED would be required.

Some of the criteria mentioned in the sustainability certification schemes are just requirements that have to be fulfilled. For example: 'the company needs to comply with legislation'; or, 'an environmental or socio-economic impact assessment has to be performed'; or, 'agrochemical use should be reported'. These requirements are relatively easy to comply with or at least it is clear how it can be incorporated in the set up and design of the project.

At present, a key bottleneck for both market players and government is how the sustainability criteria focussing on impacts can be met in practice, and how these impacts can be quantified in a verifiable and reliable manner as standardised methods to assess the impacts are lacking.

In Annex 3, the environmental and socio-economic issues listed in Table 5 are discussed. The following sections indicate what type of method is applied to assess the potential environmental and socio-economic impacts. In Annex 3, a more detailed description of the methods including the most important equations is included. The methodological concepts developed in the Biofuel screening toolkit, have been translated to a methodological framework to quantify the environmental and socio-economic impacts of biofuel production on a regional level. This methodological framework is demonstrated for the three specific case studies but could be applied to any bioenergy supply chain, any production scale level and any region in the world.

13 The overview in this study is limited to existing internationally known certification schemes specifically for biofuels and bioenergy. The certification schemes focusing on a particular crop i.e. BSI (sugar cane), RTRS (soy), RSPO (palm oil), FSC (wood) PEFC (wood and paper) are omitted from the inventory of Scarlat and Dallemand (2011). Also the certification schemes not particular for bioenergy but on agricultural products in general (GlobalGAP, SAN, Fair Trade, SAI, IFOM, US-RFS) are not included in our overview.

Table 5: Environmental and socio-economic aspects included in several international certification schemes.[14]

Impacts	Issue	EU-RED	CSBP	GBEP	RSB	ISCC	NTA8080	RFTO	MOZ
		Certification schemes [a]							
Environmental impacts	GHG emissions	√	√	√	√	√	√	√	√
	Biodiversity	√	√	√	√	√	√	√	√
	Soil		√	√	√	√	√	√	√
	Water		√	√	√	√	√	√	√
	Air emissions		√	√	√	√	√	√	√
Socio- economic impacts	Legality				√		√		√
	Land rights			√	√	√	√	√	√
	Economic viability			√	√				√
	Local prosperity			√	√		√		√
	Social well-being			√	√	√	√		
	Labour conditions		√	√	√	√	√	√	√
	Food security	√		√			√		√

[a] EU RED	Directive 2009/28/EC of the European parliament and of the council on the promotion of the use of energy from renewable sources and amending (EC 2009)
CSBP	Council on Sustainable Biomass Production (CSBP, 2012)
RSB	Roundtable on sustainable biofuels (RSB 2009, RSB 2010)
ISCC	International sustainability & carbon certification (ISCC 2010)
NTA8080	Dutch Technical agreement: Sustainability criteria for biomass for bioenergy purposes (NEN 2009)
RFTO	Renewable Transport Fuels Obligation (RFTO, 2012)
MOZ	Quadro Legal de sustentabilidade de biocombustiveis (MICOA, 2012)[15]

3.1.1 Environmental impacts

3.1.1.1 GHG emissions

GHG emissions from biofuel / bioenergy production and use can be differentiated in emissions related to land use and cultivation and emissions during the life cycle. This assessment is limited to the assessment of the GHG emissions during the feedstock cultivation including the emissions related to LUC. The GHG emission included in this study are CO_2 N_2O and CH_4.

GHG emitted during the cultivation of energy crops are related to diesel for agricultural machinery, seed, pesticides and fertilizer production. The emissions related to fertilizer application are included in the LUC related emission as they are strongly related to variations in biophysical conditions. The GHG emissions related to the production of biomass feedstock were calculated using a Lifecycle assessment (LCA) approach.

GHG emissions due to LUC are caused by changes in soil carbon stocks, above and below ground biomass and residues. In addition, LUC causes changes in N_2O emissions due to changes in fertilizer and manure application and drainage of organic soils. The livestock related emissions are not incorporated in this study. The IPCC guidelines are used to calculate the GHG emissions due to LUC (IPCC 2006).

3.1.1.2 Soil

The criteria in the certification schemes refer to the preservation of the soil quantity and soil quality. Soil Organic Carbon (SOC) is considered to be the most appropriate indicator for soil quality (Reeves 1997). The change in soil organic carbon due to land use and management change can be quantified using the methods proposed by the IPCC (2006). Preservation of the soil (quantity) implies that erosion by means of water runoff and soil loss trough wind erosion should be prevented. The water related erosion can be estimated using the revised universal soil loss equation (RUSLE)[16] (USDA and NRCS 2002). The risk on wind related erosion can be quantified using the Wind erosion Equation (WEQ)[17] (USDA and NRCS 2002).

3.1.1.3 Water

In this study, two indicators to assess the impact of bioenergy cropping on water quantity are used. To assess the potential water depletion due to the introduction of bioenergy crops, a simple water balance was made by comparing the monthly local evapotranspiration of energy crops to the monthly effective precipitation. It provides an indication of the water use and the water depletion per hectare. The water use efficiency (WUE) indicator is used to express the water requirements per unit biomass given the crop and location evapotranspiration and biomass yield. It provides an indication about the water requirements per unit crop produced.

14 Based on the inventory of Scarlat and Dallemand (2011) and van Dam et al. (2011) and supplemented with the sustainability criteria drafted in Mozambique.

15 Biofuel sustainability framework of Mozambique

16 The revised universal soil loss equation is a widely used mathematical model to estimate the annual soil loss due to water related soil erosion. It includes the factors: rainfall erosivity, soil erodibility, slope length, slope steepness, cover-management and support practice (USDA, 2002)

17 The Wind Erosion Equation is frequently used to estimate the annual soil loss due to wind erosion. It includes the factors: soil erodibility, soil roughness, climate, vegetation cover and field length.

3.1.1.4 *Biodiversity*
The impact of energy crop cultivation on biodiversity depends on both local scale effects (choice of crop, management intensity, vegetation structure, substituted land use) and landscape scale effects (geographical location, scale and distribution of crops) (Eggers *et al.* 2009). LUC is a strong driver of changes in biodiversity (Sala *et al.* 2000; UNEP 2002; Foley *et al.* 2005; Reidsma *et al.* 2006). In this study, the national conservation and protected areas and forest areas are excluded for agricultural expansion and for energy crop cultivation in the LUC modelling. To indicate the effect of LUC of current land use towards bioenergy crop production, the Mean Species Abundance (MSA) will be used as indicator. The Mean Species Abundance (MSA) is a quantitative indicator for change in biodiversity. It does not reflect individual species responses but represents the average response of the total set of original species relative to their abundance in undisturbed ecosystems (Alkemade *et al.* 2009).

3.1.1.5 *Air emissions*
Most sustainability criteria refer also to other air emissions in addition to GHG emissions. Other air emissions mentioned in certification schemes are dust, NO_x, and SO_2. These certification systems often cover both the biomass production and biomass processing. Especially during processing there is a risk on polluting air emissions. As this study focuses on the cultivation phase of the biomass supply chain, the emissions related to processing of biomass and also transport are not included. The sulphur related emissions during cultivation of biomass are mostly related to diesel usage for agricultural field practices. The nitrogen related emissions are directly related to the use of fertilizers. Most certification schemes refer to compliance with national laws and legislation concerning air quality. In addition, many of the certification schemes prohibit or discourage field burning of residues. Compliance with national laws and legislation and the avoidance of field burning are part of the best practice management assumed in this study.

3.1.2 Socio-economic impacts

3.1.2.1 *Legality*
As the criteria in the sustainability schemes related to compliance with national law and legislation refer to non-measurable and non-quantifiable principles. No methods are developed to assess these criteria. The results section on this topic will be limited to references to the most important legislations and regulations.

3.1.2.2 *Land rights*
In order to prevent conflicts over land, several areas are excluded for land use allocation in the land use modelling for the assessment of land availability for bioenergy crops. The land areas that are excluded (in addition to biophysical limitations) for land use allocation are: urban areas, community areas, protected areas, previously assigned land use right), and concession areas. In addition, all land in use for agricultural purposes is excluded for energy crop cultivation. In this assessment both a quantitative and qualitative analysis is performed. The quantitative analysis is based on the land availability assessment: When no sufficient land is available to meet the input requirements of the conversion plant, this indicates a high pressure on land and a potential risk of violation land use rights. The qualitative analysis consists of an evaluation of the land tenure or acquisition procedure, and an overview of the most important issues with land rights in the case study countries.

3.1.2.3 *Food security*
The four internationally-agreed dimensions of food security are: availability, access, stability and utilization (GBEP 2011). How the project will affect the food security in the region depend on the current food security conditions and the policy, management and practices of the project. The current food security condition will be analysed on two levels, *nationally* and regionally. If statistical data is available, common food security indicators will be used such as % of the population that is undernourished. If these figures are not available (Mozambique), the food basket methodology is used (Franke *et al.* 2012). This methodology consists of two steps (Franke *et al.* 2012):

- Step 1: Determination of relevant food basket and of its components
- Step 2: Indication of changes in prices and/or supply of the food basket in the context of biofuels

If food security is an issue in the case study country, recommendations are provided to increase positive impacts by the biofuel companies.

3.1.2.4 *Economic viability*
Feedstock production costs are assessed by calculating the net present value (NPV) of all costs items and the biomass yield during the lifetime of the biomass production plantation. The costs and revenues of crop production depend on soil and climate, the economic environment, and the farm management system. The conversion costs comprise investment costs, operation and maintenance (O&M) costs, and energy input costs. It is assumed that the costs of pre-treatment and conversion are not location specific and are therefore not calculated spatially explicitly. Biomass logistics contribute significantly to the total cost per GJ bioenergy produced and delivered (Dornburg and Faaij 2001; Hamelinck *et al.* 2005). Key factors of determining the cost of primary transport are the scale of conversion plant and the biomass availability in an area.

3.1.2.5 *Local prosperity*
Based on the data required to calculate the economic viability of the total investment, the total required labour and the affluent of wages into the region can be calculated. The size of the regional unemployed labour force, compared with required labour is used as proxy for labour migration. To what extent the project affects the local prosperity in the region, depend also on the current conditions. Therefore several background indicators are selected such as total population, labour force, current unemployment rate, poverty index, and GDP, in order to put the extent of the effect into perspective.

3.1.2.6 Social well-being

The contribution of the project to the social well-being in a region depends on the policy, management and practices of the project that is to be established and can therefore not be assessed beforehand. However, as it is assumed that sustainability criteria are to be met, it is assumed that compliance with national laws and regulations and social responsibility is part of good practice. The impact of a project on the local social well-being largely depends on the current social situation. Therefore, background details on the most important issues in the case study country are provided in order to interpret the potential impact of a biomass project on the social well-being in the region. These can be land use, health care, education, illiteracy, housing, labour immigration, infrastructure, and access to energy services. If social well-being is potentially significantly affected, the number of people affected by the project living in the immediate surroundings provides an indicator of the impact of the project on the community.

3.1.2.7 Labour conditions

Labour conditions are one of the socio-economic impacts included in many of the certification schemes. The issues most often addressed in these criteria refer to working conditions, health and safety, working hours, contracts, wages, child labour, forced labour, capacity building and training, freedom of association and sometime equality and gender issues. The labour conditions depend on the policy, management and practices of the project that is to be established and can therefore not be assessed beforehand. For this ex ante assessment, current regulations are described if available and recommendations are provided for good practices.

3.1.2.8 Gender

This aspect cannot be analysed ex-ante as it depends on project implementation. A description of the current status in the countries on gender equity will be used to assess the potential impact of the biofuel supply chain. Furthermore, recommendations for best practice to include gender equality aspects will be provided.

3.2 Results for Mozambique

3.2.1 Environmental impacts

3.2.1.1 GHG emissions

The GHG emissions are differentiated for the emissions due to LUC, for cultivation and for the entire supply chain. All results of the GHG emissions are included in Annex 3. The total effect of the cultivation of the two selected bioenergy crops in the two selected regions under the two scenario conditions was assessed by calculating the GHG emissions per ton feedstock produced and are depicted in Figure 13.

Figure 13: GHG balance per GJ feedstock including emissions of cultivation, and emissions related to changes (Δ) in soil organic carbon (SOC), below ground biomass (BGB) and above gound biomass (AGB) for eucalyptus (EU) and switchgrass (SG) in Gaza-Inhambane and in Nampula for the Business as Usual and the Progressive Scenario.

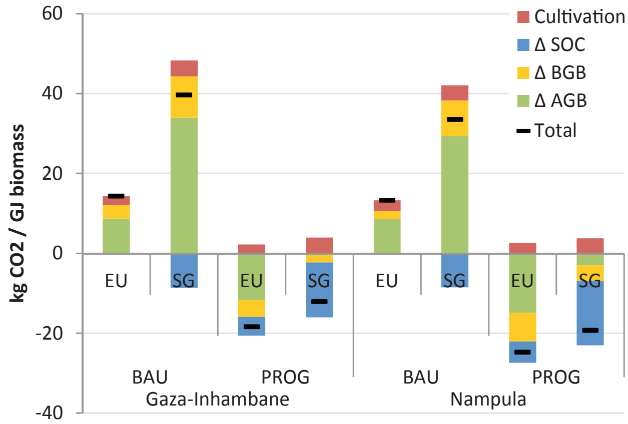


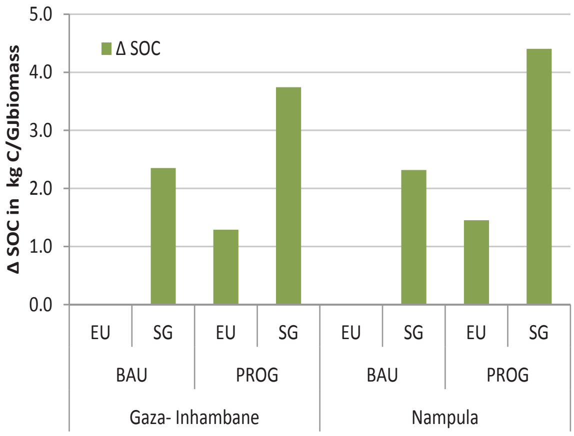
Figure 13 shows that in the progressive scenario, the cultivation of energy crops result in carbon sequestration by means of higher soil organic carbon and biomass carbon levels compared to the replaced mosaic-cropland pasture. The carbon sequestration is higher when land is converted to eucalyptus than when land is converted to switchgrass. This is the result of the higher above and below ground biomass carbon stock of eucalyptus. In the BAU Scenario, the cultivation of energy crops results in significant GHG emissions. To what extent and in what timeframe this will be offset by avoided emissions related to the replacement of fossil fuels depend on the efficiencies in the remainder of the production chain and the type of fuel that is replaced.

3.2.1.2 Soil

The change in soil organic carbon is used as a proxy indicator for the change in organic matter content of the soils and therefore as an indicator of the quality of the soil. The change in soil organic carbon is depicted in Figure 14 and is expressed in Δkg C/ GJ biomass produced. Both forest plantations (eucalyptus) and perennial grasses (switchgrass) maintain a high soil organic carbon content. In the BAU scenario, when shrubland is converted to eucalyptus there is no loss and no gain of SOC. In the progressive scenario, when mosaic cropland pasture is converted there is a gain in soil organic carbon. Because of the lower yields per hectare and the lower energy content of switchgrass the gain per GJ produced relatively high compared to eucalyptus.

Increased risks on soil erosion occur when shrubland is converted to eucalyptus, due to the prolonged soil exposure. This risk is similar for both regions as the soil texture of both regions is similar and in both regions the strongest wind speeds coincide with the end of the dry season, which makes the soil prone to erosion. The risk on erosion reduces when cropland is converted to switchgrass, as this results

Figure 14: Change in soil organic carbon in kg C/ GJBiomass due to the conversion from current land use to eucalyptus and switchgrass in the Gaza-Inhambane and Nampula region for the Business as Usual and the Progresisve Scenario.



in year round soil cover. A more detailed description of the implications for the risk on erosion is provided in Annex 3.

3.2.1.3 Water

For the water use, two indicators have been selected. The water use efficiency (WUE) and the cumulative water deficit. The results of the assessment of the water use efficiency are depicted in Annex 3. To what extent the crop related evapotranspiration of dedicated energy crops lead to changes in seasonal water deficits compared to current land uses need to be determined by a water balance. In Gaza-Inhambane, the reference evapotranspiration exceeds the precipitation levels see Figure 15. The fast growing eucalyptus and switchgrass increase the evapotranspiration levels significantly, especially eucalyptus. It is likely that a shift towards these fast growing energy crops could increase drought related problems in this region. In the Nampula region, the precipitation levels are much higher but are characterised by high seasonal fluctuations. Also here, the extraction of water by eucalyptus exceeds the water extraction by switchgrass. A more detailed description of the risk on cumulative water deficits is included in Annex 3.

3.2.1.4 Biodiversity

In the land use modelling step, the conservation areas, the national parks and forest areas have been excluded. The Mean Specie Abundance indicator has been used to assess the effect of the LUC from the current land use to energy crop cultivation. Figure 16 shows the change in MSA per GJ biomass produced. In all settings the conversion from current land use to energy crops result in a negative impact on the Mean Specie Abundance. Figure 16 shows that the negative change in $MSA/GJ_{biomass}$ is larger in the BAU scenario compared to the progressive scenario. This is the result of the conversion of native vegetation (shrubland) to cultivated land in the BAU scenario (forest plantation and perennial energy crop). The impact of large scale bioenergy production on biodiversity is mainly related to the design and the management of the project. There are many measures that can maintain and enhance biodiversity. More detailed information on the impact on biodiversity is found in Annex 3.

Figure 16: Change in cumulative mean species abundance per GJ biomass produced for Eucalyptus (EU) and switchgrass (SG) in the Gaza-Inhambane region and the Nampula region for the two scenarios (in Δ MSA value /GJBiomass x100).

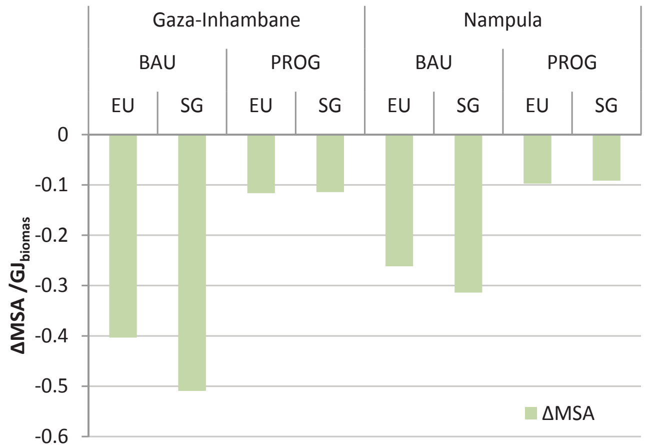
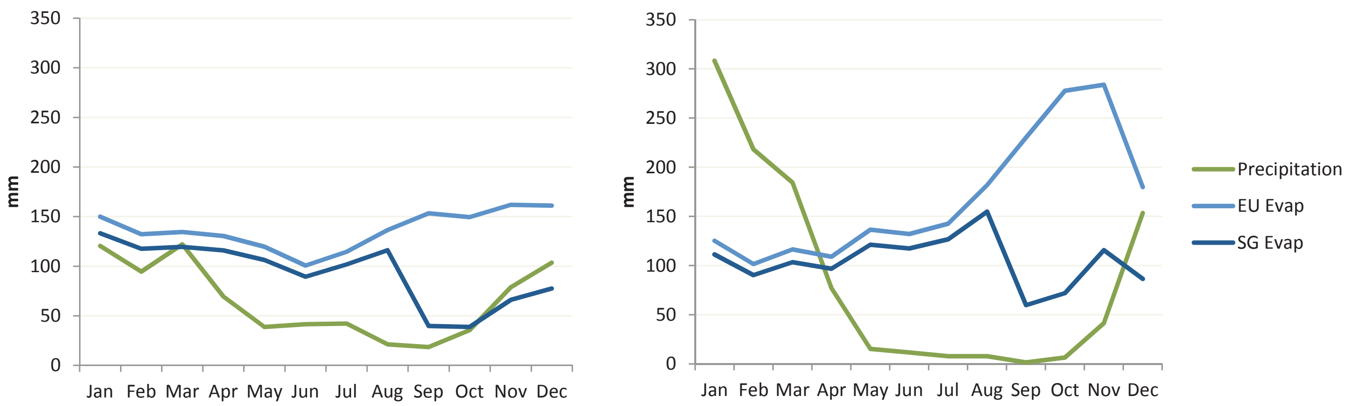


Figure 15: Monthly precipitation and crop specific evapotranspiration levels of eucaluptus (EU evap) and switchgrass (SG evap) in Gaza-Inhambane and Nampula region.



3.2.2 Socio-economic impacts

3.2.2.1 *Legality*

The government of Mozambique is supportive of (sustainable) biofuels and a 'Biofuel Sustainability Framework' and a 'Biofuel Policy and Strategy' has been implemented, see Annex 3 for more details. Investment proposal are evaluated by the Center for Investment Promotion (CPI) in collaboration with several ministries. Monitoring is done by the government and monitoring visits can take place.

3.2.2.2 *Land rights*

Both a quantitative and qualitative analysis has been performed, see Annex 3. Because the land analysis in the earlier section already excludes land that is (or will be) in use, the land availability should be no issue if the potential feedstock production is 100%. Only in the BAU scenario in Nampula region, the potential feedstock production is below 100%, indicating problematic land availability. Switchgrass has an even lower production potential than Eucalyptus; only 46% of the total feedstock that is required can be produced in Nampula in the BAU scenario. The production in Gaza-Inhambane is never below 100% indicating that land availability is not an important issue in that region, but other problems with land allocation can occur.

Land allocation procedures and land laws in Mozambique are often unclear and procedures can be problematic leading to land conflicts. This is amongst other reasons, due to informal customary land-laws that co-exist with formal land title laws, not clearly demarcated boundaries of many properties and generally undocumented land ownership, especially by local communities (Van Eijck et al. submitted). Foreign investments have to acquire land following different steps depending on size, see Annex 3 for a description.

3.2.2.3 *Food security*

Food security is an important issue in Mozambique. Food prices have increased as the population has increased but the food production has lagged behind. The situation in Nampula region is slightly better compared to Gaza-Inhambane, but in both regions the food security needs to be improved. In the land availability assessment the increase in food production as a result of the increase in population and in dietary intake per capita, has been taken into account. It is assumed that the average caloric intake per capita increases from 2100 to 2400 Kcal per capita per day, which is a considerable increase but still low compared to developed countries. Only in the BAU scenario in Nampula, land availability is a limiting factor, therefore there is a risk that land currently in use for food production is taken into production which would negatively impact food security. Although, the land availability assessment takes into account the population density and the distance to markets in claiming land for food production, it provides too little information on the local food security conditions. In the progressive scenario, it is assumed that the productivity of the agricultural sector increases significantly. This will have a significant positive impact on the food security situation. However, this impact is the result of the assumed scenario conditions and not of the implementation of the bioenergy production project. However, the bioenergy production project could contribute in the development of the agricultural sector and therefore food security in many ways, examples are provided in the Annex 3.

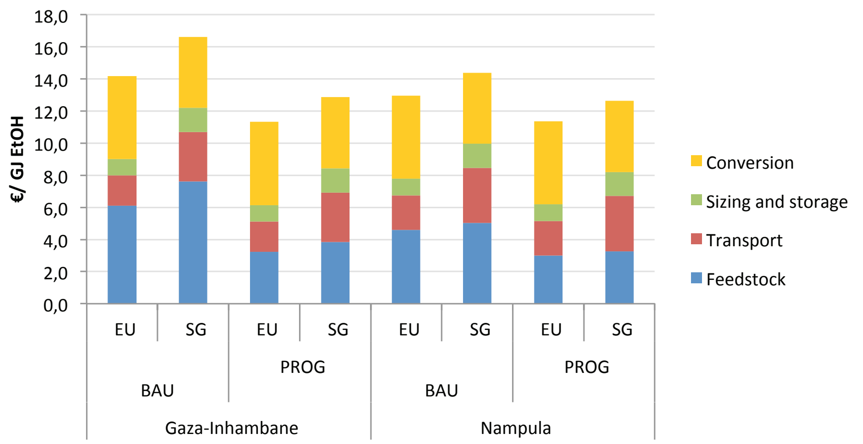
3.2.2.4 *Economic viability*

Both net present values (NPV) of the cultivation costs and the entire supply chain up to plant gate are calculated[18]. The cost in the progressive scenario are much lower compared to the BAU scenario as it is assumed that in the progressive scenario the cultivation of energy crops takes place on abandoned agricultural land which is no longer in use as the agricultural sector has become more efficient resulting in lower land requirements. In this case, no land clearing is required. In the BAU scenario, no agricultural land becomes available. In this scenario, the cultivation of energy crops takes place at the cost of shrubland. The clearance of shrubland is a costly and time consuming process.

In both regions in both the BAU and the Progressive scenario, the discounted costs for switchgrass are lower than for

18 The lifetimes of plantations assumed are 21 year for eucalyptus (3 growing cycles of 7 years) and 15 years for switchgrass (14 harvests from 2nd year on). The discount rate assumed is 12%.

Figure 17: Cost of total supply chains (plant gate) of second generation ethanol from eucalyptus and switchgrass in the Gaza-Inhambane and Nampula region for the Business as Usual and the Progressive scenario, desaggregated for various cost items. Distribution or export of biofuel is not included.



Eucalyptus. This is mainly caused by the lower cost for planting as for switchgrass only seeds are required and for eucalyptus plantlets need to be planted. In addition, as eucalyptus is only harvested every 7 years, and switchgrass annually, the discounted yield of eucalyptus is relatively lower. In both scenarios, the cultivation cost of both switchgrass and eucalyptus is lower in Nampula compared to the Gaza-Inhambane region because of the higher agro-ecological suitability of the land available in Nampula, see Annex 2.

In Figure 17 the disaggregated cost of the entire supply chains of second generation ethanol from eucalyptus and switchgrass in the Gaza-Inhambane and Nampula region are depicted for the two scenarios. The cost of sizing and storage and conversion are independent from the location and are therefore the same for the two regions. The costs of transport are lower in the Gaza-Inhambane region because of a higher biomass density related to the higher concentration of available land. Although the costs of the feedstock are lower for switchgrass, the total cost of the supply chain is slightly higher compared to ethanol from eucalyptus because of the higher cost for primary transport and handling and storage of swichgrass compared to eucalyptus. This is mainly related to the lower density of switchgrass. The cost of the entire supply chain are lower in the Nampula region because the feedstock cost have a significant contribution to the total cost and the cost of feedstock are lower in Nampula because of the better agro-ecological conditions of the available land.

3.2.2.5 Local prosperity

Mozambique is one of the poorest countries of the world and is ranked 184 out of 187 (in 2011) on the Human Development Index (UNDP). Within Mozambique there is a difference between the two chosen regions. Nampula is the most densely populated region of the two (and the second most densely populated province of Mozambique) and also has the lowest incidence of poverty, mainly due to the presence of its large harbour. The region Gaza-Inhambane is much less developed, has a very low population density, and has the highest poverty incidence (UNADF 2012), further background-details can be found in the Annex 3.

The total number of jobs is calculated, taking the amount of land that is required and available per region and the amount of jobs generated per hectare. In the progressive scenario, the amount of jobs and total investment in Gaza-Inhambane is lower than in the BAU scenario, even more than 50% in the case of Switchgrass. This is due to the higher yields and therefore reduced land requirements. However, this also means that multiple projects could be developed. In the Nampula region, the amount of jobs is higher in the progressive scenario; this is due to the fact that in the BAU scenario not enough land is available to obtain a 100% feedstock production. The total investment and total wages will have a great positive effect on regional GDP. This would even be larger if indirect employment effects would be taken into account. These effects would have to be calculated by input-output analysis, but this was not possible for Mozambique due to lack of data. The total unemployed labour force in the region is much larger than the amount of jobs generated. However, labour migration might still occur because the labour figures do not reflect the large part of the population that consist of subsistence farmers, who may not be looking for employment labour. The total amount of wages is based on 1.5 times the minimum wage and only includes feedstock cultivation. This figure can potentially be much larger if conversion and transport is also taken into account and if higher wages are paid than 1.5 times the minimum agricultural wage (which is 32 €/month).

3.2.2.6 Social well-being

Although both regions have very low enrolment in secondary education, the Nampula region is slightly better off since the number of students per teacher is lower. Nampula also has a higher number of healthcare centres and has much better transport facilities due to the presence of airport, ports and railways to Malawi (and in the near future to Tete province). This means however that a biofuel project in Gaza-Inhambane can potentially have a larger positive impact on social well-being if measures are in place to increase social well-being. Measures to increase social well-being can cover different aspects, for example: investment in education, health care, sanitation or infrastructure, furthermore services such as the provision of land clearing or ploughing equipment for private use by communities, providing fertilisers for a reduced price and so on, see e.g. (Van Eijck et al. 2013). As it is assumed that five people depend on one employee, the total number of people that are affected is five times the employment.

3.2.2.7 Labour conditions

Labour conditions relate specifically to the implementation of a project, in the Annex 3 recommendations for project implementation are provided.

3.2.2.8 Gender

Possible gender problems that can be associated with the production of liquid biofuels in general are often due to the lack of access to resources such as land and credit for women (Rossi and Lambrou 2008). Increasing land pressure increases the risk that women, as well as other vulnerable groups, lose their land access rights (Salfrais 2010). It is often women who cultivate food plots and have domestic tasks. Working as an employee on a plantation reduces the time available for these tasks, which still need to be fulfilled (Mota 2009; Arndt *et al.* 2011b). The study by Arndt et al. (2011b; Arndt *et al.* 2011a) showed that skills-shortage among female workers limits poverty reduction, and policy should therefore be addressed to increasing women's education. Women and female headed households should have the same opportunity as men and men headed households to engage in and benefit from the sustainable production of biofuels. This would improve the welfare of families and increase the agricultural productivity (Franke *et al.* 2012). Favourable working hours at a plantation can enable women to keep tending their household food plots (Peters 2009). Other positive effects are related to increased energy access, which reduces women's tasks, such as collecting firewood and milling maize (Van Eijck *et al.* 2013).

3.2.3 Overall impact assessment

Table 6 shows a summary of the potential environmental and socio-economic impacts of the two bioethanol supply chains with scale of 1400 MW in the two regions under different scenario conditions. An explanation of the results of the individual impacts, their uncertainties, and the key assumptions that are incorporated, are found in the respective sections above and in Annex 3. As some of the socio-economic impacts are directly related to the implementation and the management of the project (such as legality and labour conditions), no ex ante analysis could be made for these impacts. For these sustainability issues recommendations for best practice are provided in section 3.4.

The assessment of the developments in land availability shows that within the Gaza-Inhambane region large areas of land could be available for bioenergy crops in 2020 under both the BAU and the progressive scenario. In the BAU scenario the area that is projected to be available for bioenergy is 0.8 Mha. In the progressive scenario, more land becomes available resulting in an area of available land twice as large (1.6 Mha) compared to the BAU scenario. Assuming that the best available land is used for the bioenergy plantation, the suitability of the land is 39-41% in the BAU scenario resulting potential yield levels of 10.8 odt/ha for eucalyptus and 7.7 odt/ha for switchgrass. As in this progressive scenario, more suitable agricultural land becomes available the average suitability of the best available land available land is ± 55% of the maximum attainable yield, resulting in potential yields of 14.4 odt/ha of eucalyptus and 10.8 odt/ha for switchgrass.

In the selected area in Nampula, only 0.08 Mha is available in 2020 in the BAU scenario. This is not sufficient to meet the requirements of the conversion plant of 1400 MW. This implies that biomass feedstock from other regions would be necessary to meet the total requirements. It is assumed that all available land in the Nampula region in the BAU scenario is used for the bioenergy project. The land availability assessment is used as a strict limitation here: no more land than indicated to be available is assumed to be used for the bioenergy project. This is done in order to avoid the undesired and complex issue of indirect LUC, which would result in negative environmental and socio-economic impacts beyond the system boundaries of our research. Therefore, it should be noted that all impacts provided in this research for the Nampula region in the BAU scenario, is limited to the 82600 hectares that are available in 2020. In the progressive scenario, it is projected that 0.3 Mha could become available in the Nampula region which is sufficient to meet the input requirements for the large scale conversion plant. As the entire area is relatively suitable for agricultural production, there is no significant difference in the attainable yield levels in the BAU and the progressive scenario. The average suitability of 63% results in yield levels of 15.5 odt/ha for eucalyptus and 12.4 odt/ha for switchgrass. As the yield levels and the energy content of switchgrass are lower than of eucalyptus, larger areas are required for biomass production in order to meet the same input requirements of the conversion plant. Because the selected area in the Gaza-Inhambane is much larger than the area in Nampula, it appears that there is more land available for the expansion of bioenergy production. This is, however, mainly related to boundaries set for the selected areas. For better impressions of up scaling and expansion potentials of biomass production, the studies of Van der Hilst (2012; 2012) provide better insights for the province level, the neighbouring provinces and the entire country.

The GHG emissions are differentiated in the emissions over the lifecycle of bioenergy production, and the emissions related to LUC. The GHG emissions over the lifecycle are dominated by the emissions related to nitrogen fertilizer production and application. As switchgrass has higher nitrogen requirements, the lifecycle related GHG emissions are higher (3.7-3.9 kg CO_2-eq /$GJ_{biomass}$) compared to eucalyptus (2.2 kg CO_2-eq /$GJ_{biomass}$). It should be noted that the uncertainties related to the emission factors of nitrogen application are high (IPCC 2006; Smeets *et al.* 2009a; Lesschen *et al.* 2011). However, the GHG emissions related to the lifecycle have a relatively small contribution (9 – 35%) to the total GHG emissions. The total GHG emissions are dominated by the GHG emissions related to LUC resulting from changes in the carbon stock of above and below ground biomass and soil organic carbon. In the BAU scenario, in which shrubland is converted to bioenergy plantations, there is a loss of carbon (10-30 kg CO_2-eq / $GJ_{biomass}$) which mainly related to the loss of above ground biomass.

Although there are emissions during the lifecycle for all settings 2.2-3.9 kg CO_2-eq / $GJ_{ethanol}$, and LUC related GHG emissions in case of the BAU scenario in which shrubland is converted to energy crop cultivation (10-35 kg CO_2-eq/$GJ_{biomass}$), the overall GHG balance shows large GHG emission savings for all settings if ethanol are compared to a reference of petrol. These savings are especially high in the progressive scenario (104-119 kg CO_2-eq/$GJ_{biomass}$) as it is assumed that agricultural land is converted to energy crops resulting in high carbon stock accumulation in both biomass and soil. The avoided emissions are slightly higher for eucalyptus than for switchgrass which is mainly due to the larger carbon stock in above ground biomass of eucalyptus.

The impacts of the conversion of current land use to a perennial energy crop on the soil quality are generally positive. The soil organic carbon increases 1.3-3.9 kg C/$GJ_{biomass}$ when current land use is converted to bioenergy crops. Only in the BAU scenario, when shrubland is converted to eucalyptus, no change in soil organic carbon is expected. Also, when converted to eucalyptus, these areas are more prone to erosion as the land is cleared prior to planting and there is no soil cover for the first few years after planting and after harvest. Most positive impacts on both soil organic matter and soil erosion risk are expected when agricultural land is converted to perennial energy crops (progressive scenario) and especially when converted to switchgrass. There are negligible differences between the regions due

Table 6: Selected potential environmental and socio-economic impacts of the supply chains of ethanol from eucalyptus (EU) and switchgrass (SG) in the Gaza-Inhambane and Nampula region for the Business as Usual (BAU) and Progressive (PROG) scenario conditions.

Positive impact ***Neutral or minor impact*** ***Negative impact***

			Gaza-Inhambane				Nampula			
			BAU		PROG		BAU		PROG	
	Impact	Unit	EU	SG	EU	SG	EU	SG	EU	SG
	Scale up potential									
	Total land in selected region	Km²	37324	37324	37324	37324	9974	9974	9974	9974
	Total land availability	Km²	8323	8323	16129	16129	837	837	3146	3146
	Total land availability	% of region	22	22	43	43	8	8	32	32
	Potential suitability of available land	% of max yield	31	31	34	34	63	63	62	62
	Land requirements to meet input	Km²	2054	3008	1579	2373	826	826	1321	1885
	Suitability of best available land	% of max yield	41	39	53	50	63	63	64	62
	Total biomass production	Million Odt/ha/yr	2.2	2.3	2.2	2.3	1.4	1	2.2	2.3
	% of required capacity	%	100	100	100	100	62	45	100	100
	Impacts									
Environmental Impacts	**GHG Emission**									
	Life cycle	Kg CO_2-eq /$GJ_{biomass}$	2.3	3.9	2.2	3.8	2.2	3.7	2.2	3.7
	LUC related emissions	Kg CO_2-eq /$GJ_{biomass}$	11.9	35.2	-19.7	-14.7	10.6	29.8	-27.3	-23.0
	Total emissions	Kg CO_2-eq /$GJ_{biomass}$	14.1	39.1	-17.5	-10.9	12.9	33.5	-25.1	-19.3
	Total avoided emissions	Kg CO_2-eq /GJ_{EtOH}	58	32	90	84	59	38	97	91
	Soil									
	Soil Organic Carbon	Δ kg C/$GJ_{biomass}$	0.0	2.4	1.3	3.7	0.0	2.3	1.5	4.4
	Wind Erosion	Qualitative	-	0	+	++	-	0	+	++
	Water									
	Water use efficiency	$Odt_{biomass}$/ l water	0.7	0.7	0.9	0.9	0.8	0.9	0.8	0.9
	Water depletion	mm/season	426	-96	426	-96	523	-237	523	-237
	Biodiversity									
	MSA	ΔMSA x100 /$GJ_{biomass}$	-0.4	-0.5	-0.1	-0.1	-0.3	-0.3	-0.1	-0.1
Socio-economic Impacts	**Legality**		*No ex-ante analysis possible, recommendations to comply with national law are provided see 3.2.2.1 and Annex 3*							
	Land rights									
	Land right risk	Qualitative	+	+	+	+	-	-	+	+
	Food security									
	Food security	Qualitative	+/-	+/-	+	+	-	-	+	+
	Economic viability									
	Feedstock	€/$GJ_{biomass}$	2.44	3.05	1.29	1.54	1.84	2.01	1.03	1.31
	End product	€/GJ_{EtOH}	14.18	16.62	11.32	12.86	12.96	14.38	10.93	12.63
	Local Prosperity									
	Total jobs	X 1000 jobs	11.9	8.4	9.1	6.6	4.8	2.3	7.7	5.3
	Local labour	%	100	100	100	100	100	100	100	100
	Total investment	M€	260	297	208	230	157	127	208	226
	Total wages	M€	11.41	7.74	8.73	6.01	4.95	2.38	7.40	4.86
	Social well-being									
	Total no of people affected	X 1000 people	59	42	46	33	24	12	38	26
	Labour conditions		*No ex-ante analysis possible, recommendations to comply with (inter-) national law and best practice are provided*							
	Gender		*No ex-ante analysis possible, recommendations to comply with (inter-) national law and best practice are provided*							

to similarities in the main soil characteristics. The potential soil loss due to erosion is difficult to quantify as it mainly depend on a combination of extreme weather conditions such as strong winds and droughts in combination with the management measures taken such as perpendicular planting, in- between row planting and fencing.

The impact on water has been assessed in a first order approach. As indicated in the method section and the results, the actual effect on water tables and the effect of water depletion can only be assessed when more advanced hydrologic models are applied and more detailed data is available on the respective water basins. Due to the limitations of this analysis, the results should be interpreted with care. As for both crops it is assumed that no irrigation is required (except for nursery and panting), no surface water is depleted. Because of the low precipitation levels, there is a significant risk for water depletion in the Gaza-Inhambane region. Especially when eucalyptus is cultivated the risk on ground water depletion is significant as the roots allow for water extraction in the deep ground water tables. Additional research is required to assess the impact on the water availability for a specific site.

In order to avoid high impacts on biodiversity, the protected areas are already excluded in the land availability assessment. In the progressive scenario, the forest areas are excluded for any type of and use change and in both scenarios, forest areas are excluded specifically for bioenergy crops. Therefore, many areas with high biodiversity value are already excluded for bioenergy production. The conversion of current land use to large scale energy crop plantation generally has a negative impact on biodiversity. This is especially true when native vegetation (in the BAU scenario) is converted to bioenergy plantations. The impacts on biodiversity are more severe when larger areas are occupied. Therefore the impact on biodiversity in Gaza-Inhambane region is higher compared to the impact in Nampula. The Mean Species Abundance indicator applied in this study is a very rudimentary indicator for the impacts on biodiversity. Therefore, more research is required to quantify the potential impacts. In addition, many measures can be taken in terms of plantation design and plantation management to reduce the negative impacts or even enhance biodiversity, see section 3.4.1.4).

Many of the socio-economic impacts of large scale bioenergy production are directly related to the design, the implementation and the management of the project. Therefore, no ex-ante analysis could be made for some of the sustainability issues such as 'legality' and 'labour conditions'. Recommendations for best practice to comply with the relevant legislation and regulations have been provided in the related sections.

The risk for land competition has mainly been avoided by excluding the land already in use for other functions for bioenergy crop production in the land availability assessment. Under the BAU scenario conditions there is not sufficient land available in Nampula. If it is aimed for to scale up the biomass production beyond the limitations indicated by the land availability assessment, competition for land is most likely to occur. In Gaza-Inhambane, there are yet large areas of land that are unutilized. Therefore, conflicts over land and violation of land rights are less of a risk in this area. The risk on violating the land rights is equal for the two feedstock types.

In both regions, the food security situation is currently poor. In the progressive scenario, it is assumed that the productivity of the agricultural sector increases significantly. This will have a major positive impact on the food security situation. However, this impact is the result of the assumed scenario conditions and not of the implementation of the bioenergy production project. The low land availability in the Nampula region and potential land competition when exceeding the indicated land availability limits could further threaten the food security situation in the area. However, the implementation of a large scale bioenergy project in the region could contribute in many ways to the food security situation in the regions by providing employment, equipment and services described in 3.4. There is no apparent difference in the impact on food security between the two energy crops.

The costs of biomass feedstock are lower in the Nampula region (eucalyptus 1.03 - 1.84 €/GJ and switchgrass 1.31 - 2.01€/GJ) than in the Gaza-Inhambane region (eucalyptus 1.29 - 2.44 €/GJ; and switchgrass 1.54 - 3.05 €/GJ), due to the higher agro-ecological suitability in Nampula. The costs of ethanol are higher for ethanol from switchgrass (12.63 - 16.62 €/GJ_{EtOH}) than for ethanol from eucalyptus (10.93 - 14.18 €/GJ_{EtOH}). This is mainly due to the higher cost for transport related to the low density of switchgrass.

The impact of large scale bioenergy production on the prosperity in the regions is indicated by the number of jobs generated, the wages paid and the total investment of the project. As labour and equipment requirements are often expressed per hectare, the total labour and capital is directly related to the size of the area in use for the bioenergy plantation.

Because of the lower yield levels in the Gaza-Inhambane region, the impact on prosperity is higher compared to the Nampula region. In the Gaza-Inhambane region the number of jobs varies between 9.6 and 11.7 thousand for eucalyptus and between 6.7 and 8.3 thousand jobs for switchgrass. The total investment varies between 208 and 260 M€ for eucalyptus ethanol production and between 230 and 297 M€ for switchgrass production. In the Nampula region the number of jobs varies between 4.8 - 7.7 thousand jobs for eucalyptus and 2.3 - 5.3 thousand for switchgrass. The total investment varies between 157-201 M€/yr for eucalyptus and 127 - 226 M€/yr for switchgrass and the total wages paid varies between 4.9 and 7.4 M€/yr for eucalyptus and 2.4 - 4.9 M€ for switchgrass. Although the yields of eucalyptus is higher compared to Switchgrass and therefore less land is required for the same biomass production, the impact on local prosperity is higher compared to switchgrass because eucalyptus is more labour and capital intensive. Because in the progressive scenario the average suitability of the land is higher, the impact on local prosperity is lower. In the BAU scenario in Nampula, the impacts on local prosperity are much lower because the land availability is not sufficient to meet the entire input requirements of the conversion plant.

The impact on social well-being in the region is quantified by the number of people affected by the bioenergy plantation. The total number of people affected equals the number of employees plus their dependencies. The average number of dependencies is 5 in both regions (average household size). The total number of people affected varies between 29 and 55 thousand people in Gaza-Inhambane region and between 12 and 34 thousand people in the Nampula region. As the current standard of living is very low in both regions (but especially in the Gaza-Inhambane region) the implementation of a large scale bioenergy project could contribute significantly to the well-being of the communities in the regions depending on the project design and management and the measures taken to improve the situation. Examples of measures that can be taken by the bioenergy project are described in section 3.4.

In general, the progressive scenario scores better on almost all impacts compared to the BAU scenario. Only the impact of large scale bioenergy production on local prosperity and social well-being are better in the BAU scenario. The positive environmental impacts are mainly a consequence of the conversion of abandoned agricultural land to perennial energy crops. This results in a gain in biomass carbon stocks of 2 - 22 kg CO_2-eq/$GJ_{biomass}$, and a gain is soil organic matter of 0 - 4.4 kg CO_2-eq/$GJ_{biomass}$, resulting in total avoided emissions of 84 to 97 kg CO_2-eq/GJ_{EtOH}. In addition, there is a decrease in the risk on erosion and little risk on the loss of biodiversity. The positive socio-economic impacts are mainly related to the higher yields in the progressive scenario. Therefore, there is a low risk on land disputes, a positive impact on the food security, and the costs of biomass and ethanol production are lower. The impacts on local prosperity and social well-being are better in the BAU scenario, because of the higher land requirements and the related labour and capital requirements. The impacts on water are less affected by the type of scenario.

The impacts of large scale bioenergy clearly differ between the two regions especially for the impact on water and the socio-economic impacts. Nampula scores better on the impacts on water and the economic viability. Gaza-Inhambane scores better on the impacts on land use rights, food security, local prosperity and social well-being. Because of the limited amount of precipitation in the Gaza-Inhambane region, the impact on water is more severe in this region. Also, the cost of feedstock and ethanol production is more expensive in this region (1.29 - 3.05 €/GJ_{biomas}, compared to 1.03 - 1.84 €/$GJ_{biomass}$ in Nampula) due to the lower biophysical suitability for crop production. However because of the lower yields, the impacts on local property in terms of number of jobs (6.7 - 11.7 thousand), total investment (208 - 297 M€) and total wages (5.8 - 10.1 M€) is much higher in this region compared to the Nampula region. Also, because of the high land availability in Gaza-Inhambane, there is little risk for the violation of land use rights or negative impacts on food security.

The differences in impacts are mainly explained by the differences in scenarios and regions but also (to a lesser extent) by the differences in crops. Eucalyptus scores better on the GHG balance and the impacts on local prosperity and the impact on social well-being. Switchgrass scores better on the impact on soil, water, and economic viability. The total avoided emissions vary between 58 and 97 kg CO_2-eq/GJ_{EtOH} for eucalyptus compared to 32 - 91 CO_2-eq/GJ_{EtoH} for switchgrass. The employment generation varies between 4.8 - 11.7 thousand jobs for eucalyptus and 2.3-8.4 thousand jobs for switchgrass. The total investment varies between 157-260 M€ for eucalyptus and 127-297 M€ for switchgrass, and the total wages paid varies between 4.9 - 10.1 M€ for eucalyptus and 2.4 - 7.1 M€ for switchgrass. The conversion of current land use to eucalyptus result in a gain in SOC of 0 - 2.1 kg CO_2-eq/$GJ_{biomass}$ for eucalyptus compared to 2.1 - 4.4 kg CO_2-eq/$GJ_{biomass}$ for switchgrass. The cultivation of eucalyptus has a higher risk on water depletion than switchgrass because of the deep rooting system and a higher risk on soil erosion because of the lack of soil cover directly after planting and harvesting of eucalyptus. The cost for ethanol production are lower for eucalyptus (10.4 - 14.2 €/ GJ) than for switchgrass (12.7 - 16.6 €/GJ).

3.3 Results for Argentina

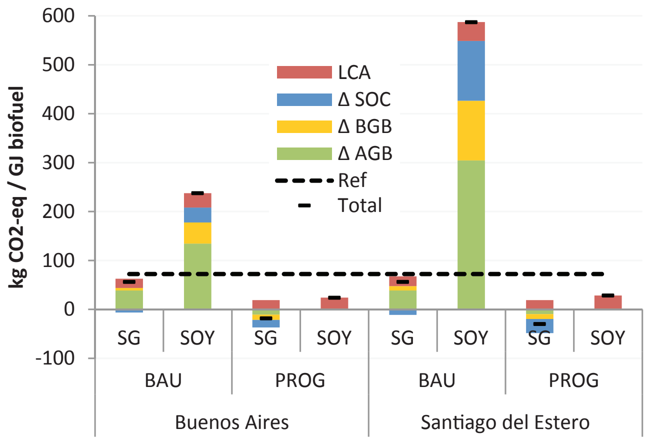
3.3.1 Environmental impacts

3.3.1.1 GHG emissions

The GHG emissions during the cultivation of switchgrass and soy in Argentina are included in Annex 3. The total GHG emissions of the total lifecycle of bioethanol production form switchgrass and biodiesel production from soy are depicted in Figure 18. It includes the emissions related to LUC (changes in above and below ground biomass and in soil organic carbon) and emissions over the lifecycle (cultivation, transport and processing). In Figure 18, the GHG emission per GJ of the fossil reference is also depicted (±72 kg CO_2-eq / GJ).

The GHG emissions of soy biodiesel are very high in the BAU scenario (238 kg CO_2-eq / GJ biodiesel in Buenos Aires and 587 kg CO_2-eq / GJ biodiesel in Santiago del Estero). Also the emissions of switchgrass ethanol are high in the BAU scenario. This is due to the high loss of soil organic carbon and above and below ground biomass when shrubland is cleared for the cultivation of energy crops. In Santiago del Estero, the soy yields per hectare are relatively low. Therefore, the GHG emissions LUC related GHG emissions per GJ biodiesel are very high. In the progressive scenario, large GHG emissions reductions are achieved. The abandoned cropland is converted to switchgrass results even in a net carbon sequestration in above and below ground biomass and in soil organic carbon.

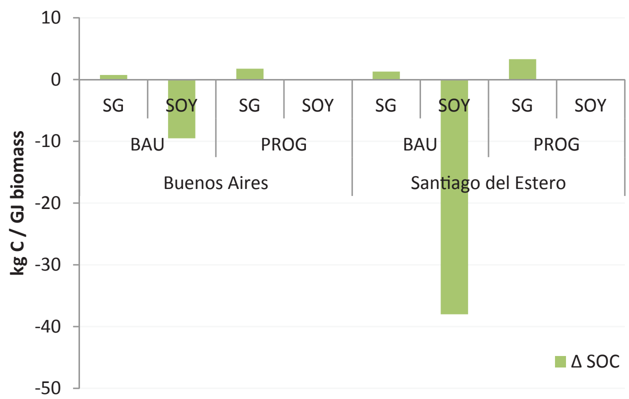
Figure 18: GHG emissions of switchgrass ethanol and soy biodiesel production in Buenos Aires and Santiago del Estero for the Business as Usual and the progresisve scenario including the emissions related to changes Δ in carbon stocks due to LUC and the emisssions related to the production chain (LCA) (AGB = above ground biomass, BGB = Below ground biomass, SOC = soil organic carbon, LCA = lifecycle emissions). Ref depicts the GHG emissions of the fossil diesel / petrol reference.



3.3.1.2 Soil

The change in soil organic carbon is expressed in Δkg C/GJB$_{iomass}$ produced and is depicted in Figure 19. The low soil disturbance and to the fertilizer use during switchgrass cultivation results in gains in soil organic carbon (0.74 and 1.17 kg C/GJ$_{Biomasss}$ in the BAU scenario and 1.76 - 3.31 kg C/GJ$_{Biomasss}$ in the Progressive scenario). In the BAU scenario when shrubland is converted to soy, soil organic carbon is lost (9.5 and 38.0 kg C/GJ$_{Biomasss}$) due to the soil disturbance related to the cultivation of annual crops. In the progressive scenario there is no net change in SOC when cropland is converted to soy cultivation.

Figure 19: Change (Δ) in soil organic carbon in kg C/GJ$_{biomass}$ due to the conversion from current land use to switchgrass and soy cultivation.

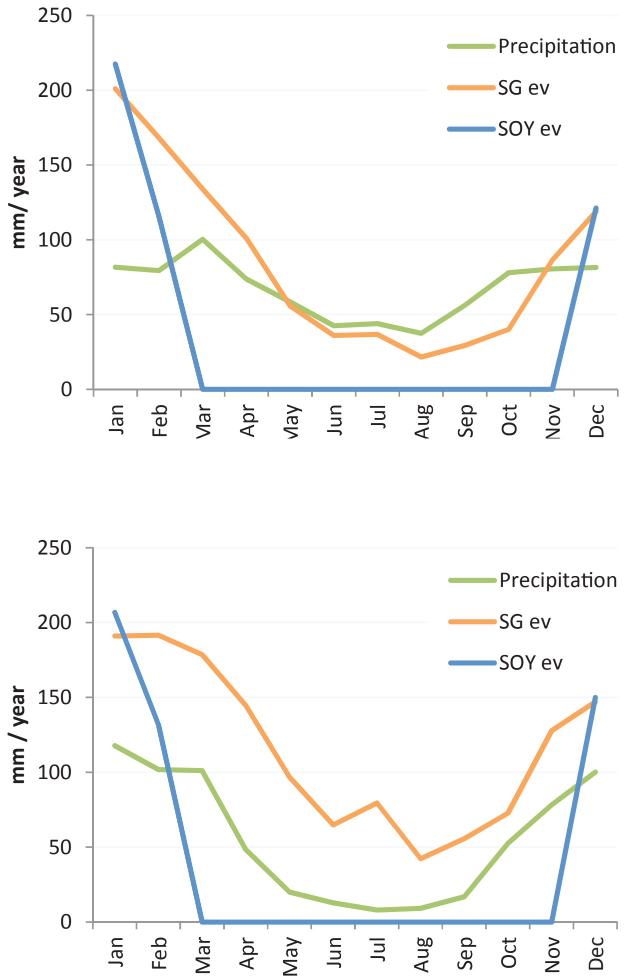


The risk on erosion is high when the soil has a light texture, there is little soil moisture content, when there is a strong wind and there is little or no soil cover. In both regions, the soil characteristics are heterogeneous. The dominating soil classes in Buenos Aires and Santiago del Estero are Phaeozems, which are sandy loam soils which can be prone to erosion. In Buenos Aires the precipitation levels are relatively high and more equally distributed over the year. Therefore, periodic droughts and risk and therefore risk on erosion are relatively low. In Santiago del Estero the precipitation levels are lower (667 mm/year) and unevenly distributed over the year. In both regions, the average wind speed is low to modest (2-4 Beaufort). As the higher wind speed do not coincides with the end of the dry season the risk on erosion is not very significant.

3.3.1.3 Water

For the water use, two indicators have been selected. The water use efficiency (WUE) and the cumulative water deficit. The assessment of the water use efficiency is provided in Annex 3. To what extent the crop related evapotranspiration of dedicated energy crops lead to changes in seasonal water deficits compared to current land uses need to be determined by a water balance

Figure 20: Monthly precipitation and crop specific evapotranspiration levels of switchgrass (SG ev) and soy (SOY ev) in Buenos Aires (above) and Santiago del Estero (under).

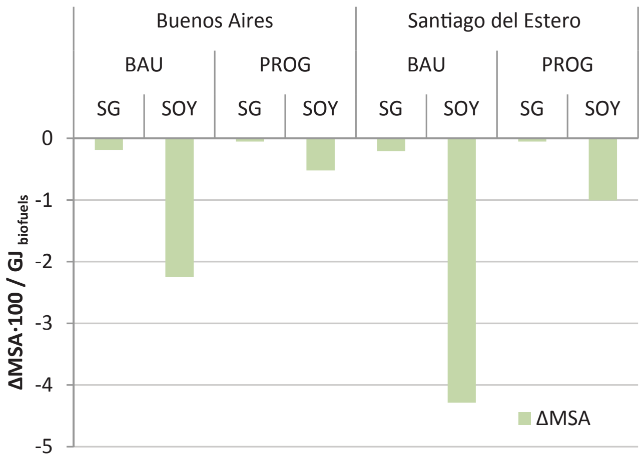


The growth season of soy is only 3 months a year. Therefore only the water evapotranspiration in the growing season is taken into account. The evapotranspiration of soy exceeds the precipitation in the rainy season. However, as there is no evapotranspiration outside the growing season, the water shortage can be replenished. Because of the long growth stage of switchgrass and its high kc value[19], the evapotranspiration levels of switchgrass are high compared to soy. Especially in Santiago del Estero, cumulative water deficits can be significant as evapotranspiration continues during the dry months (see Figure 20).

3.3.1.4 *Biodiversity*

The Mean Specie Abundance indicator has been used to assess the effect of the LUC from the current land use to energy crop cultivation. Figure 21 shows the change in MSA per GJ biomass produced. In all settings the conversion from current land use to energy crops result in a negative impact on the Mean Specie Abundance. However, the impacts of the conversion from natural vegetation to soy have the most severe impacts on biodiversity. The impact of the conversion of extensive managed cropland to intensive cultivated switchgrass is only minor. This is also the result of the high switchgrass yields per hectare which results in low impacts per GJ biomass produced. In the progressive scenario it is assumed that energy crops are cultivated on land previously in use as agricultural land which is abandoned because of higher agricultural productivity.

Figure 21: Change in cumulative mean species abundance per GJ biomass produced for switchgrass (SG) and soy in Buenos Aires and Santiago del Estero for the two scenarios (in Δ MSA value /GJ biomass x100).



3.3.2 Socio-economic impacts

3.3.2.1 *Legality*

Argentina has a supportive policy climate for liquid biofuels, since late 1990 including tax exemptions, efficiency requirements for conversion plants and a blending target (J. A. Hilbert *et al.* 2011). Export tax rates are high in Argentina, above 20% for soybean and its by products, which means the internal price is lower (Costa *et al.* 2009). Annex 3 includes all laws and resolutions related to ethanol and biodiesel.

3.3.2.2 *Land Rights*

The land analysis in the earlier section provides the % of required production that can be achieved in the regions per scenario, excluding all land that is currently in use. In all scenarios except the BAU in Santiago del Estero, land availability is not an issue. In Santiago del Estero, especially for soy, there is a lack of land.

The most important issues with land and land rights in Argentina stem from the massive purchases of land by urban and external investors, the increase of land prices due to amongst others, soy cultivation, the displacement of small producers in agricultural areas and new models of agricultural management with emphasis on leasing (Sbarra and Hilbert 2011; Sili and Soumoulou 2011). More information can be found in Annex 3.

3.3.2.3 *Food security*

Argentina does not have a widespread food security problem with less than 5% of the population undernourished (FAOSTAT 2012). Currently 6.5 % of the population lives below the poverty line, and the government provides a monthly sum of US$ 63 per child to working families under the poverty line (Sbarra and Hilbert 2011). The land analysis excludes the amount of land in use for the cultivation of food crops, so the cultivation of soy and switchgrass should not lead to a decrease of food security. Employment in the sector can lead to an increased household income and thus increased food security. Therefore all scenarios except the BAU scenario in Santiago del Estero, have a positive impact on food security. Measures can be taken to offset any negative impact on food security, such as sufficient wages.

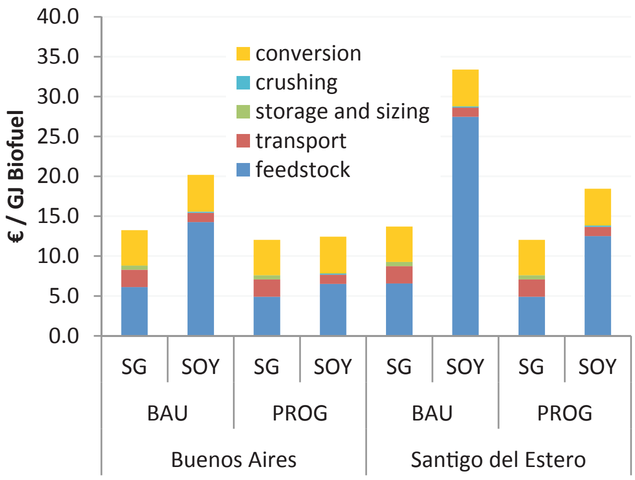
3.3.2.4 *Economic viability*

Both net present values (NPV) of the cultivation costs and the entire supply chain up to plant gate are calculated. The costs for soy cultivation are higher compared to switchgrass due more intensive management and the lower yield, especially in Santiago del Estero. In general the costs are higher in the BAU scenario compared to the progressive scenario because in the BAU scenario, the cost of land clearing is included and less suitable areas are available for energy crop production; See Annex 3. In Figure 22, the cost of switchgrass ethanol and soy biodiesel (in €/ $GJ_{biofuel}$ at plant gate) are depicted for the two regions and the two scenarios.

The cost of switchgrass ethanol and soy biodiesel per GJ end product are almost equal when the suitability for the cultivation of switchgrass and soy are similar, for instance in Buenos Aires in the progressive scenario where both crops achieve maximum yields. However in all other settings, the suitability of the available land is much higher for switchgrass compared to the suitability for soy. Therefore, the overall costs of switchgrass ethanol production are lower compared to soy

19 The Kc value is a multiplying factor for the reference evapotranspiration (ET_0) which is crop and growth stage specific.

Figure 22: Cost of total supply chains (plant gate) of second generation ethanol from switchgrass and biodiesel from soy in Buenos Aires and in Santiago del Estero for the Business as Usual and the Progressive scenario, disaggregated for various cost items. Distrbution or export of biofuel is not included.



biodiesel. More details can be found in Annex 3.

3.3.2.5 Local prosperity

Argentina is relatively wealthy with a per capita income of US$ 15,800 (PPP) in 2010. The official unemployment rate is 8.2% for Argentina, but is higher in Santiago del Estero, 10%. More background information is provided in Annex 3. The total amount of jobs that can be generated in feedstock cultivation ranges from 60 to 1400, in all cases there should be sufficient local labour available to fulfil these positions. The total employment, investment and total wages will have a great positive effect on regional GDP. This would even be larger if transport, conversion and indirect employment effects would be taken into account.

3.3.2.6 Social well-being

Santiago del Estero is the least urbanized and one of the poorest regions of Argentina. The largest social issues are with peasants (campesinos) who often occupy the marginal areas where agricultural expansion (mainly soy) takes place (Wald and Hill 2011). Also the introduction of genetically modified crops can marginalize small scale farmers (Arza *et al.* 2012). For more information on these issues, see Annex 3. By creating employment biofuel companies can also have a positive impact. Additional emphasis can be placed on the inclusion of the *campesinos*.

3.3.2.7 Labour conditions

In Argentina many labour conditions are regulated by laws and regulations. In Annex 3 an overview is provided of the most important issues with wages and labour contracts, health insurance, right to a pension, working hours, union agreements, occupational health and risks and secondary benefits. The new companies should as minimum comply with the laws and regulations, and can choose to provide for example additional secondary benefits depending on company views and values.

3.3.2.8 Gender

Argentina has a relatively high participation of women in political, social and domestic fields, with a history of female leaders. However, due to the Catholic influence and 'machismo' culture the genders are not equal, and there is e.g. a lack of access to women's health care. In wages, men and women are almost equal with women earning 98% of men's wages. Illiteracy rates of men (3.1%) and women (3.2%) are almost equal and Argentina is ranked 15th on a global list that ranks female participation in national legislation. In 2005 female representation in national legislation was over 33% (FSD 2013). The participation of women in agricultural enterprises has decreased however, from 180,000 in 1998 to only around 120,000 in 2002 (Sbarra and Hilbert 2011). Maternity leave is regulated by law, more details can be found in Annex 3 (ILO 2013). The impact of the biofuel supply chain can have a positive influence on gender if emphasis is placed on equal wages, and a significant number of females are employed.

3.3.3 Overall impact assessment

Table 7 shows a summary of the potential environmental and socio-economic impacts of the switchgrass ethanol and soy biodiesel supply chains with scale of 4.47 PJ biofuel production per year for the two regions under different scenario conditions. An explanation of the results of the individual impacts, their uncertainties, and the key assumptions that are incorporated, are found in the respective sections above and in Annex 3. As some of the socio-economic impacts are directly related to the implementation and the management of the project (such as legality and labour conditions), no ex ante analysis could be made for these impacts. For these sustainability issues recommendations for best practice are provided in 3.4.

The assessment of the developments in land availability shows that, large areas of land are still available for bioenergy crops in both Buenos Aires (0.5 Mha) and Santiago del Estero (0.2 Mha) 2020 in the BAU scenario. However especially in Santiago del Estero, large areas of the available land are not suitable for energy crop production, especially not for soy cultivation. Therefore, in the BAU scenario, not sufficient biomass could be produced in Santiago del Estero to meet the input requirements of the conversion plant to produce 108.000 ton biodiesel or the energy equivalent of that (4.67 PJ) of ethanol. This implies that biomass feedstock from other regions would be necessary to meet the total input requirements. It is assumed that all land in Santiago del Estero that is available and suitable for energy corps in the BAU scenario is used for the energy crop cultivation. The land availability assessment is used as a strict limitation here: no more land than indicated to be available and suitable is assumed to be used for the bioenergy project. This is done in order to avoid the undesired and complex issue of iLUC, which would result in negative environmental and socio-economic impacts beyond the system boundaries of our research. In Buenos Aires in the BAU scenario a sufficient proportion of

Table 7: Selected potential environmental and socio-economic impacts of switchgrass ethanol (SG) and soy biodiesel (SOY) production in Buenos Aires and Santiago del Estero for the Business as Usual (BAU) and Progressive (PROG) scenario conditions.

Positive impact (green) ***Neutral or minor impact*** (yellow) ***Negative impact*** (red)

			Buenos Aires				Santiago del Estero			
			BAU		PROG		BAU		PROG	
	Impact	Unit	SG	SOY	SG	SOY	SG	SOY	SG	SOY
Land availability / suitability	**Scale up potential**									
	Total land in selected region	1000 Km²	306	306	306	306	137	137	137	137
	Total land availability	1000 Km²	5.2	5.2	85.4	85.4	2.4	2.4	34.5	34.5
	Total land availability	% of region	2	2	28	28	2	2	25	25
	Potential suitability of available land	% of max yield	49	32	56	45	5	1	22	8
	Land requirements to meet input	1000 Km²	0.31	2.83	0.31	1.48	0.13	0.12	0.31	2.86
	Suitability of best available land	% of max yield	100	52	100	100	91	27	100	52
	Impacts									
Environmental Impacts	**GHG Emission**									
	Life cycle	Kg CO_2-eq /$GJ_{biomass}$	3.84	11.48	3.73	5.43	3.92	21.85	3.73	10.50
	LUC related emissions	Kg CO_2-eq /$GJ_{biomass}$	15.69	236.88	-15.56	0.00	15.33	624.47	-20.40	0.00
	Total emissions	Kg CO_2-eq /$GJ_{biomass}$	56	238	-18	24	56	587	-30	28
	Total avoided emissions	Kg CO_2-eq /$GJ_{Biofuel}$	-16	166	-90	-48	-16	515	-102	-44
	Soil									
	Soil Organic Carbon	Δ kg C /$GJ_{biomass}$	0.7	-9.5	1.8	0.0	1.3	-38.0	3.3	0.0
	Wind Erosion	Qualitative	o	--	++	-	o	--	++	-
	Water									
	Water use efficiency	$Odt_{biomass}$/ l water	1.93	0.47	1.93	0.91	1.29	0.23	1.43	0.44
	Water depletion	mm/season	-302	-216	-402	-180	-302	-216	-402	-180
	Biodiversity									
	MSA	ΔMSA x100 /$GJ_{biomass}$	-0.2	-2.3	-0.1	-0.5	-0.2	-4.3	-0.1	-1.0
Socio-economic Impacts	**Legality**		*No ex-ante analysis possible, recommendations to comply with national law and regulation are provided, see 3.3.2.1 and Annex 3.*							
	Land rights									
	Land right risk	Qualitative	+	+	+	+	-	-	+	+
	Food security									
	Food security	Qualitative	+	+	+	+	+-	+-	+	+
	Economic viability									
	Feedstock	€/$GJ_{biomass}$	2.44	13.75	1.96	6.27	2.62	26.47	1.96	12.06
	End product	€/$GJ_{biofuel}$	13.24	20.19	12.03	12.44	13.70	33.40	12.03	18.45
	Local Prosperity									
	Total jobs	Jobs	940	1417	940	738	384	59	940	1428
	Local labour	%	100	100	100	100	100	100	100	100
	Total investment	M€	74	113	67	70	28	4	67	103
	Total wages	M€	10	15	10	8	4	1	10	15
	Social well-being		*No ex-ante analysis possible, recommended to comply with (inter-) national law and regulations. Recommendations for best practices are provided, see 3.4.1.10*							
	Labour conditions		*No ex-ante analysis possible, recommended to comply with (inter-) national law and regulations.*							
	Gender		*No ex-ante analysis possible, recommended to comply with (inter-) national law and regulations. Recommendations for best practice are provided, see 3.4.1.12*							

the available land is suitable for energy crop production, especially for switchgrass cultivation. Therefore, in the BAU scenario sufficient biomass can be produced to meet the input requirements in Buenos Aires. In the progressive scenario, large areas of land become available in both Buenos Aires and in Santiago del Estero. Also more productive land becomes available. It is assumed that the best suitable areas of the available land are used for energy crop production. As the crop requirements of switchgrass are less demanding than the crop requirements of soy, the average suitability is higher for swichgrass than for soy. The maximum attainable yield is set at 19.7 odt/ha/yr for switchgrass and 4.13 ton/ha/yr for soy.

The GHG emissions are differentiated in the emissions over the lifecycle of bioenergy production, and the emissions related to LUC. The GHG emissions over the lifecycle of switchgrass are dominated by the emissions related to nitrogen fertilizer production and application, whereas the GHG emissions of soy cultivation are dominated by GHG emissions of diesel usage. The cultivation related GHG emissions contribute 20-50% to the overall life cycle emissions. However, the total GHG emissions are dominated by the GHG emissions related to LUC resulting from changes in the carbon stock of above and below ground biomass and soil organic carbon. Especially the conversion of shrubland to soy cultivation results in very high GHG emissions 232 -587 kg CO_2-eq/GJ $_{biodiesel}$). The production of biofuels in the progressive scenario, in which abandoned agricultural land is used for the cultivation of energy crops, results in high GHG emission avoidance. Switchgrass ethanol production could result in the avoidance of 90 -12 kg CO_2-eq/GJ_{EtOH}.

The impacts of energy crop cultivation on soil quality are positive when switchgrass is cultivated. Both in the BAU and in the progressive scenario the soil organic carbon increases (0.74-3.31 kg C/GJ $_{biomass}$). When cropland is converted to switchgrass, the risk on erosion is expected to decrease. Negative impacts on soil quality are expected when soy is cultivated in the BAU scenario. This will result in a large loss of soil organic carbon (9.5 -3.08 kg C/GJ $_{biomass}$) and an increased risk on soil erosion.

The impact on water has been assessed in a first order approach. Due to the limitations of this analysis, the results should be interpreted with care. As for both crops it is assumed that no irrigation is required (except for nursery and panting), no surface water is depleted. Because of the lower and uneven distributed precipitation levels in Santiago del Estero, there is more risk on water depletion. Because of the low rooting depth of soy it is not able to extract water from the lower water tables. Therefore it soy not contribute to additional water deficits but there could be a risk on high crop mortality. As switchgrass is relative resistant to drought, it will be able to survive dry months but the yields will be affected. The water use efficiency is higher for switchgrass (1.3 - 1.9 g biomass / l water) compared to soy 0.2 - 0.5 g biomass/l water) because of its high yield.

In order to avoid high impacts on biodiversity, the protected areas and forest are already excluded in the land availability assessment. The conversion of current land use to large scale energy crop plantation generally has a negative impact on biodiversity. This is especially true when native vegetation (in the BAU scenario) is converted to soy plantations.

Many of the socio-economic impacts of large scale bioenergy production are directly related to the design, the implementation and the management of the project. Therefore, no ex-ante analysis could be made for some of the sustainability issues such as 'legality', 'labour conditions' and gender. Recommendations for best practice to comply with the relevant legislation and regulations have been provided in the related sections.

The risk for land competition has mainly been avoided by excluding the land already in use for other functions for bioenergy crop production in the land availability assessment. Under the BAU scenario conditions there is not sufficient land available in Santiago del Estero for both Switchgrass and soy production. If it is aimed to scale up the biomass production beyond the limitations indicated by the land availability assessment, competition for land is most likely to occur. In Buenos Aires there is sufficient land available to meet the requirements, therefore conflicts over land and violation of land rights are less of a risk in this area.

The food security situation in Argentina is good and food security is not considered to be an important issue. However, in the BAU scenario in Santiago del Estero, there is not enough land available to meet the plant requirement. If biomass production is increased above the limitation indicated by the land availability assessment, food security could be negatively affected, due to potential land competition. However, since Argentina is a food exporter, the impact is likely to be minor. Furthermore, by providing employment in the region, household income can be increased which can mitigate the potentially negative impact.

The costs for soy cultivation are much higher compared to switchgrass due to the lower yield (in GJ biomass/ha/year) of soy and the relative intensive management in terms of inputs and field operations. The costs for soy are especially high in Santiago del Estero in the BAU scenario; this is due to the very low yields that are achieved here. In general the costs are higher in the BAU scenario compared to the progressive scenario because in the BAU scenario, the cost of land clearing are included and in less suitable areas are available for energy crop production. The cost of switchgrass ethanol and soy biodiesel per GJ end product are almost equal when the suitability for the cultivation of switchgrass and soy are similar, for instance in Buenos Aires in the progressive scenario where both crops achieve maximum yields. However in all other settings, the suitability of the available land is much higher for switchgrass compared to the suitability for soy. Therefore, the overall costs of switchgrass ethanol production are lower compared to soy biodiesel. More details can be found in Annex 3.

The impact of large scale bioenergy production on the local prosperity in the regions is indicated by the number of jobs generated, the wages paid and the total investment of the project. Also potential labour migration is including by comparing the local unemployed labour force with labour requirements. As labour and equipment requirements are often expressed per hectare, the total labour and capital is directly related to the size of the area in use for the bioenergy plantation. In Buenos Aires, the number of jobs varies between 940 for switchgrass, to 738 - 1417 for soy. In Santiago del Estero, this range is 384-940 jobs for switchgrass, and 59 to 1428 for soy. The low amount of jobs for soy and switchgrass in this region is due to the lack of land in the BAU scenario. This also affects the total wages that are paid, which varies in total between 1 and 15 M€, but would vary between 8 - 15 M€ if only the scenarios in Buenos Aires region are taken into account, and the progressive scenario for Santiago del Estero. Nevertheless, the total amount of jobs, wages and investment creates a large positive effect on local prosperity levels. Due to the relatively large unemployment and limited labour requirements, all labour requirements can be fulfilled by the local labour force, not taking into account the skill-levels that are required.

In general, the progressive scenario scores better on almost all impacts compared to the BAU scenario. The conversion of native vegetation (shrubland) to energy crop cultivation results generally in negative environmental impacts. Only the impact of large scale bioenergy production on local prosperity and social well-being are better in the BAU scenario compared to the progressive. Soy biodiesel production has generally more negative impacts compared to switchgrass ethanol production, especially in the BAU scenario. The exception is the impact on water as the risk on water depletion is more severe for switchgrass. In switchgrass ethanol production in the progressive scenario has many positive impacts.

The socio-economic impacts are directly related to the amount of hectares in use for bioenergy production. In the BAU scenario, only a small area could be used for bioenergy crop production in Santiago del Estero. Therefore, little positive socio-economic impacts can be accomplished here. In Buenos Aires and in the progressive scenario in Santiago del Estero, both soy biodiesel production and switchgrass ethanol production could have large positive socio-economic impacts.

3.4 Recommendations for best practice

The environmental and socio-economic impact assessment of the supply chains in Mozambique and Argentina showed that the impacts depend strongly on the environmental and socio-economic context of the region, the type of energy crop, the type of end product and the scenario conditions.

However, the impacts of large scale bioenergy production are also related to the design and the management of the project. There are many measures that can be taken to enhance the sustainability of large scale biofuel production. Some recommendations for best practice for each of the impacts are provided here.

3.4.1.1 GHG emissions

- Apply a low till / no till regime. Avoid deep soil ripping
- Leave large (native) trees in the field when clearing the plantation area
- Use a cover crop between the rows of tree plantations
- Leave part of the residues in the field to enhance soil organic carbon

3.4.1.2 Soil

- Apply a low till/ no till regime. Avoid deep soil ripping
- Leave part of the residues in the field to increase soil organic carbon content and maintain soil cover to avoid erosion
- Time the harvest of switchgrass wisely in order to allow for full crop drying in the field before harvest, allow for re-growth of the crop during the rainy season, and prevent soil exposure in the end of the dry season, the most critical period of the year.
- Harvest eucalyptus after the most critical months for erosion and if possible maintain soil cover (grass) between the row spacing
- Differentiate the growth stages of different plots: the length of field and therefore the erosion risk can be reduced by blocking the wind by more mature trees.
- For both switchgrass and eucalyptus it is wise to sow/ plant perpendicular to the prevailing wind direction in order to reduce the risk on erosion

3.4.1.3 Water

- The ground water availability could be highly heterogeneous. Therefore a thorough assessment of the entire potential plantation site prior to planting and continuous monitoring is required.
- Long term irrigation has detrimental effects on environment and biomass production cost, therefore select a site where rain fed cultivation is possible.
- Irrigation for the nursery or at time of planting is often required. Only renewable water resources should be used. When making use of water from rivers or streams, downstream water usage should not be affected.
- In case of low water availability, it is recommended to distribute the plots of bioenergy crops over a larger area instead of concentrating the plantation at one location.

3.4.1.4 Biodiversity

- Avoid monocultures: scatter bioenergy crop / tree plots within natural areas
- Avoid clearance of native tree species within the bioenergy plots
- Maintain important corridors for key species
- Maintain natural vegetation in riparian areas
- Minimize disturbance within the field

- For forest plantations: maintain different plot in different growth stages to enhance diversity within the landscape.

3.4.1.5 Legality
- Comply with national and international laws and legislations as well as with regional and customary laws.

3.4.1.6 Land rights
Recommendations for a proper land acquisition process include:
- Comply with the legal process for land acquisition
- Perform a thorough and continuous participatory community consultation process involving in addition, to representatives of the project, the local government, and the local community, also a local NGO to ensure the rights of the communities are properly covered and do not proceed with the project without proper informed consent.
- Provide documents in local language
- Find long term solutions for all stakeholders involved
- Ensure continuation of services access and rights or compensate properly

3.4.1.7 Food security
- Providing storage facilities, enabling the storage of food crops to balance seasonal fluctuations in food availability, both for own consumption for farmers but also maintain the quality of seed material for the succeeding season. Moreover, storage can prevent temporally flooding of the market resulting in low prices and therefore low farmer's income.
- Improving infrastructure, enabling access to markets and therefore famer's income and incentives for higher production.
- Providing extension services to the surrounding farmers and employees of the energy plantation, to let them benefit from agricultural knowledge and skills available on the bioenergy plantation
- Enabling a market for agricultural inputs. Currently there is no market for fertilizers and other agricultural inputs.
- Allow employees that have their own plots, time to work on their food crops in addition to the work they provide for the bioenergy plantation
- Facilitate a renting system for agricultural machinery and tools that enable employed substance farmers and farmers in the surroundings of the bioenergy plantation to rent equipment to improve their farming practices.
- Use part of the land of the plantation premises for food crop production to provide food for employees.
- Employment generation by the project will likely increase household income and therefore food security. The prices of staple crops have increased over the years; therefore wages should be high enough to overcome this risk.

3.4.1.8 Economic viability
- The clearance of the plantation area results in large volumes of biomass. This can also be used for biofuel production. This ensures revenues in an early stage of the project which will reduce the cost of biomass, especially for tree plantations.
- The costs of feedstock production have a significant contribution to the overall cost. Therefore, the selection of sites with high productivity is recommended.
- Transportation costs have a significant contribution to the overall cost, especially for low density (e.g. switchgrass) or moist (e.g. sugar cane) biomass. Therefore, cost can be reduced when the design and location of the plantation are optimized for transport distance

3.4.1.9 Local prosperity
- Employ people and obtain products and services from the region as much as possible
- When foreigners are required for certain tasks, train local people to substitute foreign employees over time
- Organize the work on the plantation in such a way that temporary and seasonal labour is minimized (e.g. different plots in different growth stages).

3.4.1.10 Social well-being
- Identify the most urgent and required measures to improve socio-economic conditions within a region together with employees, local communities, NGOs and local government.
- Provide services for employees. Such as meals, health facilities, education, fire wood substitutes, etc.
- Invest in the development of the region by investing in e.g.: infrastructure, electrification, sanitation, drinking water, education, health facilities, etc.

3.4.1.11 Labour conditions
- Comply with national and international labour laws

3.4.1.12 Gender
- Provide the same opportunities for men and women to engage in and benefit from the sustainable production of biofuels.
- Allow for flexible working hours at a plantation to enable women to keep tending their household food plots
- Facilitate energy access for employees and the local rural population, to reduce women's tasks, such as collecting firewood and milling maize.

4. Conclusions

This study focuses on the sustainability of scaling up the production of biofuels for transport in developing countries. A methodological framework has been developed to make a first order and ex-ante analysis of the potential environmental and socio-economic impacts of large scale production of biofuels. As the land availability and the LUC for dedicated energy crop production plays a key role in the sustainability of biofuel production, the assessment of land availability and LUC was the first methodological step to take in a sustainability assessment. Subsequently, an ex-ante assessment of the selected potential environmental and socio-economic impacts of large scale biofuel production on a regional level was performed. The methodological framework for the assessment of the development in land availability for energy crops was demonstrated for three case study countries: Mozambique, Argentina and Ukraine. The environmental and socio-economic impact assessment was demonstrated for specific settings in Mozambique and Argentina. This impact assessment was deemed not feasible for Ukraine due to a lack of data availability.

The land use model developed in this study is an advanced tool to assess future land use dynamics and land availability for bioenergy crops. Applying a scenario approach on the key drivers of LUC and using a food first paradigm[20], allows for an evaluation of the biomass potentials that can be achieved without competition with food and feed, and for the identification of the required conditions to realize these potentials. This is a major step forward in modelling the land availability for energy crops. As biomass yields, production costs, logistics, and environmental and socio-economic impacts are strongly related to location specific biophysical (e.g. agro-ecological suitability, availability of infrastructure, soil properties, climate conditions etc) and socio-economic conditions (poverty, unemployment, food security, access to services etc); spatially explicit assessment of land availability for bioenergy crops is an important precondition to design bioenergy supply chains and logistics and assess bioenergy production potential and environmental and socio-economic impacts. The LUC model has now been tailored to, and demonstrated for Mozambique, Argentina and Ukraine. Still, it is a flexible model which can be used for other countries or regions when input data, allocation rules and characteristics of suitability factors are adapted.

In addition, a methodological framework was developed to make a first order ex ante environmental and socio-economic impact assessment on a regional level. This methodological framework can be applied after the land availability assessment when the hotspots for land availability are identified. The methodological framework addresses the key environmental and socio-economic concerns raised by several (inter-) national initiatives on the sustainability and certification of biomass production for energy i.e. GHG emissions, impacts on soil, water and biodiversity, legality, land rights, economic viability, local prosperity, social well-being, labour conditions, food security and gender. The developed approach enables the quantification of environmental and socio-economic impacts of large scale biomass production on a regional level. For some of the socio-economic-impacts, no ex ante assessment could be made as the impacts are mainly related to the design and management of the project. It does not replace an environmental and socio-economic impact assessment of a specific project, which could identify mitigating measures to address key concerns through project design and management of the plantation. However, the methodological framework enables the selection of promising regions and supply chains and identifies the key concerns that need to be addressed when a project is implemented.

This *ex-ante* analysis of the land availability, the economic viability and the environmental and socio-economic impacts contributes to the identification of go and no- go areas for bioenergy production. This enables a sound planning of land use, sustainable investment in bioenergy production capacity, and infrastructure over time. It could also help investors and policymakers to make realistic estimations of the economic viability of a project and it provides the ability to define the preconditions to comply with sustainability criteria. This could help to prevent competition for land, reduce investment risks, avoid large scale project failures, minimise negative environmental and socio-economic impacts and optimize positive effects of large scale bioenergy production.

20 In this study, it is assumed that food production has priority over biofuel production. For that reason, the land use allocation process aimed at the allocation of land food (and feed). The residual of land, the land not in use of food and feed or other land use functions, is assumed to be available for the production of energy crops. In this way, it is assessed how much land could be used for biofuel production if no competition with food and feed production is allowed.

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Abbreviations

AGB	Above Ground Biomass
BGB	Below ground Biomass
BAU	Business as Usual
CA	Cellular Automata
CLUE	Conversion of Land Use and its Effects
CO_2-eq	Carbon dioxide equivalent
DUAT	Direito de Uso e Aproveitamento da Terra (land Use Right)
EF	Emission Factor
EU	Eucalyptus
ET	Evapotranspiration
EtOH	Ethanol
FAO	Food and Agriculture Organisation of the United Nations
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gas
GI	Gaza-Inhambane
GIS	Geographic Information System
GJ	Giga Joule
Ha	Hectare
HAZ	Homogeneous Agro-economic Zones
HHV	Higher Heating Value
IIAM	Instituto de Investigação Agrária de Moçambique
iLUC	Indirect Land Use Change
INTA	Instituto Nacional de Tecnologia Agropecuaria
Kc	Crop Coefficient
km	Kilometre
LCA	Lifecycle assessment
LHV	Lower heating Value
LU	Land Use
LUC	Land Use Change
m	meter
m^3	Cubic meter
M	Million
MC	Monte Carlo
Mha	Mega hectare
Mm	Millimetre
Moz	Mozambique
MSA	Mean Species Abundance
Mt	Megaton
MW	Mega Watt
N	Nampula
NPV	Net Present Value
NUTS	Nomenclature of Units for Territorial Statistics
Odt	Oven Dried Tonne
O&M	Operations and Maintenance
PLUC	PC Raster Land Use Change
PPP	Purchasing power Parity
PROG	Progressive
RUSLE	Revised Universal Soil Loss Equation
SD	Standard Deviation
SEC	Scientific Engineering Centre
SG	Switchgrass
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SRC	Short rotation Coppice
SSR	Self Sufficiency Ratio
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation
WEQ	Wind Erosion Equation
Y	Year

ENERGY AND CLIMATE CHANGE BRANCH

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